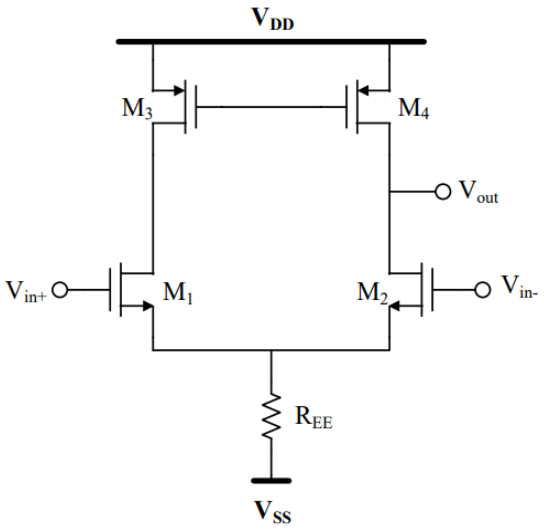
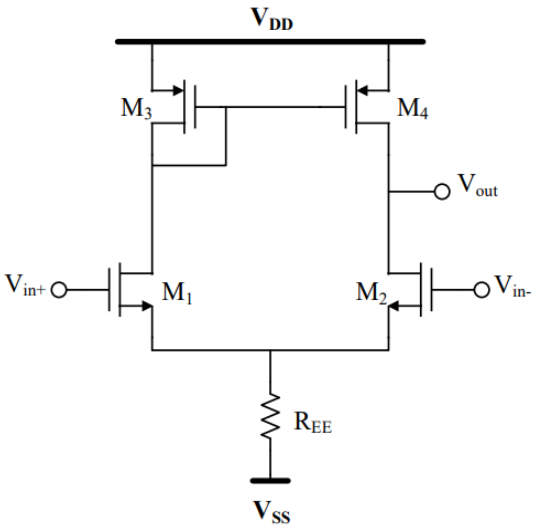
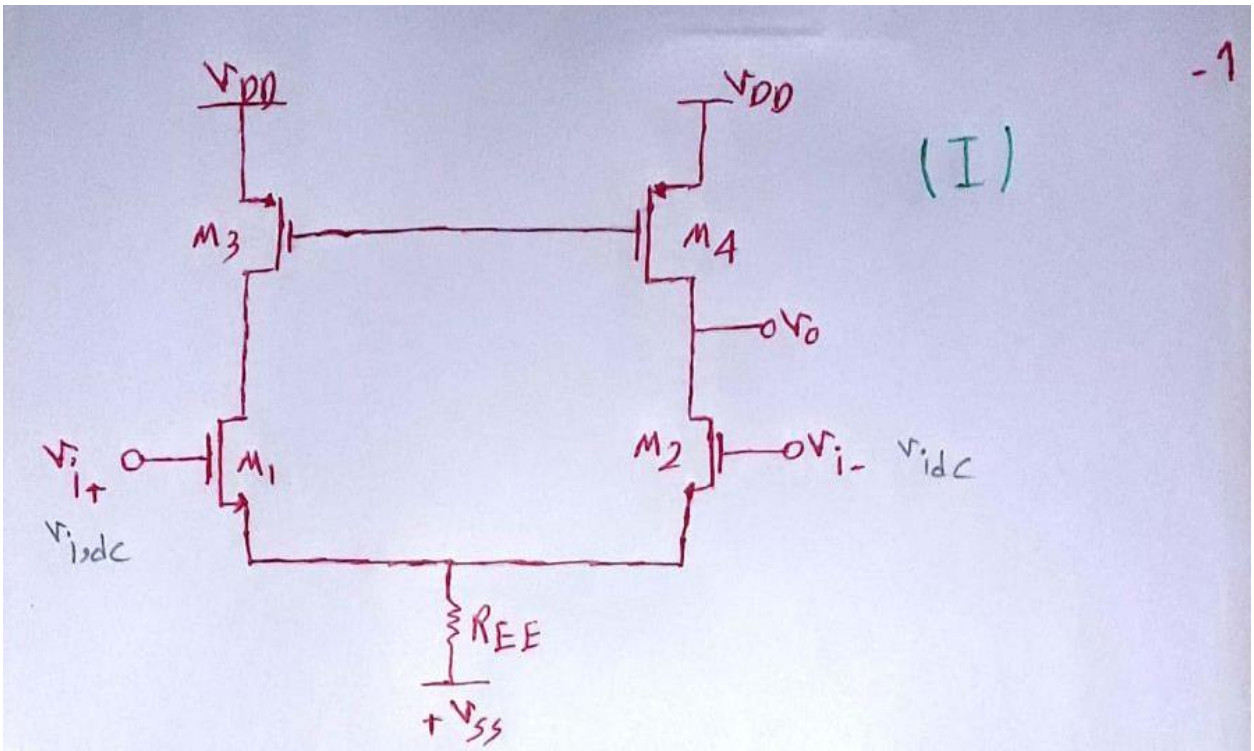
1- Compare the following circuits in terms of input DC common-mode range, output voltage swing, differential voltage gain and common-mode voltage gain.



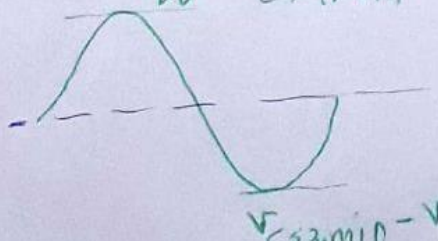




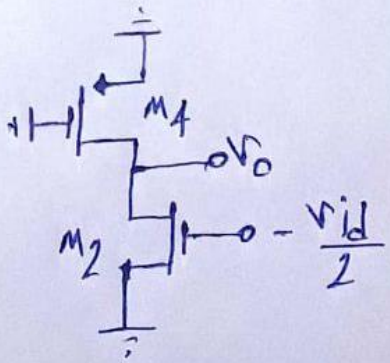
1) KVL: $-V_{DD} + V_{SG3} - V_{GD1} + V_{idc} = 0$

$V_{idc,max} = V_{DD} - \left(V_{SG3} - |V_{TH}|\right) + V_{TH} \rightarrow V_{idc} \leq V_{DD} - V_{SG3} + 2V_{TH}$

2)



3) $A_d = ?$

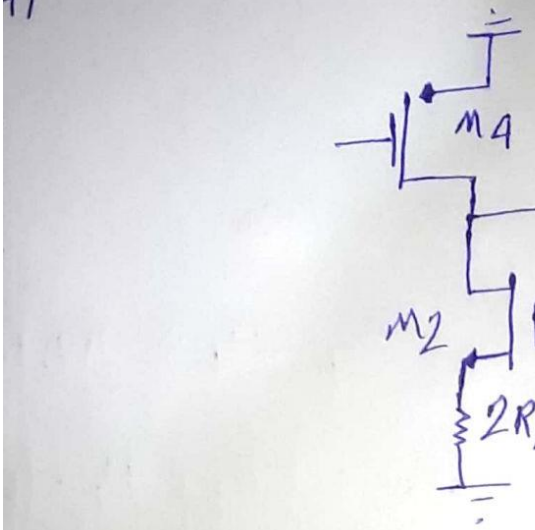


$$\frac{v_o}{-v_{id}/2} = -g_{m2}\left(r_{ds2} \| R_{D2}\right)$$

$$\frac{v_o}{v_{id}} = A_d = +\frac{1}{2} g_{m2}\left(r_{ds2} \| r_{ds4}\right) \checkmark$$

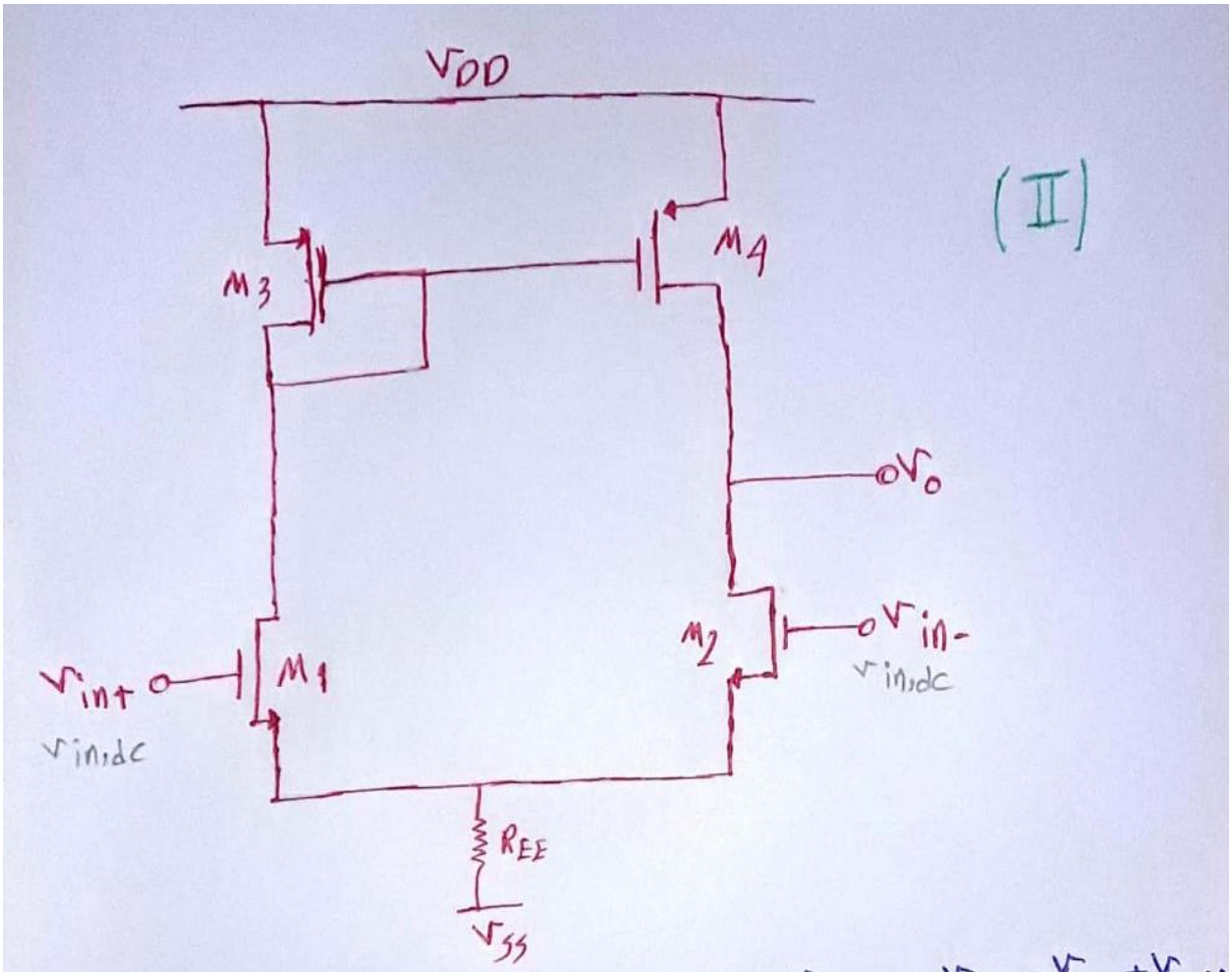
$$A_d = +\frac{1}{2} g_{m2}\left(\frac{1}{2} r_{ds}\right) = \frac{1}{4} g_{m2} r_{ds}$$

4)



$$\frac{V_o}{V_{CM}} = \frac{-RD_2}{R_{S2} + \frac{1}{g_{m2}}}$$

$$A_{CM} = \frac{-r_{ds}}{2R_{EE} + \frac{1}{g_m}}$$

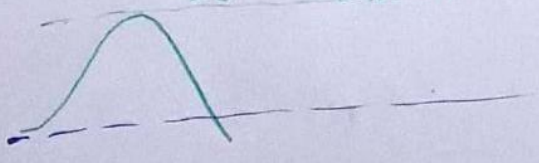


(II)

1/ $-V_{DD} + V_{SG3} - V_{GD1} + V_{in,dc} = 0 \rightarrow V_{in,dc_{max}} = V_{DD} - V_{SG3} + V_{TH}$

$V_{in,dc} \leq V_{DD} - V_{SG3} + V_{TH}$

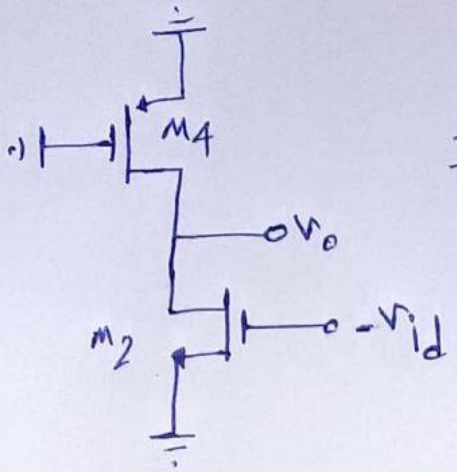
2/ $V_{DD} - V_{CS4,min}$



در منبع جریان cascode $V_{CS4,min}$ نسبت به حالت قبل بیشتر کاهش می یابد.

3) $A_d = ?$

روش 1



$$\frac{v_o}{-v_{id}} = g_{m2}\left(r_{ds2} \| r_{ds4}\right)$$

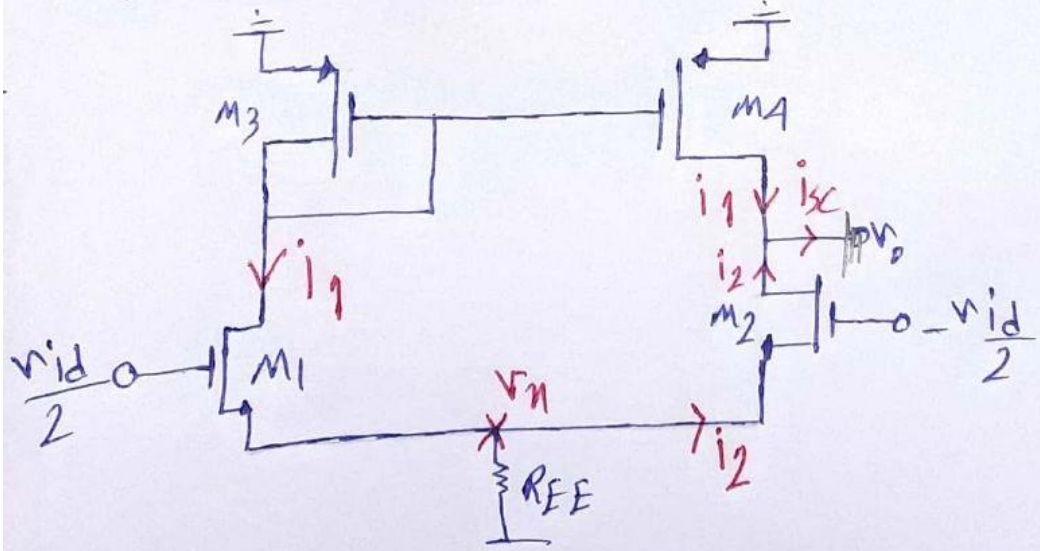
$$A_d = +g_{m2}\left(r_{ds2} \| r_{ds4}\right) = \frac{g_{m2} r_{ds}}{2}$$

روش 2

$$A_d = G_m R_{out}$$

$R_{EE} \gg \frac{1}{g_{m1}}$

$R_{out} = r_{ds2} \| r_{ds4} = \frac{r_{ds}}{2}$ $\quad G_m = ?$

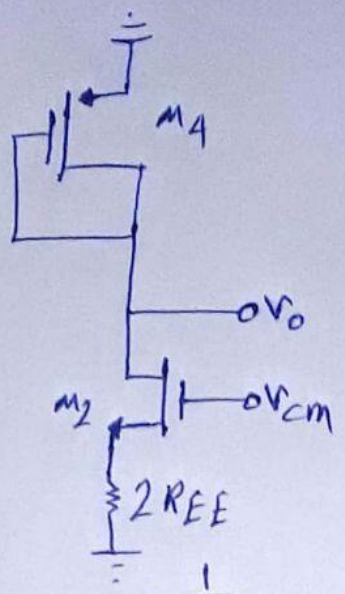


$$i_1 = g_{m1}\left(\frac{v_{id}}{2} - v_x\right), \quad i_2 = g_{m2}\left(v_x + \frac{v_{id}}{2}\right)$$

KCL @ v_x: $i_1 - i_2 = \frac{v_x}{R_{EE}} \rightarrow v_x\left(R_{EE}\left(g_{m1}+g_{m2}\right)+1\right) = 0 \rightarrow v_x = 0$

KCL @ $\frac{1}{\div}$: $i_1 + i_2 = i_{sc} \rightarrow \frac{g_{m1}}{2} v_{id} + \frac{g_{m2}}{2} v_{id} = i_{sc} \rightarrow G_m = g_m \rightarrow A_d = \frac{g_m r_{ds}}{2}$

4) $A_{cm} = ?$



$$\frac{v_o}{v_{cm}} = \frac{-R_{D2}}{R_{S2} + \frac{1}{g_{m2}}} = \frac{-\frac{1}{g_{m4}}}{2R_{EE} + \frac{1}{g_{m2}}}$$

1) $V_{in,dc}$ مدار (I) بزرگتر از مدار (II)

2) سوئینگ مدار (I) بیشتر از مدار (II)

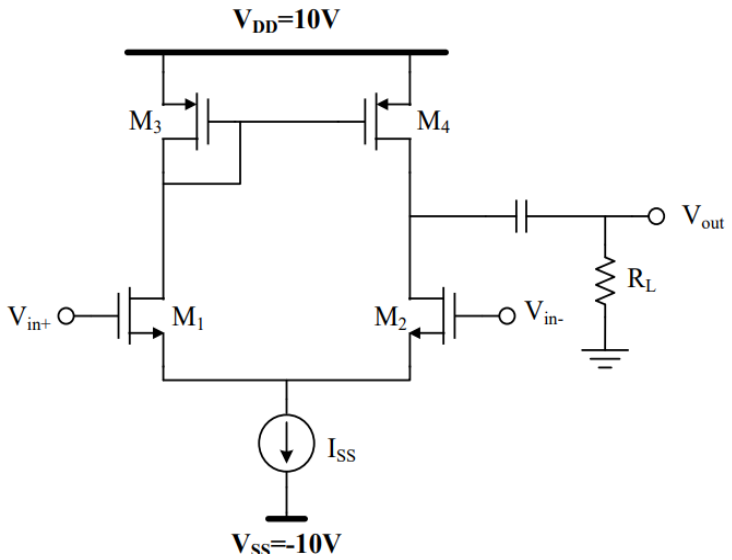
3) بهره تفاضلی مدار (II) تقریبا 2 برابر مدار (I)

4) بهره حالت مشترک مدار (II) نسبت به مدار (I) به شدت کاهش یافت

2- In the following circuit, the specifications of the transistors are the same.

a) Calculate the differential voltage gain directly. Discuss about the result.

b) Determine the common-mode voltage gain directly. Discuss about the result.



$$\begin{cases} \beta = 1mA/V^2 \\ |V_{TH}| = 2V \\ \lambda = (\frac{1}{75})V^{-1} \\ R_L = 50k\Omega \\ I_{SS} = 1mA \end{cases}$$

DC) $i_{D1} = i_{D2} = 0.5mA \rightarrow g_{m1,2} = 2\sqrt{k i_D} = 2\sqrt{\frac{1}{2} \times \frac{1}{2}} = 1ms$ | -2

$V_{ds} = \frac{1}{\lambda i_D} = 75 \times \frac{1}{\frac{1}{2}} = 150k\Omega$

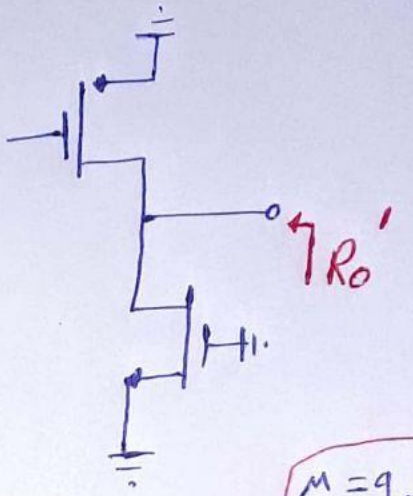
a) $A_d = ?$

$A_d = G_m R_{out}$ $\quad R_{out} = ?$

$R_{out} = R_o' \| R_L$

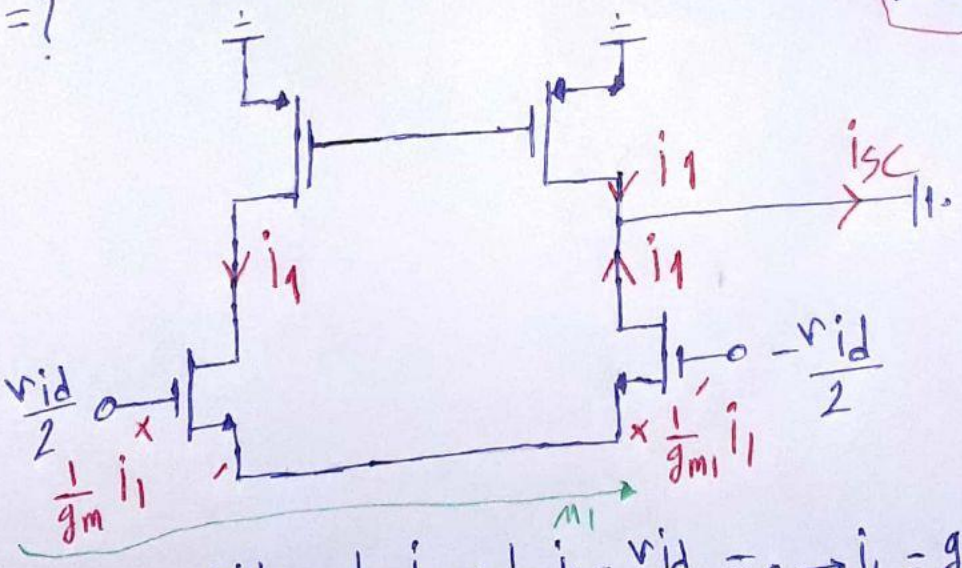
$R_{out} = (r_{ds4} \| r_{ds2}) \| 50k$

$R_{out} = 30k\Omega$



$G_m = ?$

$\mu = g_m r_{ds} \gg 20$

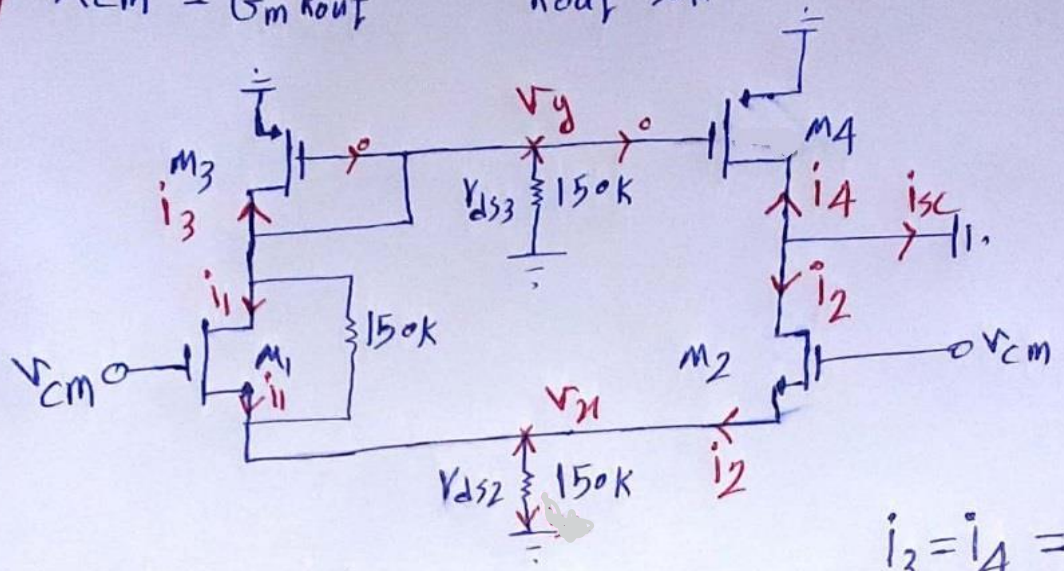


KVL @ M_1: $-\frac{v_{id}}{2} + \frac{1}{g_m} i_1 + \frac{1}{g_m} i_1 - \frac{v_{id}}{2} = 0 \rightarrow i_1 = \frac{g_m v_{id}}{2}$

KCL @ $\frac{1}{\infty}$: $2 i_1 = i_{sc} \rightarrow g_m v_{id} = i_{sc} \rightarrow G_m = g_m$

$A_d = g_m (r_{ds2} \| r_{ds4} \| R_L) = 30 \frac{V}{V}$

b) $A_{cm} = G_m R_{out}$ $\quad R_{out} = 30K$ $\quad \mu \gg 20$



$i_3 = i_4 = v_y$

$i_1 = g_m(v_{cm} - v_x) = v_{cm} - v_x \quad i_1 = i_2$

$i_2 = g_m(v_{cm} - v_x) = v_{cm} - v_x$

KCL @ v_x: $\frac{v_x}{150} - \frac{2(v_{cm} - v_x)}{150} + \frac{v_x - v_y}{150} = 0$

$302 v_x - v_y = 300 v_{cm}$ (I)

KCL @ v_y: $\frac{v_y}{150} + \frac{v_y + v_{cm} - v_x}{150} + \frac{v_y - v_x}{150} = 0$ (150)

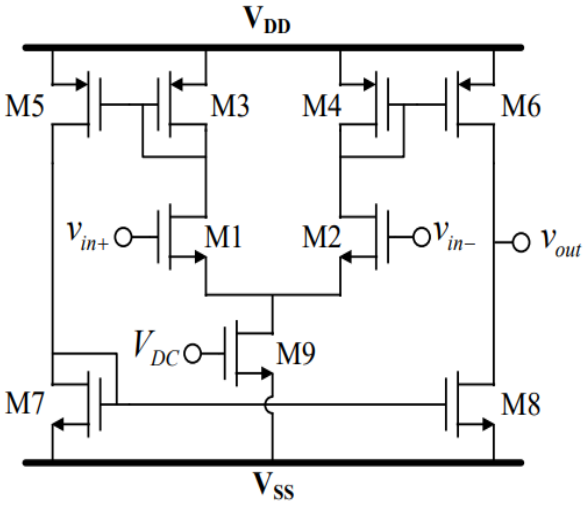
$-151 v_x + 152 v_y = -150 v_{cm}$ (II)

(I), (II) $\rightarrow v_x = \frac{150}{151} v_{cm}, v_y = 0$

$i_{sc} = -(i_2 + i_4) + \frac{v_x}{150} = -i_2 + \frac{v_x}{150} = -v_{cm} + \frac{151 v_x}{150} = 0$

$i_{sc} = 0 \rightarrow G_m = 0 \rightarrow A_{cm} = 0$

3- In the following circuit, determine the CMRR and input differential resistance.



$$\begin{cases} V_{eff1,2} = 0.1V, V_{eff3-9} = 0.2V \\ \lambda = 0.1V^{-1} \\ I_{D9} = 1mA \\ (\frac{W}{L})_{5,6} = 2(\frac{W}{L})_{3,4} \\ (\frac{W}{L})_{7} = (\frac{W}{L})_{8} \end{cases}$$

DC) $i_{D9} = 1mA$

$i_{D1} = i_{D2} = i_{D3} = i_{D4} = 0.5mA$ ✓

$v_{SG5} = v_{SG3} = v_{SG4} = v_{SG6}$ → $i_{D5} = i_{D6} = 2i_{D3} = 2i_{D4}$

$\left(\frac{W}{L}\right)_{5,6} = 2\left(\frac{W}{L}\right)_{3,4}$

$i_{D5} = i_{D6} = 1mA$ ✓

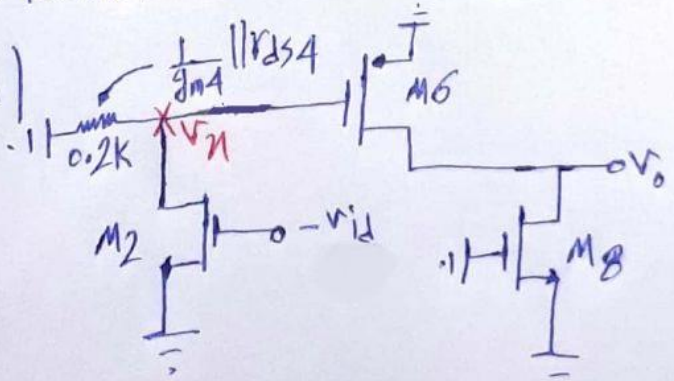
$i_{D7} = i_{D8} = 1mA$ ✓

$i_{D1,2,3,4} = 0.5mA \rightarrow g_{m1,2} = \frac{2i_D}{v_{eff}} = 1ms$ ✓

$g_{m3,4} = 5ms$ ✓ $g_{m5,6,7,8,9} = 1ms$ ✓

$r_{ds1,2,3,4} = 20k\Omega$ ✓ $r_{ds5,6,7,8,9} = 10k\Omega$ ✓

Ad)



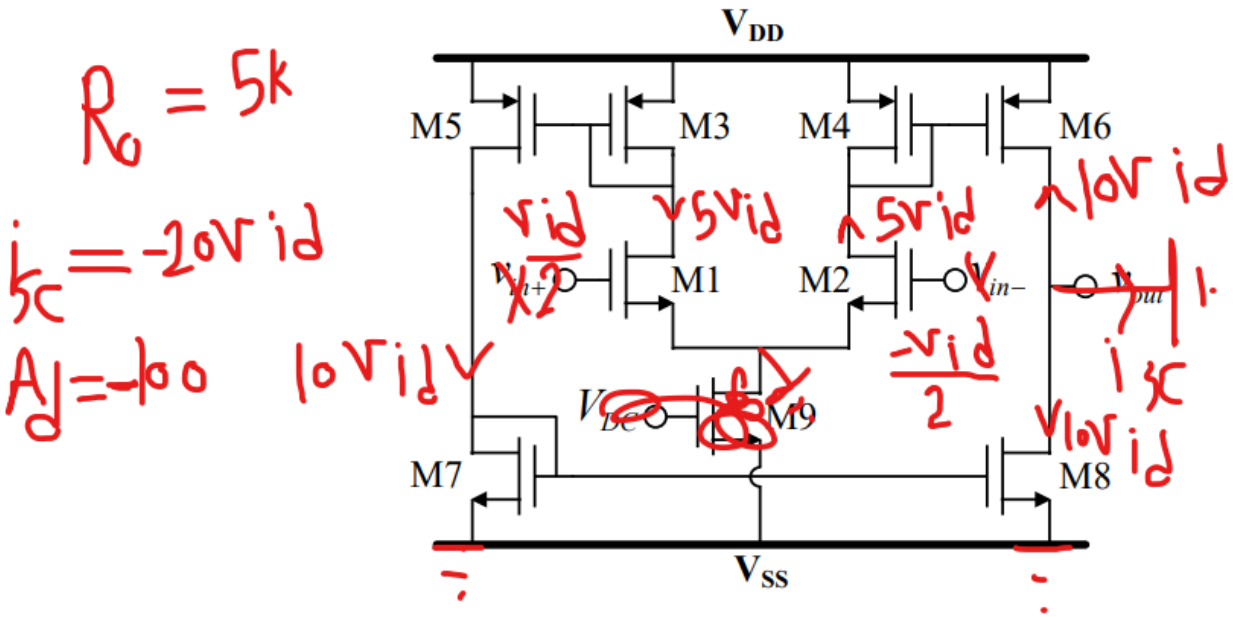
$\frac{v_o}{v_x} = -g_{m6}(R_{D6} || r_{ds6}) = -g_{m6}(r_{ds8} || r_{ds6}) = -50 \frac{V}{V}$

$\frac{v_x}{-v_{id}} = -g_{m2}(R_{D2} || r_{ds2}) = +g_{m2}\left(\frac{1}{g_{m4}} || r_{ds2}\right) = +2$

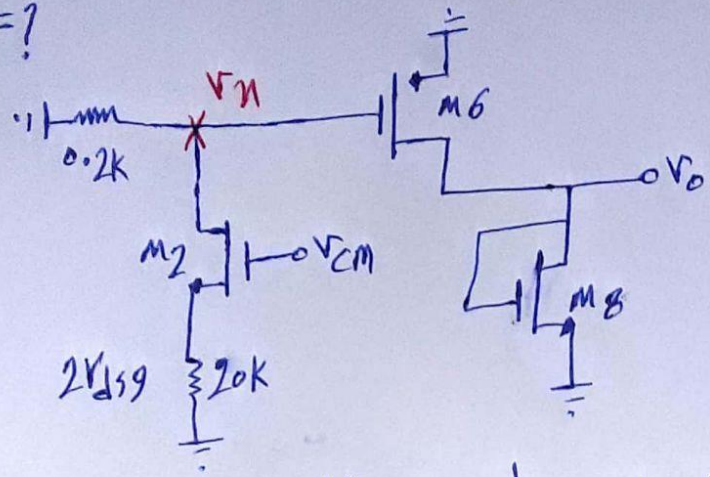
$\frac{v_o}{v_{id}} = -100$

$R_{id} = \infty$

روش دوم محاسبه بهره تفاضلی (روش Gm*Rout)



$A_{cm} = ?$



$$\frac{v_o}{v_n} = -g_{m6}\left(R_{D6} \,||\, r_{ds6}\right) = -g_{m6}\left(\frac{1}{g_{m8}}\right) = -1$$

$$\frac{v_n}{v_{cm}} = \frac{-R_{D2}}{R_{SS}/2 + \frac{1}{g_{m2}}} = \frac{-0.2}{20 + \frac{1}{10}} = \frac{-0.2}{20} = -0.01$$

$$A_{CM} = -1 \times -0.01 = +0.01$$

$$CMRR = \left|\frac{A_d}{A_{CM}}\right| = 10^4$$