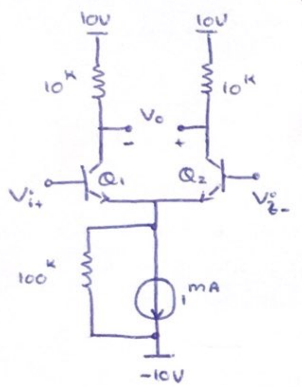
In the name of God

Assignment 6:

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



$V_A = \infty$

$V_T = 25^{mV}$

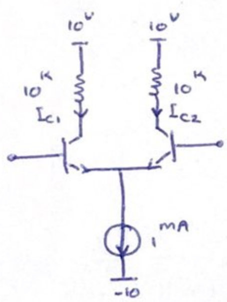
$\beta = 100$

$V_{i+} = 0.5\, V_{id}$

$V_{i-} = -0.5\, V_{id}$

$V_{id} = 10 \sin 10t^{\ mV}$

dc Analysis :



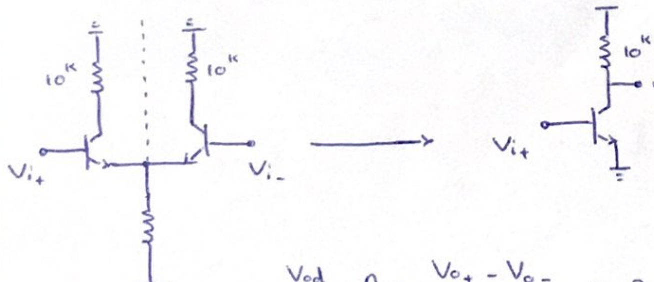
$I_{c1} = I_{c2} = 0.5^{mA}$

$g_{m1} = g_{m2} = 40(0.5) = 20^{mmho}$

$r_{\pi 1} = r_{\pi 2} = \dfrac{\beta}{g_m} = \dfrac{100}{20} = 5^{K}$

$r_{o1} = r_{o2} = \infty$

ac Analysis: inputs are diffrential $\Longrightarrow$ draw half circuit $\Longrightarrow$ V in symmetry line is equal to 0



خروجی از سر مثبت

$A_{vd} = \dfrac{V_o}{V_{id}} = \pm \dfrac{1}{2} g_m R_c$

خروجی از سر منفی

$= \dfrac{1}{2}(20)10 = \boxed{100}$

$\dfrac{V_{od}}{V_{id}} = A_{vd} = \dfrac{V_{o+} - V_{o-}}{V_{id}} = -g_m R_c = -200$

$V_{o+} = A_{vd} V_{id} = 100\,(10 \sin 10t) = 1000 \sin 10t^{\ mV} = 1 \sin 10t^{\ V}$

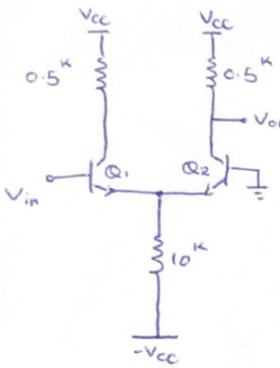
$V_{o-} = A_{vd} V_{id} = -100\,(10 \sin 10t) = -1000 \sin 10t^{\ mV} = -1 \sin 10t^{\ V}$

$V_{o+} - V_{o-} = 2000 \sin 10t^{\ mV} = 2 \sin 10t^{\ V}$

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

a) Direct analysis:

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



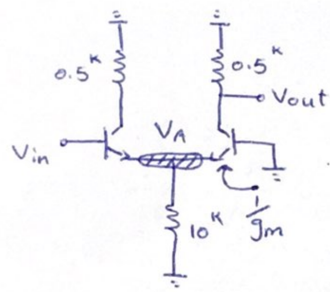
$I_{C1} = I_{C2} = 1^{mA} \Rightarrow g_{m1} = g_{m2} = 40^{mmho}$

$\beta = 100 \Rightarrow r_{\pi 1} = r_{\pi 2} = \frac{\beta}{g_m} = 2.5^K$

$V_A = \infty \Rightarrow r_{o1} = r_{o2} = \infty$

$V_T = 25^{mV}$

ac Analysis:

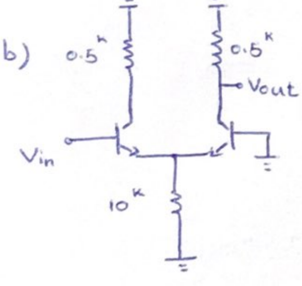


$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_A} \times \frac{V_A}{V_{in}}$$

$$= \left[+g_m R_C \right] \times \left[\frac{R_E}{R_E + \frac{1}{g_m}} \right]$$

$$= (40 \times 0.5) \times \left(\frac{10^K \| \frac{1}{40}}{(10^K \| \frac{1}{40}) + \frac{1}{40}} \right) \simeq \boxed{9.98}$$

b)



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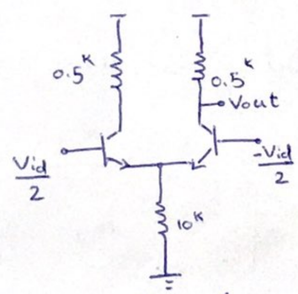

differential mode

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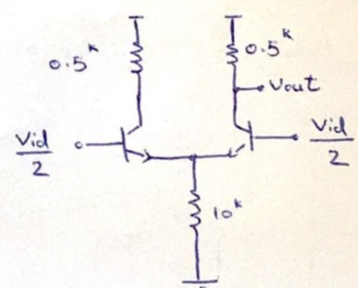
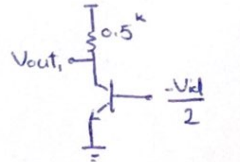


Common mode

$$A_v = A_v \Big|_{differential} + A_v \Big|_{common\ mode}$$

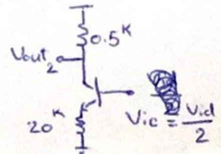
half circuit (diff):



$$\frac{V_{out1}}{-\frac{V_{id}}{2}} = -g_m R_C \Rightarrow \boxed{V_{out1} = \frac{1}{2} g_m R_C V_{in}} \quad (1)$$

$V_{out1} = 10\, V_{in}$

half circuit (cm):



$$\frac{V_{out2}}{V_{ic}} = \frac{-R_C}{2R_{EE} + \frac{1}{g_m}} = \frac{-0.5^K}{20 + \frac{1}{40}} \Rightarrow \frac{V_{out2}}{V_{id}} = \frac{1}{2}\left(\frac{-0.5}{20 + \frac{1}{40}}\right) = -0.012$$

$\Rightarrow V_{out2} = -0.012\, V_{id}$

$V_{out} = V_{out1} + V_{out2} = 10\, V_{in} - 0.012\, V_{in} = 9.98\, V_{in} \Rightarrow A_v = \frac{V_{out}}{V_{in}} = \boxed{9.98}$

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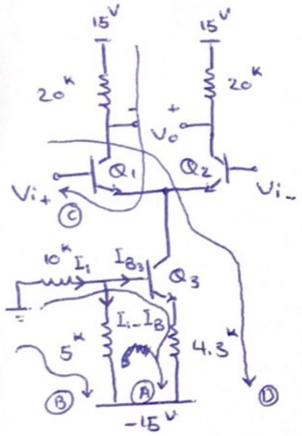
3. In the Circuit shown below, the transistor are the same. neglect β effect in dc Analysis.

   a) Calculate the input dc Common mode Voltage range and the output swing?

   b) Determine CMMR? $V_{BE} = 0.6$, $V_{CE,sat} = 0$, $V_A = 10$, $\beta = 100$



KVL @ A : $10^k I_1 + 0.6 + 4.3^k I_{C3} - 15 = 0 \xrightarrow{I_{C3} = 100 I_{B3}}$

$\boxed{10 I_1 + 430 I_B = 14.4}$ (I)

KVL @ B : $10^k I_1 + 5^k (I_1 - I_B) - 15 = 0 \Rightarrow \boxed{15 I_1 - 5 I_B = 15}$

$\xrightarrow{(I), (II)} \begin{cases} I_1 = 1^{mA} \\ I_B = 0.01^{mA} \end{cases} \longrightarrow I_{C3} = 100\, I_B = \boxed{1^{mA}}$

KVL @ C : $-15 + 20^k (0.5^m) + V_{CE} - 0.6 + V_{in,dc} = 0 \Rightarrow V_{in,dc} = 15 - 10 - V_{CE}$

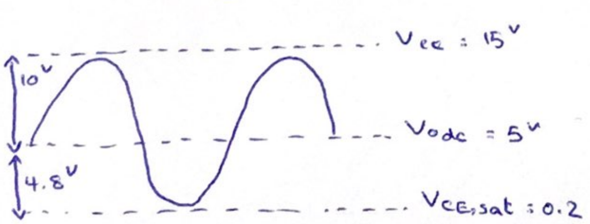
$V_{idc} = 5 - V_{CE} \longrightarrow Max\{V_{in,dc}\} = 5^V$

KVL @ D : $-V_{in,dc} + 0.6 + V_{CE3} + 4.3^k (1^m) - 15 = 0 \Rightarrow V_{in,dc} = -10.1 + V_{CE3}$

$Min\{V_{in,dc}\} = -10.1$

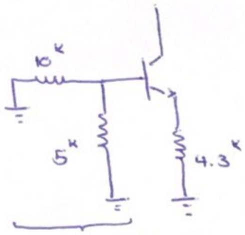
$\boxed{-10.1 < V_{in,dc} < 5^V}$

calculate swing : $V_{cc} - V_{odc} = 20^k \frac{I_{EE}}{2} \Rightarrow V_{odc} = V_{cc} - 20 \frac{I_{EE}}{2} = 15 - 20\left(\frac{1}{2}\right) = 5$



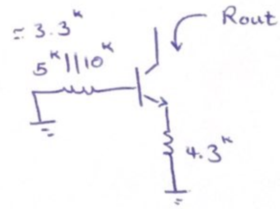
$\Rightarrow$ swing $\{V_o\} = 10 + 4.8 = \boxed{14.8^V}$

b)



in parallel

$\equiv$



$$CMMR = \frac{A_{v,d}}{A_{v,cm}}$$

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

$$= 10^k\left(1 + \frac{100(4.3^k)}{4.3^k + 2.5^k + (5^k \| 10^k)}\right) \simeq 436^k$$

$I_{c1} = I_{c2} = 0.5^{mA}$

$g_{m1} = g_{m2} = 20^{mmho}$

$r_{\pi1} = r_{\pi2} = \frac{\beta}{g_m} = \frac{100}{20} = 5^k$

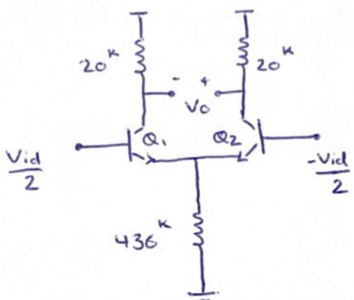
$r_{o1} = r_{o2} = \frac{V_A}{I_c} = \frac{10}{0.5} = 20^k$

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

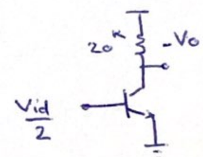
$g_{m3} = 40^{mmho}$

$r_{\pi3} = \frac{100}{40} = 2.5^k$

$\Rightarrow$



I) diffrential mode :

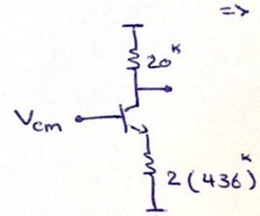


$$A_v = \frac{-V_o}{\frac{V_{id}}{2}} = -g_m(R_c \| r_o)$$

$$= 20(20^k \| 20) = 200$$

$$\Rightarrow \frac{V_o}{V_{id}} = \frac{1}{2}(200) = 100$$

II) common mode :



$$A_v = \frac{-R_c}{R_E + \frac{1}{g_m}} = \frac{-20}{2(436) + \frac{1}{20}}$$

$$= -0.023$$

به دلیل خروجی دیفرانسیل

$$\Rightarrow CMMR = \frac{A_{vd}}{A_{v,cm}} = \frac{2(100)}{0.023} = \boxed{8695.65}$$

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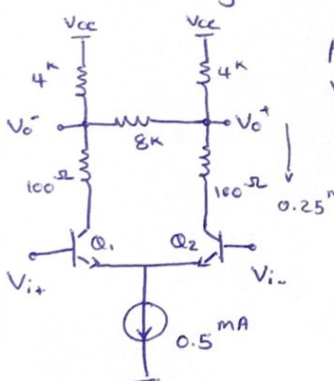
4. In the following circuit, Q_1 and Q_2 are the same and are biased in the active regin. Calculate the diffrential voltage gain ($A_{vd} = \frac{V_o}{V_{id}} = \frac{V_{o+} - V_{o-}}{V_{i+} - V_{i-}}$)



$\beta = 100$

$V_A = \infty \longrightarrow r_o = \infty$

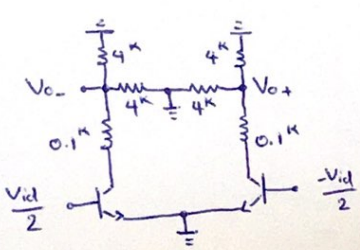
$V_T = 25^{mV}$

$g_{m1} = g_{m2} = 10^{mmho}$

$r_{\pi1} = r_{\pi2} = \frac{100}{10} = 10^k$

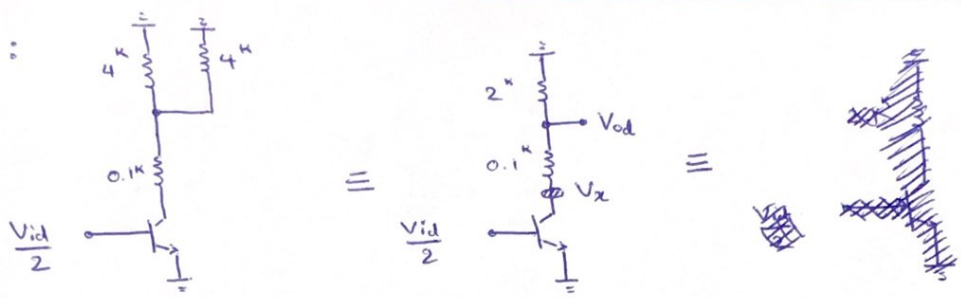
$r_{o1} = r_{o2} = \infty$

ac Analysis :



$$A_{vd} = \frac{V_{od}}{V_{id}} = \frac{V_{o+} - V_{o-}}{V_{id}}$$

half Circuit :



$$A_{vd} = \frac{V_{od}}{\frac{V_{id}}{2}} = \frac{V_{od}}{V_x} \times \frac{V_x}{\frac{V_{id}}{2}} = \left[-g_m R_c\right] \times \left[\frac{2}{2+0.1}\right] = \left[-10\,(0.1)\right] \times \left[\frac{2}{2.1}\right] = \boxed{-0.9}$$

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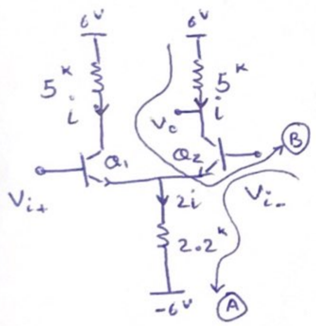
5. In the following diffrential Amplifier Circuit, determine the input dc common mode range. $(V_{BE} = 0.6^V,\ V_{CE,sat} = 0.2)$



$$\text{KVL @ A}: \ -V_{in,dc} + 0.6 + 2.2^k(2i) - 6 = 0$$

$$\Rightarrow i = \frac{5.4 + V_{in,dc}}{4.4} \qquad (I)$$

$$\text{KVL @ B}: \ -6 + 5^k i + V_{CE_2} - 0.6 + V_{in,dc} = 0$$

$$\Rightarrow V_{CE_2} = 6 - 5i + 0.6 - V_{in,dc} \xrightarrow{(I)}$$

$$V_{CE_2} = 6.6 - 5\left(\frac{5.4 + V_{in,dc}}{4.4}\right) - V_{in,dc}$$

$$V_{CE_2} = -2.13\, V_{in,dc} + 0.46 \geqslant 0.2$$

$$\Rightarrow \boxed{V_{in,dc} \leq 0.122^V}$$

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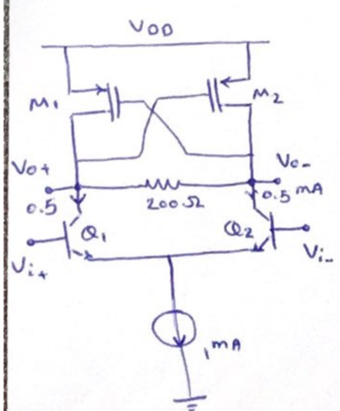
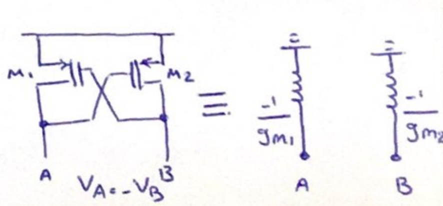
6. Calculate the Single-ended Voltage gain as well as the fully diffrential voltage gain $\left(\frac{V_o^+ - V_o^-}{V_i^+ - V_i^-}\right)$ for the following Circuit.



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

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

hint :



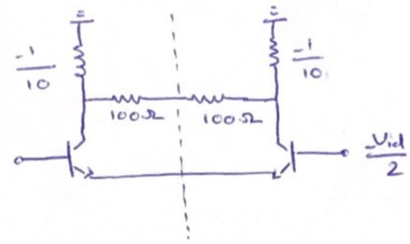
* Cross-Coupled Configuration

$I_{c1} = I_{c2} = 0.5^{mA}$

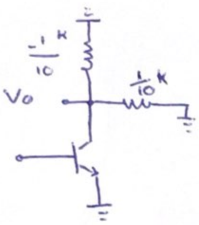
$g_{m1} = g_{m2} = 20^{mmho}$

$r_{\pi 1} = r_{\pi 2} = \dfrac{\beta}{g_m} = 5^K$

$r_{o1} = r_{o2} = \dfrac{V_A}{I_c} = 20^K$



half circuit :



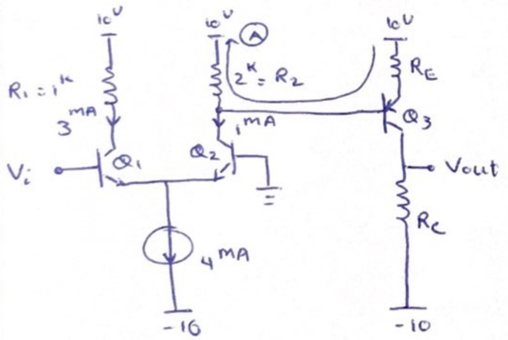
$A_{vd} = \dfrac{V_o}{\frac{V_{id}}{2}} = -g_m (R_c \| r_o) = -20 \left(\underbrace{-0.1 \| 0.1 \| 20^K}_{=\infty} \right)$

$= -400$

$\dfrac{V_o}{V_{id}} = \frac{1}{2} \times -400 = \boxed{-200} \longrightarrow \dfrac{V_{od}}{V_{id}} = 2(200) = 400$

7. In the following circuit, the dc output voltage is equal to zero.

Calculate the voltage gain : $(V_i(DC) = 0^V,\ V_o(DC) = 0^V,\ |V_{BE}| = 0.6^V,\ V_T = 25^{mV},$ $V_A = \infty,\ \beta \gg 1,\ R_E \gg \frac{1}{g_m})$



DC Analysis : $I_{c1} = 3^{mA}$, $I_{c2} = 1^{mA}$

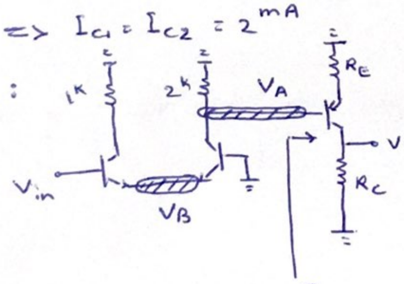
$g_{m1} = 120^{mmho}$, $g_{m2} = 40^{mmho}$

$r_\pi = \infty$, $r_o = \infty$

KVL @ A : $-10 + R_E I_{c3} + 0.6 - 2^k (1^m) + 10 = 0$

if $R_1 = R_2 \Rightarrow I_{c1} = I_{c2} = 2^{mA}$

ac Analysis :



$A_v = \dfrac{V_o}{V_i} = \dfrac{V_o}{V_A} \times \dfrac{V_A}{V_B} \times \dfrac{V_B}{V_i} = \left[\dfrac{-R_c}{R_E + \underbrace{\frac{1}{g_{m3}}}_{=0}} \right] \times \left[g_{m2} (R_c \| r_o) \right] \times \left[\cancel{\dfrac{R_E}{R_E + \underbrace{\frac{1}{g_m}}_{=0}}} \right]$

$R_E \gg \frac{1}{g_{m3}}$ طبق صورت سوال

$= \dfrac{-R_c}{R_E} \times \left(g_{m2} R_c \right) = \boxed{-80 \dfrac{R_c}{R_E}}$