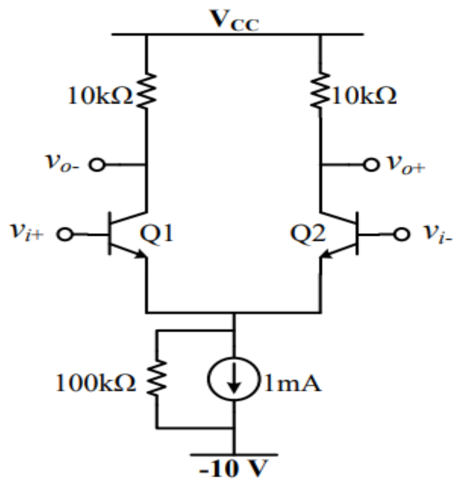
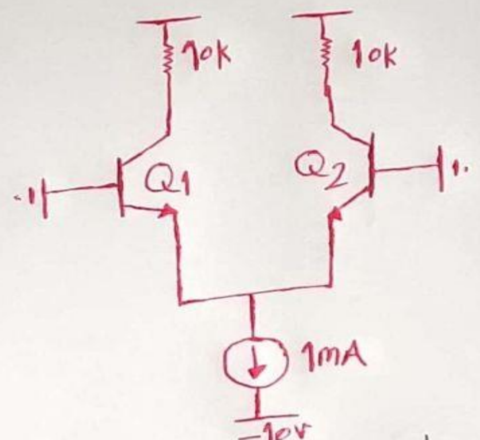
1- Determine v_{o-}, v_{o+}, and $v_{od} = (v_{o+} - v_{o-})$ for the following circuit.



$$\begin{cases} V_A = \infty \\ V_T = 25mV \\ \beta = 100 \\ V_{i+} = +0.5 \times V_{id} \\ V_{i-} = -0.5 \times V_{id} \\ V_{id} = 10\sin 10t \quad mV \end{cases}$$

-1

DC)



$i_{C1} = i_{C2} = \frac{1}{2} mA$

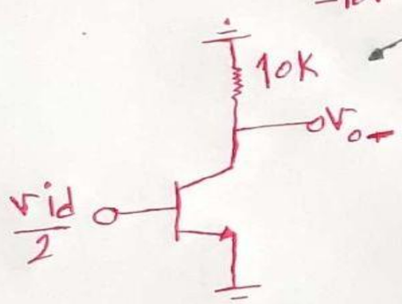
$g_{m1,2} = 20\,mS$

$r_{\pi 1,2} = 5k\Omega$

$r_{o1,2} = \infty$

ac)

نیم مدار



$\frac{v_{o-}}{v_{id}} = -\frac{1}{2} g_m R_C = -100$

$\frac{v_{o+}}{v_{id}} = \frac{1}{2} g_m R_C = +100$

$v_{id} = 10m \sin(10t)$

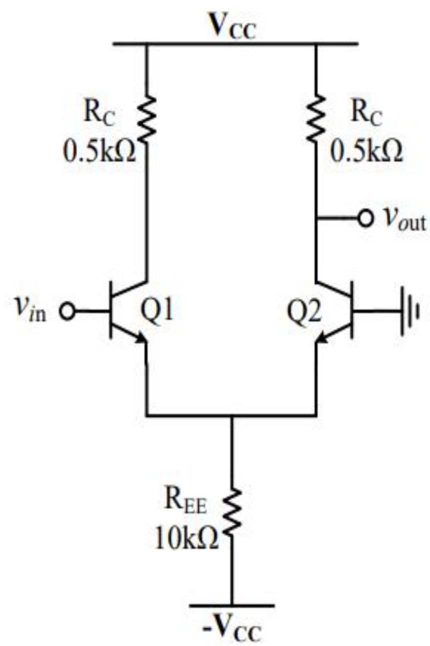
$v_{o-} = -1000m \sin(10t)$

$v_{o+} = +1000m \sin(10t)$

$v_{o+} - v_{o-} = +2v \sin(10t)$

2- Calculate the voltage gain ($A_v = \frac{v_{out}}{v_{in}}$) of the circuit shown below using the following methods:

a) Direct analysis.
b) Half-circuit analysis (break the input voltage to a differential term and a common-mode one, compute the differential and common-mode output voltages and add the results together).



$$\begin{cases} I_{C1} = I_{C2} = 1mA \\ \beta = 100 \\ V_A = \infty \\ V_T = 25mV \end{cases}$$

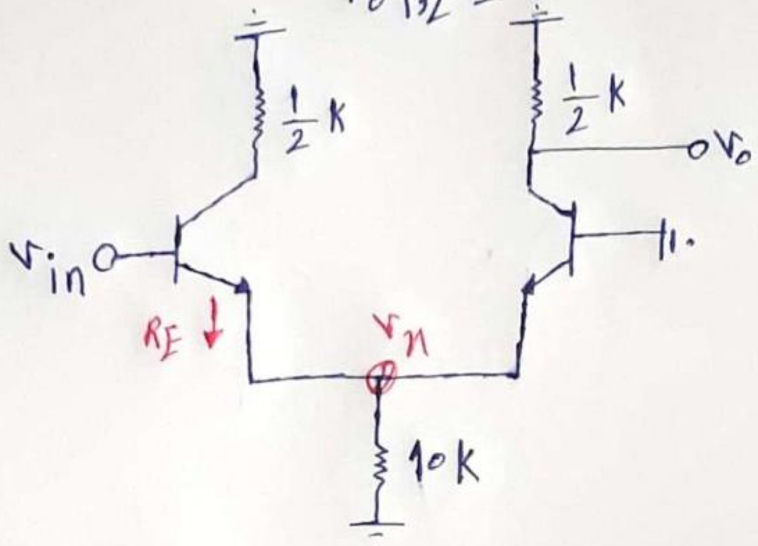
$i_{C1} = i_{C2} = 1mA \longrightarrow g_{m1,2} = 40mA$

$r_{\pi 1,2} = 2.5K$

$r_{o1,2} = \infty$

$A_v = ?$ -2

1a



$$A_v = \frac{v_o}{v_x} \times \frac{v_x}{v_{in}}$$

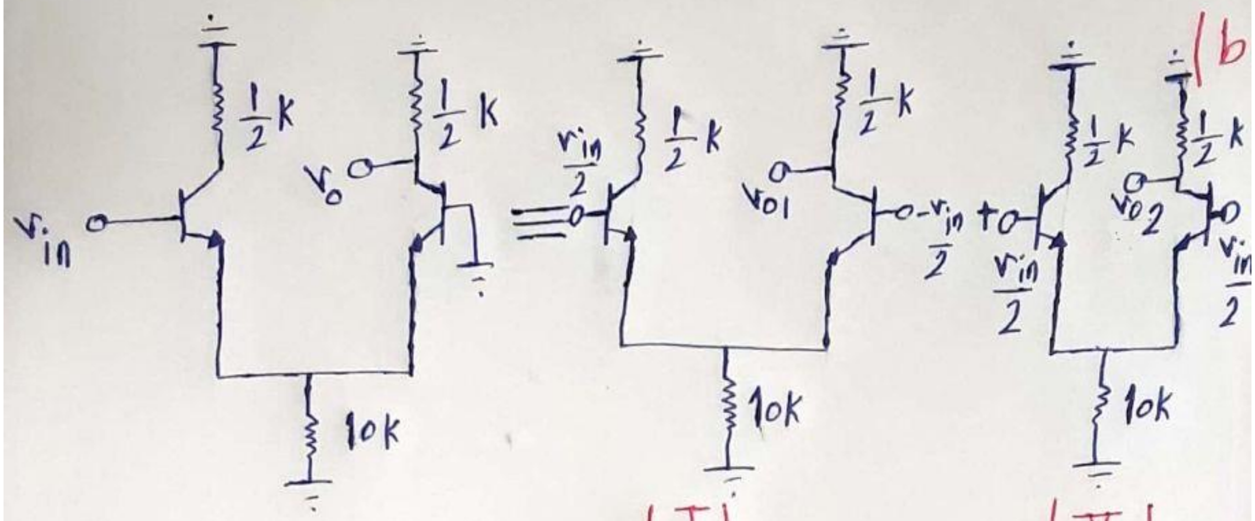
$$\frac{v_o}{v_x} = +g_m R_C = +40 \times \frac{1}{2} = +20$$

$$\frac{v_x}{v_{in}} = \frac{R_E}{R_E + \frac{1}{g_m}} \qquad R_E = 10K \,||\, \frac{1}{g_m} = 0.02493765$$

$$\frac{v_x}{v_{in}} = 0.49937572$$

$$A_v = \frac{v_o}{v_{in}} = 9.98751$$

b)

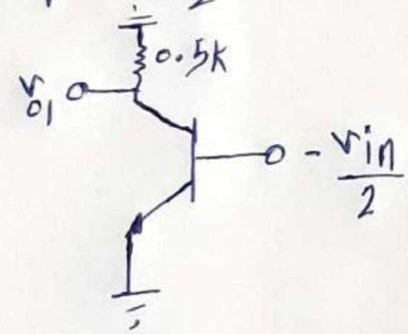


(I) تفاضلی

(II) مشترک

$$v_o = v_{o1} + v_{o2}$$

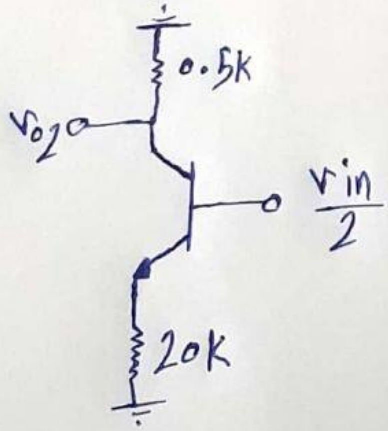
(I)



$$\frac{v_{o1}}{-\frac{v_{in}}{2}} = -g_m R_C \Rightarrow v_{o1} = \frac{1}{2} g_m R_C v_{in}$$

$$v_{o1} = 10 v_{in}$$

(II)



$$\frac{v_{o2}}{\frac{v_{in}}{2}} = \frac{-R_C}{R_E + \frac{1}{g_m}} \Rightarrow$$

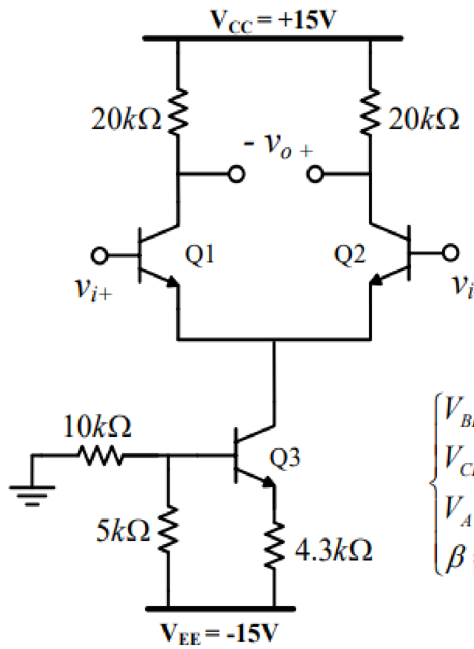
$$\frac{v_{o2}}{v_{in}} = \frac{1}{2}\,\frac{-0.5}{20 + \frac{1}{40}} = -0.012484$$

$$v_{o2} = -0.012484\, v_{in}$$

$$v_o = v_{o1} + v_{o2} \Rightarrow v_o = 9.98751\, v_{in} \rightarrow A_v = 9.98751$$

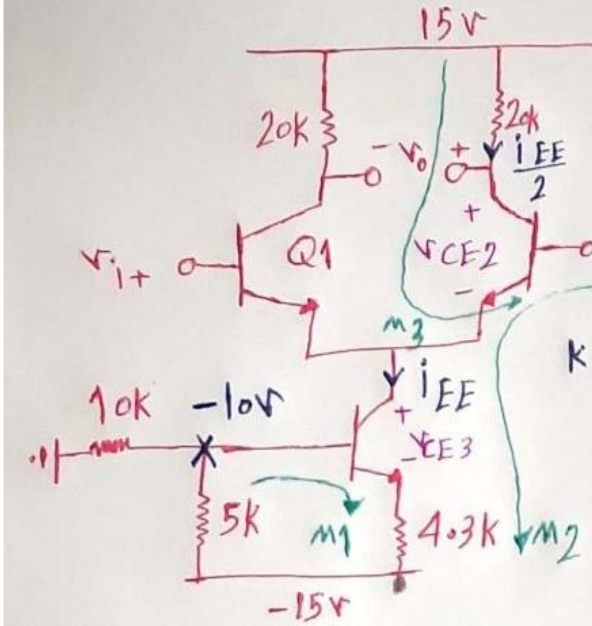
3- In the circuit shown below, the transistors are the same. Neglect β effect in DC analysis.

a) Calculate the input DC common-mode voltage range and the output swing.
b) Determine CMRR.



$$\begin{cases} V_{BE} = 0.6V \\ V_{CEsat} = 0V \\ V_A = 10V \\ \beta = 100 \end{cases}$$

13



$v_{BE} = 0.6v$

$v_{CS} = 0v$

$v_A = 10v$

$\beta = 100$

$KVL@m_1: +10+6+4.3i_{EE}-15=0$

$i_{EE} \simeq 1mA$

$KVL@m_2: -v_{in,dc}+0.6+v_{CE3}+4.3i_{EE}-15=0$

$v_{CE3} = v_{in,dc}+10.1 \geq 0 \rightarrow v_{in,dc} \geq -10.1$ (I)

$KVL@m_3: -15+\frac{20\times i_{EE}}{2}+v_{CE2}-0.6+v_{in,dc}=0 \rightarrow$

$v_{CE2} = -v_{in,dc}+5.6 \geq 0 \rightarrow v_{in,dc} \leq 5.6v$ (II)

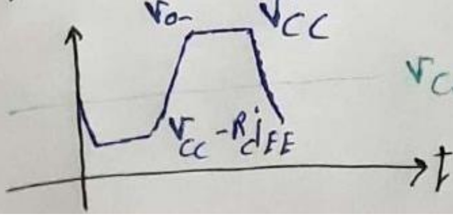
$\mathrm{I} \cap \mathrm{II} \rightarrow -10.1v \leq v_{in,dc} \leq 5.6v$

محاسبه $swing\{v_o\}$:

$v_{o,dc} = v_{o-dc} = v_{CC} - R_C\frac{i_{EE}}{2}$

$v_{i+} \rightarrow Q_1: off \rightarrow v_{o-} = v_{CC} = 15v$

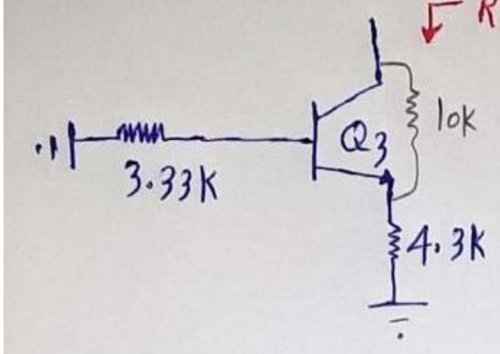
$i_{C2} = i_{EE} \rightarrow v_{o+} = v_{CC} - R_E i_{EE}$



$v_{CC} - R_C\frac{i_{EE}}{2}$

$swing\{v_o\} = 2R_C\frac{i_{EE}}{2} = 20v$

$$CMRR = \frac{A_d}{A_{cm}} = ?$$ 1b



$g_{m1} = g_{m2} = 20mS$

$r_{\pi 1,2} = 5k\Omega$

$r_{o1,2} = 20k\Omega$

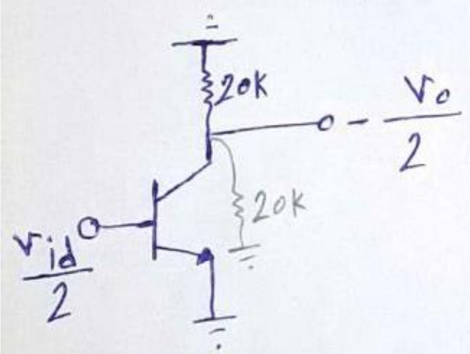
$r_{o3} = \frac{10}{1} = 10k\Omega$

$g_{m3} = 40mS$

$r_{\pi 3} = 2.5k\Omega$

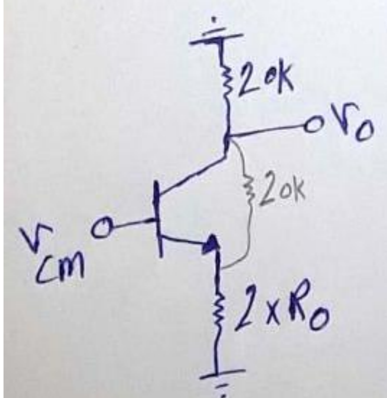
$$R_{out} = r_o\left(1 + \frac{\beta R_E}{R_E + r_\pi + R_B}\right)$$

$$R_{out} = 10\left(1 + \frac{100 \times 4.3}{4.3 + 2.5 + 3.33}\right) = 434.5k\Omega$$



$$\frac{-\frac{v_o}{2}}{\frac{v_{id}}{2}} = -g_m(R_C \| r_o) =$$

$$\frac{v_o}{v_{id}} = +20(20\|20) = +200 = A_d$$

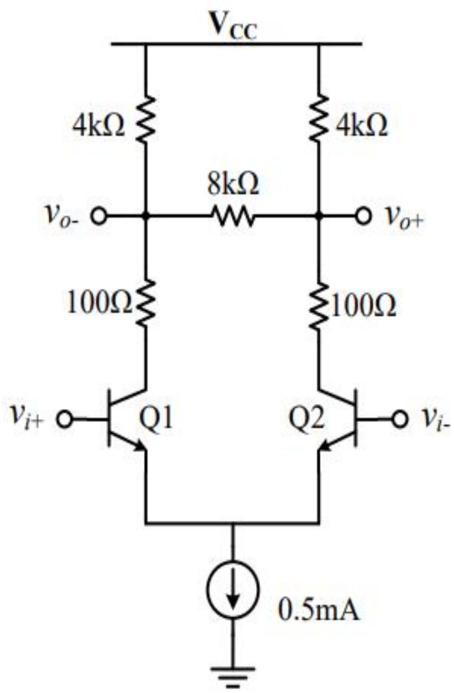


$$\frac{v_o}{v_{cm}} \simeq \frac{-R_C}{R_E + \frac{1}{g_m}} = \frac{-20}{2 \times 434.5 + \frac{1}{20}}$$

$$\frac{v_o}{v_{cm}} = -0.023 = A_{cm}$$

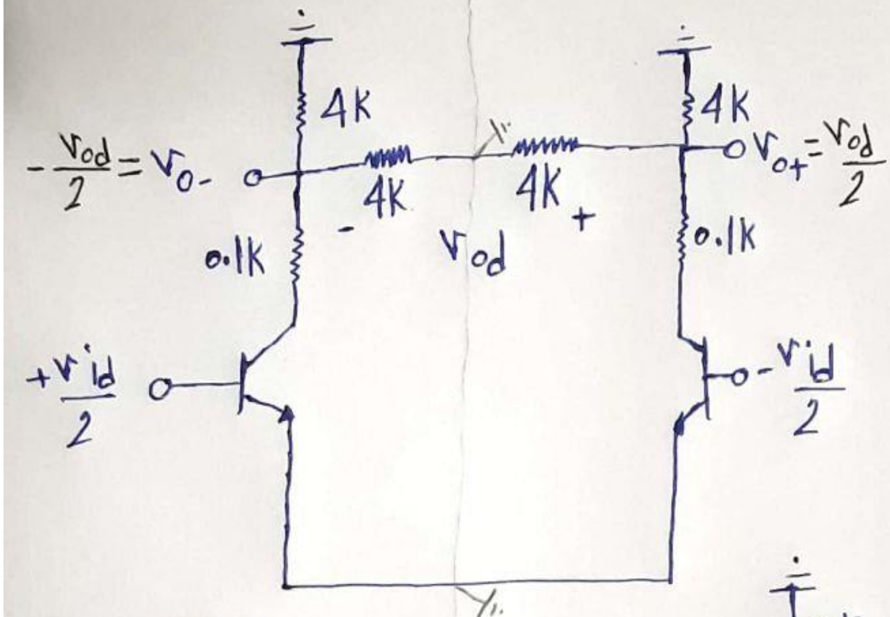
$$CMRR = 8695.65$$

4- In the following circuit, Q_1 and Q_2 are the same and are biased in the active region. Calculate the differential voltage gain ($A_d = \frac{v_{od}}{v_{id}} = \frac{v_{o+} - v_{o-}}{v_{i+} - v_{i-}}$).



$$\begin{cases} \beta = 100 \\ V_A = \infty \\ V_T = 25mV \end{cases}$$

-4



$A_d = ?$

$i_{C1} = i_{C2} = \frac{1}{4} mA$

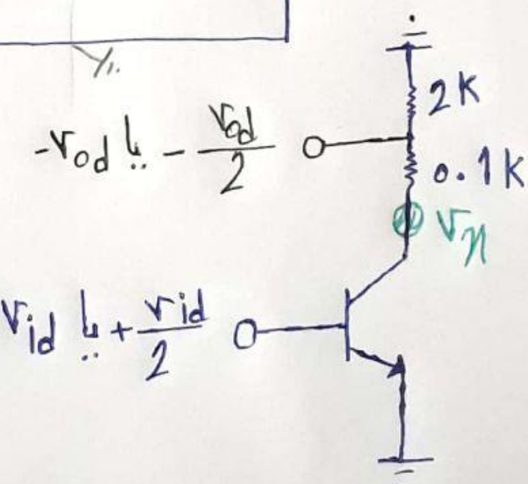
$g_{m1,2} = 10 mS$

$r_{\pi 1,2} = 10K\Omega$

$r_o = \infty$

$$A_d = \frac{v_{od}}{v_{id}}$$

$$A_d = \frac{v_{o+} - v_{o-}}{v_{id}}$$

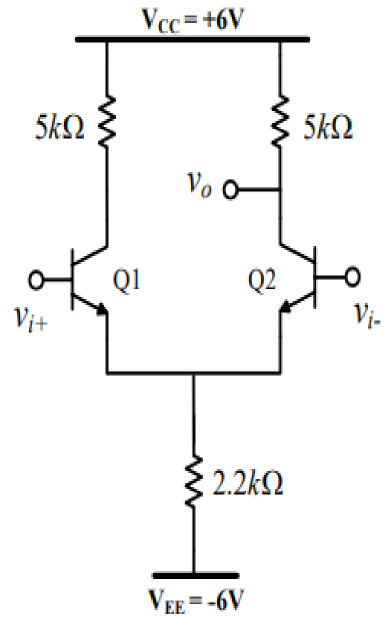


$$\frac{v_{od}}{v_{id}} = \frac{v_{od}}{v_x} \times \frac{v_x}{v_{id}}$$

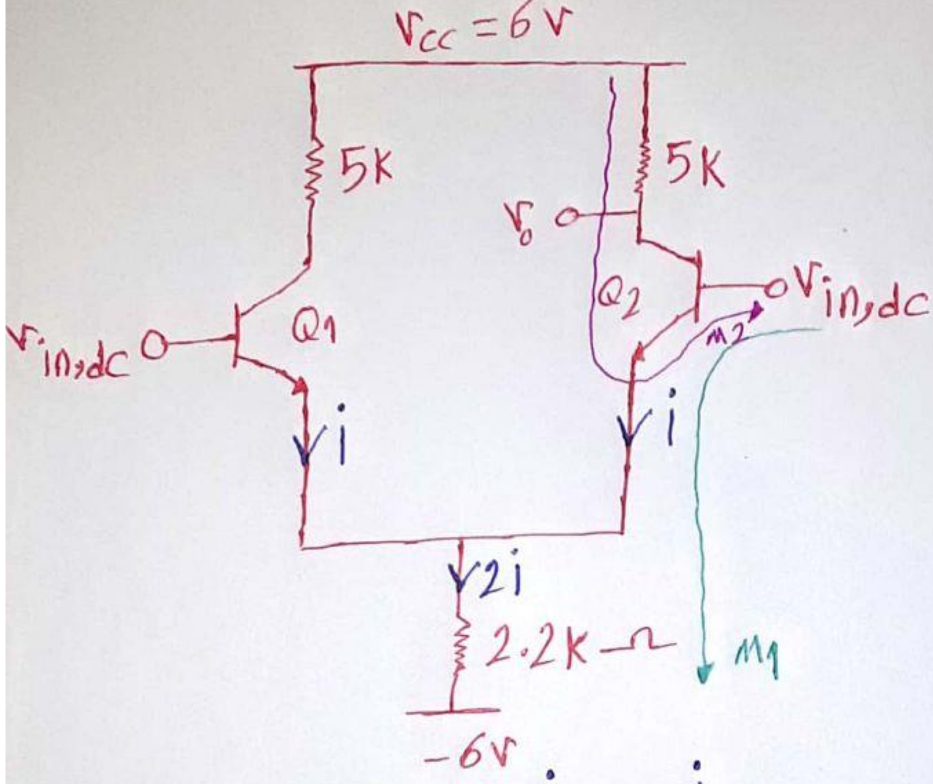
$$\frac{v_{od}}{v_x} = \frac{-2}{2.1} \qquad \frac{v_x}{v_{id}} = -g_m R_C = -10 \times 2.1 = -21$$

$$A_d = +20$$

5- In the following differential amplifier circuit, determine the input DC common-mode range.



$$\begin{cases} V_{BE} = 0.6V \\ V_{CE,sat} = 0.2V \end{cases}$$



-5

$V_{BE} = 0.6V$

$V_{CE,sat} = 0.2V$

$$V_{BE1} = V_{BE2} \rightarrow i_{C1} = i_{C2} = i$$

$$KVL\ @\ M_1:\ -V_{in,dc} + 0.6 + 4.4i - 6 = 0 \rightarrow i = \frac{5.4 + V_{in,dc}}{4.4}$$

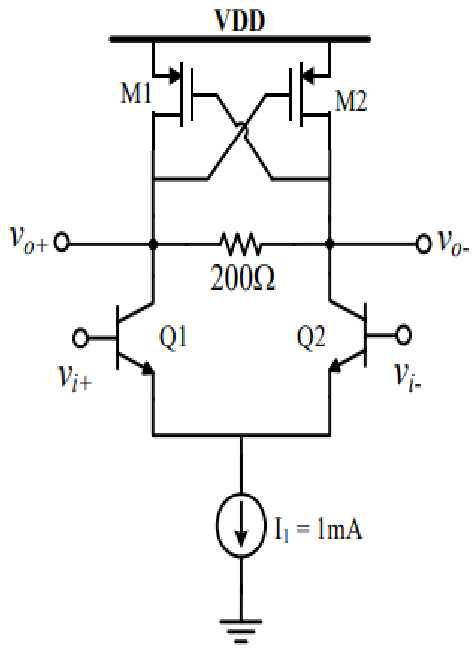
$$KVL\ @\ M_2:\ -6 + 5i + V_{CE2} - 0.6 + V_{in,dc} = 0$$

$$V_{CE2} = 6.6 - 5i - V_{in,dc} = 6.6 - 6.136 - 1.1363 V_{in,dc} - V_{in,dc}$$

$$V_{CE2} = 0.464 - 2.1363 V_{in,dc} \geq 0.2$$

$$V_{in,dc} \leq 0.123V$$

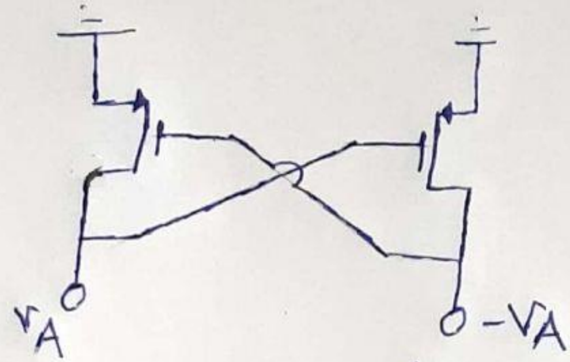
6- Calculate the single-ended voltage gain $\{v_{o+}/(v_{i+}-v_{i-})\}$ as well as the fully-differential voltage gain $\{(v_{o+}-v_{o-})/(v_{i+}-v_{i-})\}$ for the following circuit.

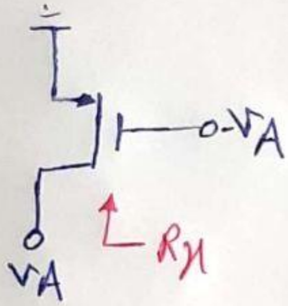


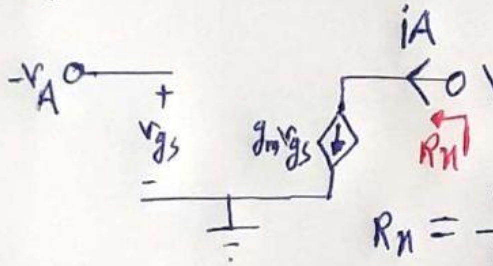
$$Q_{1,2}: \begin{cases} \beta = 100 \\ V_T = 25mV \\ |V_A| = 10V \end{cases}$$

$$M_{1,2}: \begin{cases} g_m = 10\frac{mA}{V} \\ |\lambda| = 0V^{-1} \end{cases}$$

-6







$R_x = \frac{v_A}{i_A}$

1- تفاضلی
2- تقارن

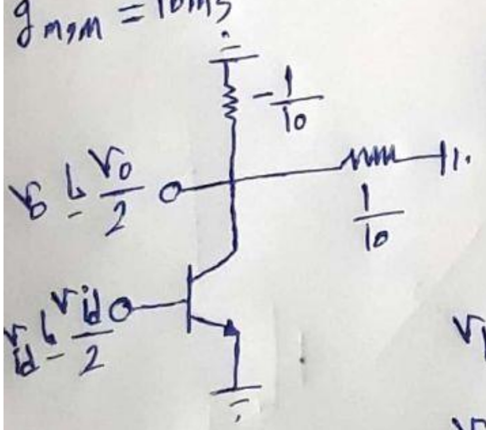
$v_{gs} = -v_A$

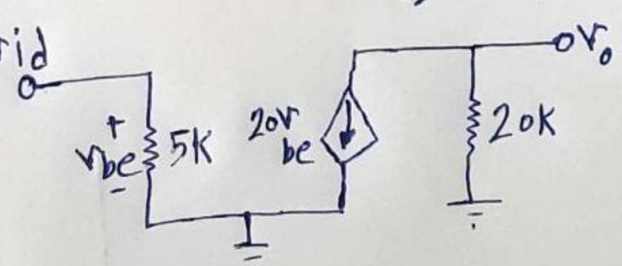
$i_A = g_m v_{gs} = -g_m v_A = i_A \to \boxed{R_x = -\frac{1}{g_m}}$

$i_{C1} = i_{C2} = 0.5mA \to g_{m\,Q1,2} = 20mS \to r_{\pi 1,2} = 5k\Omega$

$r_{o1,2} = 20k\Omega$

$g_{m,M} = 10mS$



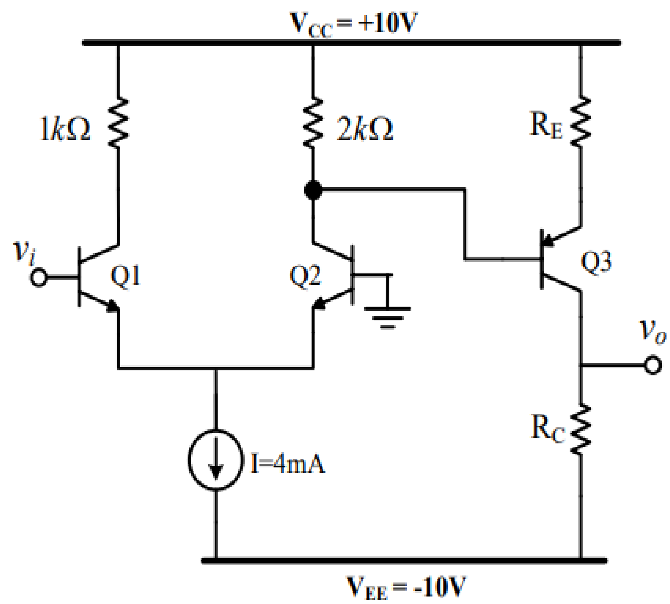


$v_{be} = v_{id}$

$v_o = -20 \times 20\, v_{be} = -400\, v_{id}$

$\frac{v_o}{v_{id}} = \boxed{A_d = -400}$

7- In the following circuit, the DC output voltage is equal to zero. Calculate the voltage gain.



$$
\begin{cases}
V_i(DC) = 0V \\
V_O(DC) = 0V \\
|V_{BE}| = 0.6V \\
V_T = 25\,mV \\
V_A = \infty \\
\beta \gg 1 \\
R_E \gg \dfrac{1}{g_m}
\end{cases}
$$

DC)

$\beta >> 1$ -7

$R_E >> \frac{1}{g_{m3}}$

$v_{BE1} = v_{BE2} \rightarrow i_{C1} = i_{C2} = 2mA$

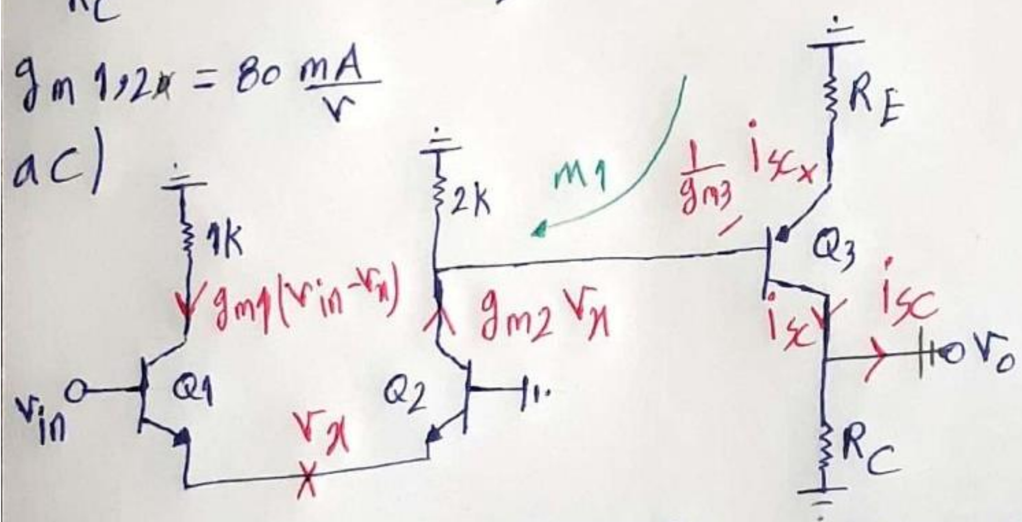
$v_o = 0 \rightarrow i_{C3} = \frac{10}{R_C} \simeq i_{E3} \quad i_{B3} \simeq 0$

KVL: $-10 + R_E i_{E3} + 0.6 - 2 i_{C2} + 10 = 0$

$\frac{R_E \times 10}{R_C} = 3.4 \rightarrow \frac{R_C}{R_E} = \frac{10}{3.4} \quad (I)$

$g_{m1,2} = 80 \frac{mA}{V}$

ac)



$A_v = G_m \times R_{out} \qquad R_{out} = R_C \qquad G_m = ?$

$G_m = \frac{i_{sc}}{v_{in}} \qquad g_{m1}(v_{in} - v_x) = g_{m2} v_x$

$$v_x = \frac{g_{m1} v_{in}}{g_{m1} + g_{m2}}$$

KVL@m_1: $R_E i_{sc} + \frac{1}{g_{m3}} i_{sc} + 2 g_{m2} \frac{g_{m1} v_{in}}{g_{m1} + g_{m2}} = 0$

$$G_m = \frac{i_{sc}}{v_{in}} = \frac{-2 g_{m1} g_{m2}}{(g_{m1} + g_{m2})(R_E + \frac{1}{g_{m3}})} = \frac{-2}{(\frac{1}{g_{m1}} + \frac{1}{g_{m2}})(R_E + \frac{1}{g_{m3}})}$$

$$A_v = G_m \times R_{out} = \frac{-2R_C}{\left(\frac{1}{g_{m1}} + \frac{1}{g_{m2}}\right)\left(R_E + \frac{1}{g_{m3}}\right)}$$

$$R_E \gg \frac{1}{g_m} \longrightarrow A_v = \frac{-2R_C}{\left(\frac{1}{g_{m1}} + \frac{1}{g_{m2}}\right)\left(R_E\right)} \xrightarrow{(I)}$$

$$A_v = \frac{-2}{\frac{1}{80} + \frac{1}{80}} \times \frac{10}{3.4} \longrightarrow \boxed{A_v = -235.3}$$