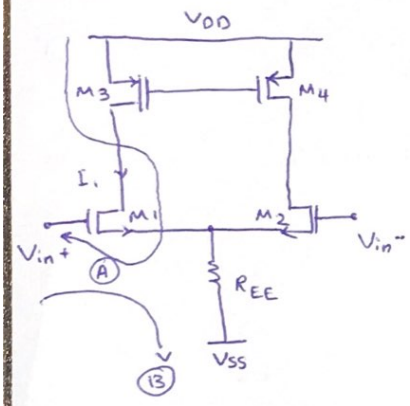
In the name of God

Assignment 7 :

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



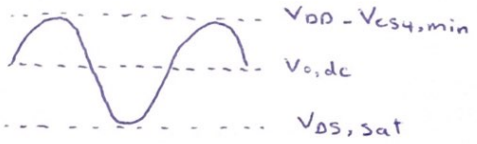
a) ICMR : KVL @ A : $-V_{DD} + V_{SD_3} - V_{sg} + V_{SD_1} + V_{in,dc} = 0$

$$V_{in,dc_{max}} = V_{DD} - V_{SD_3} - V_{SD_1} + V_{sg}$$

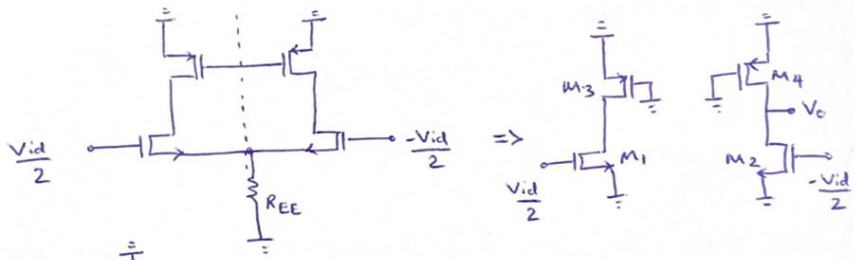
KVL @ B : $-V_{in,dc} + V_{gs} + 2I_1 R_{EE} - V_{SS} = 0$

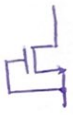
$$V_{in,dc_{min}} = V_{gs} + 2I_1 R_{EE} - V_{SS}$$

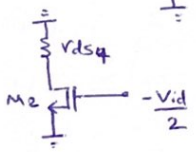
b) output swing :



c) diffrential half circuit :



hint :  $\equiv r_{ds}$

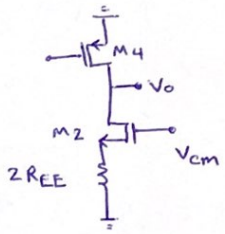


$$\frac{V_o}{V_{id}} = g_m (R_D \| r_{ds}) = g_m (r_{ds_2} \| r_{ds_4})$$

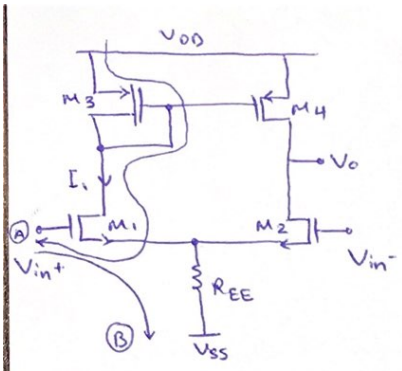
if $r_{ds_2} = r_{ds_4}$ $\Rightarrow \frac{V_o}{V_{id}} = \frac{1}{2} g_m r_{ds}$

$$\Rightarrow \frac{V_o}{V_{id}} = \frac{1}{4} g_m r_{ds}$$

Common mode gain :



$$A_{vcm} = \frac{V_o}{V_{cm}} = \frac{-R_D}{R_S + \frac{1}{g_m}} = \frac{-r_{ds_4}}{2R_{EE} + \frac{1}{g_m}}$$



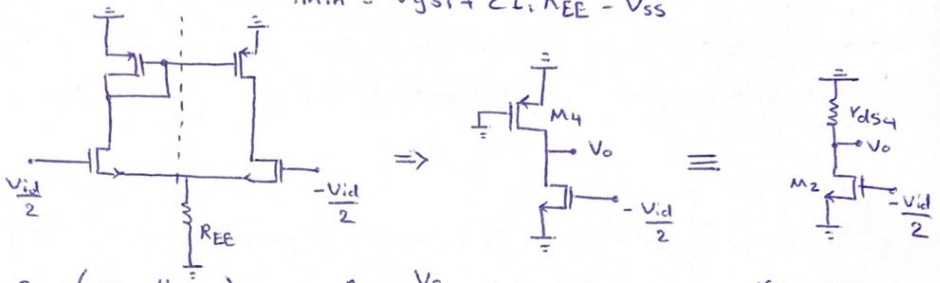
a) ICMR : KVL @ A : $-V_{DD} + V_{sg3} + V_{OS1} - V_{sg1} + V_{in,dc} = 0$

$$V_{indc_{max}} = V_{DD} - V_{sg3} - V_{OS1} + V_{sg1}$$

KVL @ B : $-V_{in,dc} + V_{gs1} + 2I_1 R_{EE} - V_{SS} = 0$

$$V_{indc,min} = V_{gs1} + 2I_1 R_{EE} - V_{SS}$$

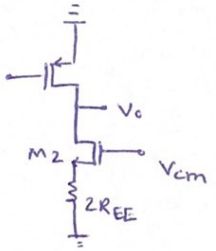
b) diffrential gain :



$$\frac{V_o}{\frac{-V_{id}}{2}} = -g_{m2}(R_o \| r_{ds}) = -g_{m2}(r_{ds4} \| r_{ds2}) \Rightarrow A_{vd} = \frac{V_o}{V_{id}} = \frac{1}{2} g_{m2}(r_{ds4} \| r_{ds2}) \xrightarrow{r_{ds2} = r_{ds4}}$$

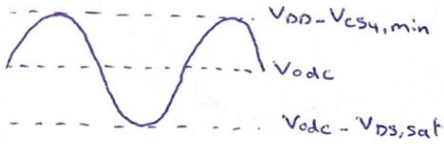
$$\boxed{A_{vd} = \frac{1}{4} g_{m2} r_{ds}}$$

common mode gain :



$$\Rightarrow A_{vcm} = \frac{V_o}{V_{cm}} = \frac{-R_D}{R_S + \frac{1}{g_m}} = \frac{-r_{ds4}}{2R_{EE} + \frac{1}{g_{m2}}}$$

c) output swing :



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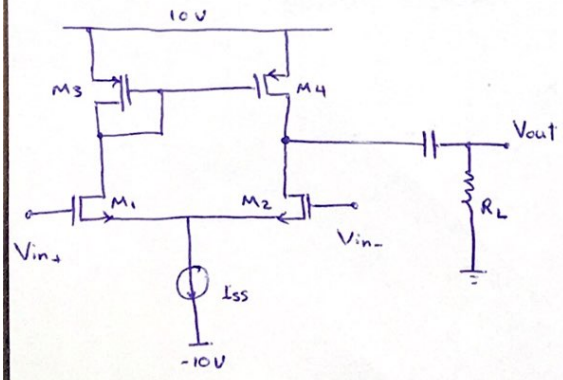
2. In the following Circuit, the specification of the transistors are the same.

a) Calculate the diffrential Voltage gain directly. Discuss about the result.

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



$\beta = 1 \frac{mA}{V^2}$

$|V_{th}| = 2\,V$

$\lambda = \frac{1}{75} V^{-1}$

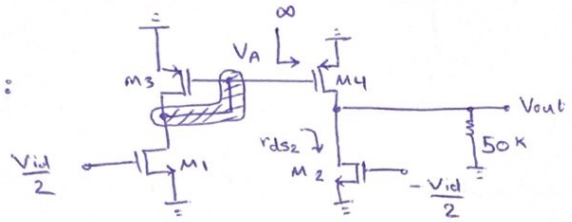
$R_L = 50^{K}$

$I_{SS} = 1^{mA}$

dc analysis: $I_{D1} = I_{D2} = 0.5^{mA}$ $\longrightarrow$ $g_{m1} = g_{m2} = 2\sqrt{K I_D} = 2\sqrt{\frac{1}{2} \times \frac{1}{2}} = 1^{mmho}$ $\quad (= \sqrt{2\beta I_D})$

$$r_{ds} = \frac{1}{\lambda I_D} = \frac{1}{\frac{1}{75} \times \frac{1}{2}} = 150^{K}$$

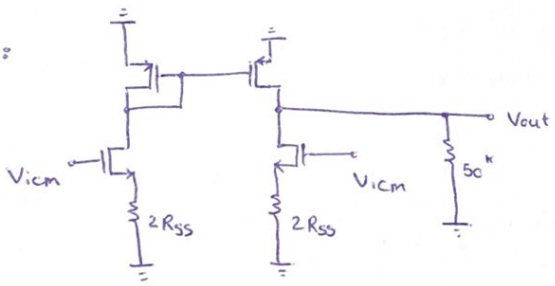
diffrential gain:



$$\frac{V_{out}}{\frac{V_{id}}{2}} = \frac{V_{out}}{V_A} \times \frac{V_A}{\frac{V_{id}}{2}} = \left[-g_{m4}\left(r_{ds2} \| 50^{K} \| r_{ds4}\right)\right] \times \left[-g_{m1}\left(r_{ds1} \| r_{ds3}\right)\right]$$

$$= \left(-1\left(150^{K} \| 50^{K} \| 150^{K}\right)\right) \times \left(-1\left(150^{K} \| 150^{K}\right)\right) = -30(-75) = 2250$$

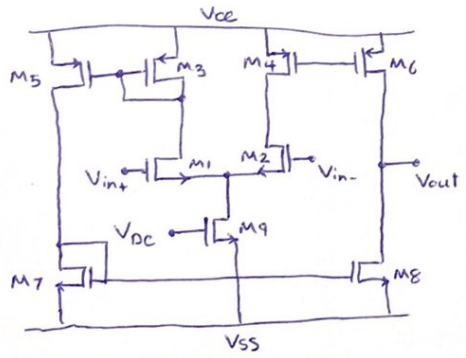
Common mode gain:



$$A_{vcm} = \frac{-R_D}{R_E + \frac{1}{g_m}}$$

$$= \frac{-r_{ds3}}{2R_{SS} + \frac{1}{g_m}}$$ (اگر $R_{SS}=\infty$ آنگاه حالت ایده‌آل) هرچه R_{SS} زیادتر باشد، بهره حالت مشترک کوچکتر می‌شود

3. In the following circuit determine the CMRR and input diffrential resistance.



$V_{eff1,2} = 0.1^{V}$, $V_{eff3:9} = 0.2^{V}$

$\lambda = 0.1^{V^{-1}}$

$I_{D9} = 1^{mA}$

$\left(\frac{W}{L}\right)_{5,6} = 2\left(\frac{W}{L}\right)_{3,4}$ $\longrightarrow$ $I_{D5} = I_{D6} = 2I_{D3} = 2I_{D4}$

$\left(\frac{W}{L}\right)_7 = \left(\frac{W}{L}\right)_8$

dc analysis: $I_{D9} = 1^{mA}$, $I_{D1} = I_{D2} = I_{D3} = I_{D4} = 0.5^{mA}$, $I_{D5} = I_{D6} = I_{D7} = I_{D8} = 1^{mA}$

$$g_{m1,2} = \frac{2I_D}{V_{eff}} = \frac{2 \times \frac{1}{2}}{0.1} = 10^{mmho}$$

$$g_{m5,6} = \frac{2(1)}{0.2} = 10^{mmho}$$

$$r_{ds1:4} = \frac{1}{\lambda I_D} = 20^{K}$$

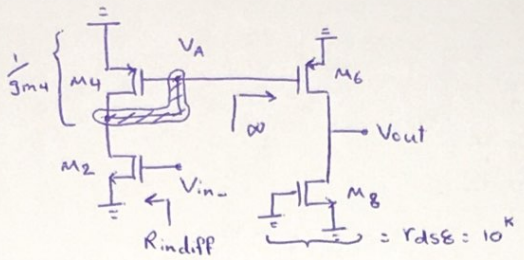
$$g_{m3,4} = \frac{2(0.5)}{0.2} = 5^{mmho}$$

$$g_{m7,8} = \frac{2(1)}{0.2} = 10^{mmho}$$

$$r_{ds5:9} = 10^{K}$$

diffrential gain :

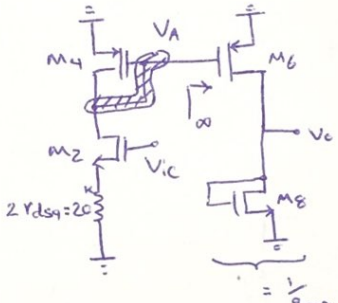
half circuit :



$$A_{vd} = \frac{V_{out}}{V_{in-}} = \frac{V_{out}}{V_A} \times \frac{V_A}{V_{in-}} = \left[-g_{m6}\left(R_O \| r_{ds8}\right)\right] \times \left[-g_{m2}\left(R_O \| r_{ds2}\right)\right] = \left[-10\left(10^K \| 10^K\right)\right]$$

$$\times \left[-10\left(20^K \| \frac{1}{5^K}\right)\right] = (-2) \times (-50) = 100$$

Common mode input :



$$A_{vcm} = \frac{V_o}{V_A} \times \frac{V_A}{V_{ic}} = \left[-g_{m6}\left(R_O \| r_{ds6}\right)\right] \times \left[\frac{-R_{O2}}{R_{S2} + \frac{1}{g_{m2}}}\right] = \left[-10\left(\frac{1}{10^m} \| 10^K\right)\right] \times \left[\frac{-\frac{1}{g_{m4}}}{20^K + \frac{1}{10^m}}\right]$$

$$= -0.1\left(\frac{-0.2}{20.1}\right) = 0.00099 \approx \boxed{0.001}$$

$$CMMR = \frac{A_{vd}}{A_{vcm}} = \frac{100}{0.001} = 100000 \Rightarrow 20\log(100000) = \boxed{100\ dB}$$

$\boxed{R_{in\,diff} = \infty}$