7

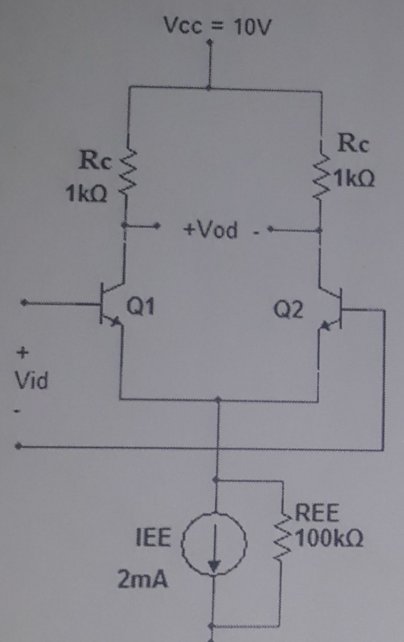
Differential Amplifiers

Problem (1)

The differential amplifier shown in Figures (1,2,3) are use two matched BJT`s Q_1 and Q_2 with $\beta = 100$ and $V_A = \infty$.

Calculate:

1. The Value of collector current for Q_1 and Q_2.
2. The differential mode gain A_{dm} .
3. The common mode gain A_{cm}.
4. The CMRR in decibel (dB).



Figure(1)

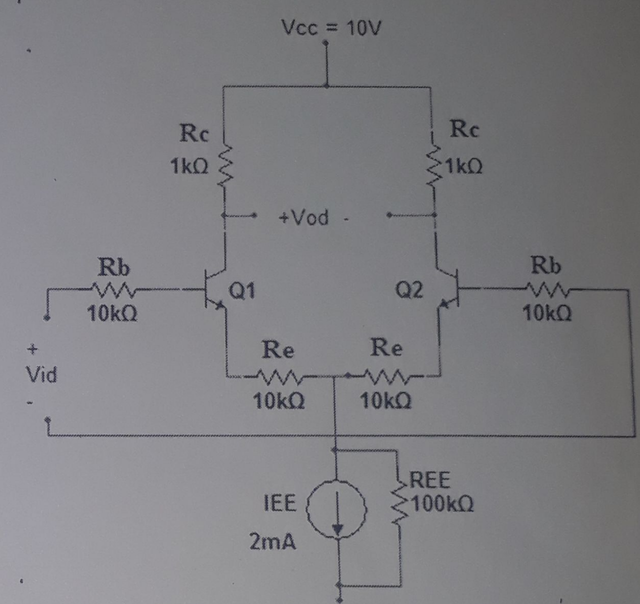


Figure (2)

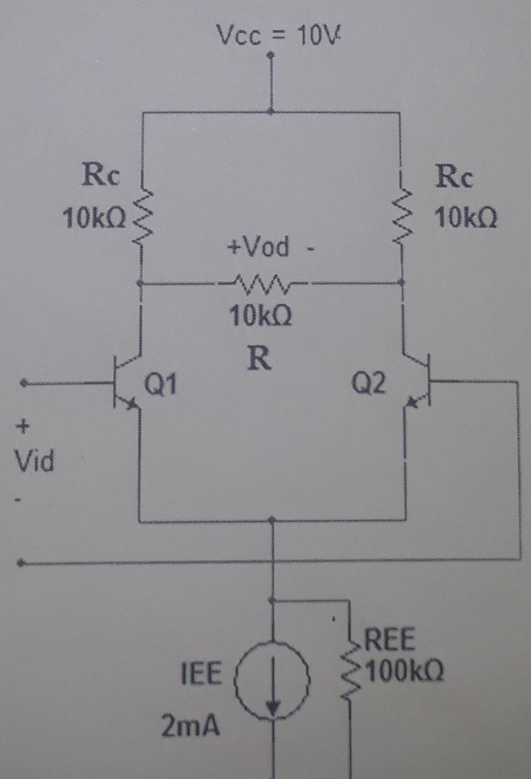


Figure (3)

Problem (2)

The differential amplifier shown in Figure (4) uses the current mirror current source Q3 and Q4 with $\beta = 200$ and $V_{A3} = V_{A4} = 120V$. If $V_{A1} = V_{A2} = \infty$, Calculate:

1. The Value of collector current for Q_1 and Q_2.
2. The differential mode gain A_{dm}.
3. The common mode gain A_{cm}.
4. The CMRR in decibel (dB).

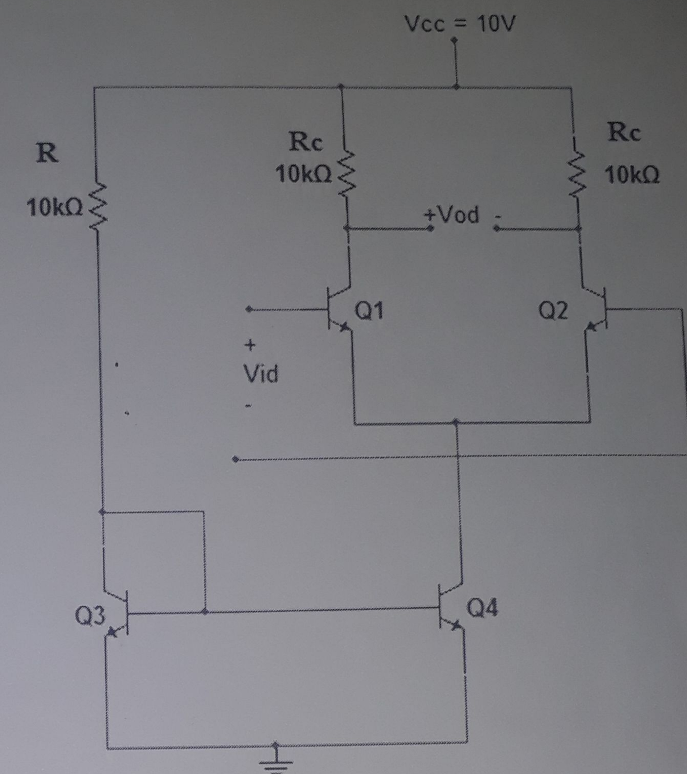
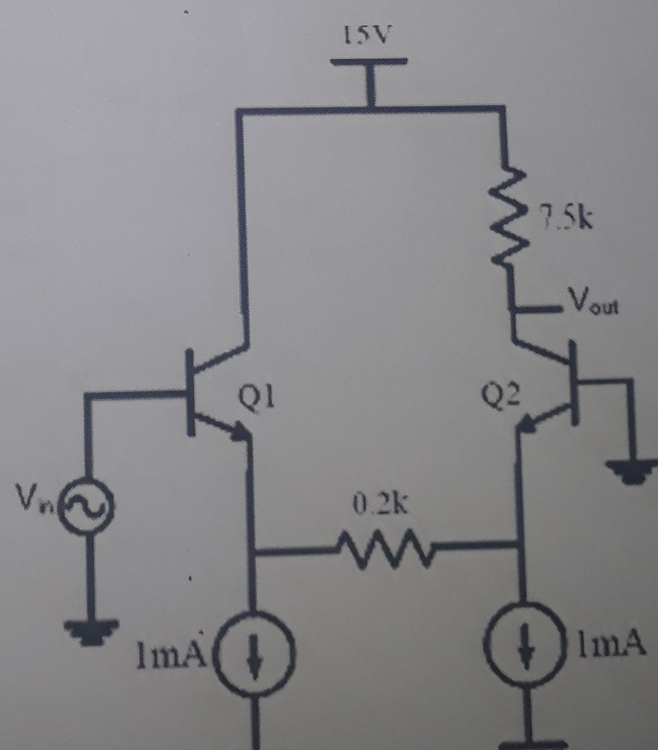


Figure (4)

Problem (3)

For the differential amplifier shown in Figure (5), calculate the voltage gain, input and output resistances. (β=100, $V_{A1} = V_{A2} = \infty$).



Figure(5)

Problem (4)

The MOS-differential amplifier shown in Figure (6,) uses two matched MOSFET`s M_1 and M_2 with $K = 2mA/V^2$ and $V_A = \infty$.
Calculate:

1. The Value of the drain current for M_1 and M_2.
2. The differential mode gain A_{dm}.
3. The common mode gain A_{cm}.
4. The CMRR in decibel (dB).

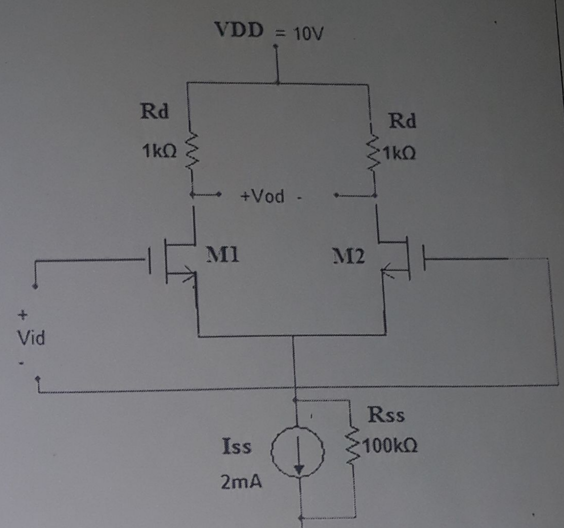


Figure (6)

Problem (5)

The differential amplifier shown in Figure (7) uses the current mirror current source M3 and M4 with $K = 0.5mA/V^2$ and $V_{A3} = V_{A4} = 120V$. If $V_{A1} = V_{A2} = \infty$, Calculate:

1. The differential mode gain A_{dm}.
2. The common mode gain A_{cm}.
3. The CMRR in decibel (dB).

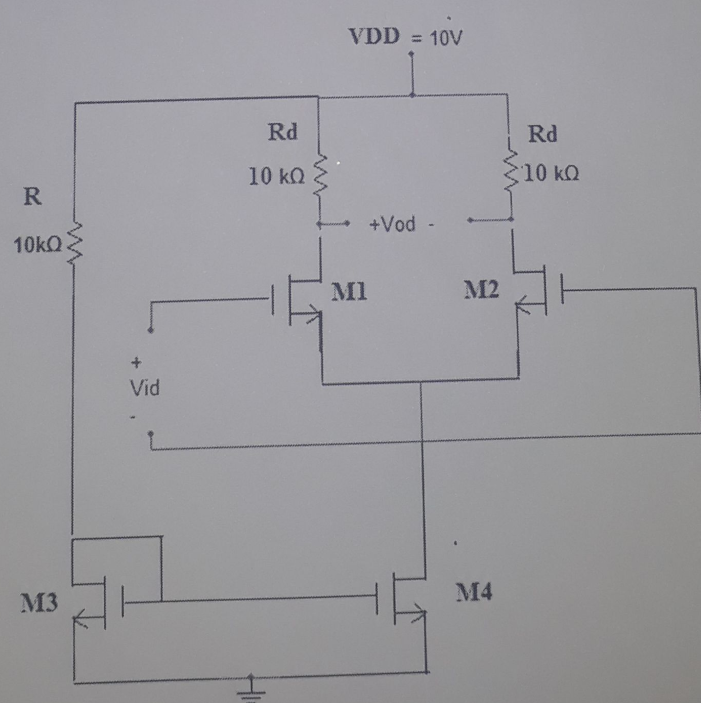


Figure (7)

Problem (2)

The differential amplifier shown in Figure (4) uses the current mirror current source Q_3 and Q_4 with $\beta = 200$ and $V_{A_3} = V_{A_4} = 120V$. If $V_{A_1} = V_{A_2} = \infty$, Calculate:

1) The value of collector current for Q_1 and Q_2
2) the differential mode gain (A_{dm})
3) The common mode gain (A_{cm})
4) the CMRR in decibel (dB)

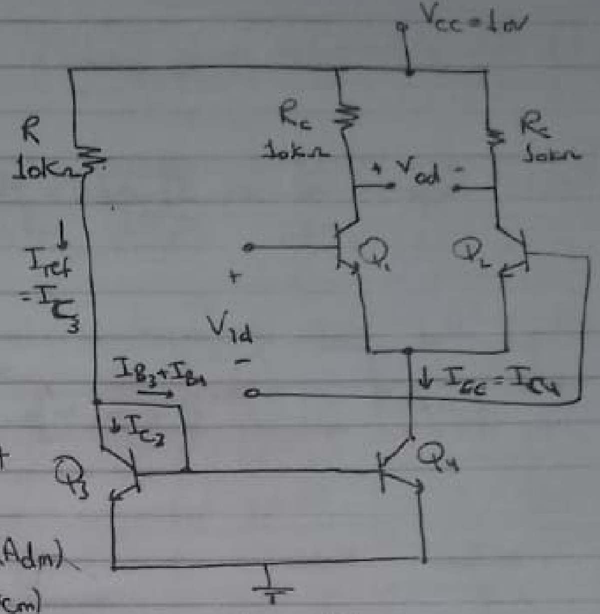


Figure (4)

Solution

① $I_{ref} = \dfrac{V_{CC} - V_{CE_3}}{R} = \dfrac{V_{CC} - V_{BE_3}}{R} = \dfrac{10 - 0.7}{10} = \boxed{0.93\,mA}$

$I_{ref} = I_{C_3} + I_{B_3} + I_{B_4}$

$V_{BE_3} = V_{BE_4}$; $I_{C_3} = I_{C_4}$, $I_{B_3} = I_{B_4}$

$I_{ref} = I_{C_4} + \dfrac{I_{C4}}{\beta} + \dfrac{I_{C4}}{\beta} = I_{C4}\left[1 + \dfrac{2}{\beta}\right]$

$I_{C_4} = I_{EE} = \dfrac{I_{ref}}{1 + \frac{2}{\beta}} = \dfrac{0.93}{1 + 2/200} = \boxed{0.921\,mA}$

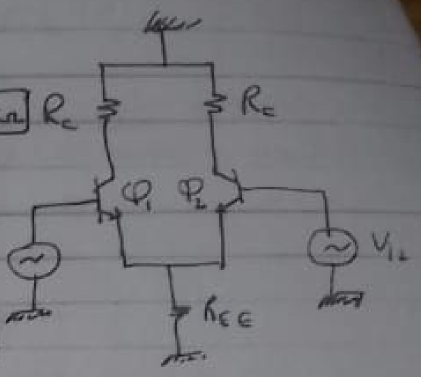
$I_{E_1} = I_{E_2} = \dfrac{I_{EE}}{2} = \dfrac{0.921}{2} = \boxed{0.46\,mA}$

$I_{C_1} = I_{C_2} = \dfrac{\beta}{1+\beta} I_{E_1} = \dfrac{200}{1+200} \cdot 0.46 = \boxed{0.458\,mA}$

Scanned with CamScanner

② The differential mode gain:

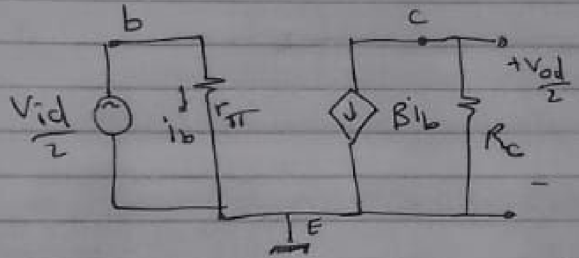
$$R_{EE} = r_{o_4} = \frac{V_{A_4}}{I_{C_4}} = \frac{120}{0.921} = \boxed{130.29\,k\Omega}$$

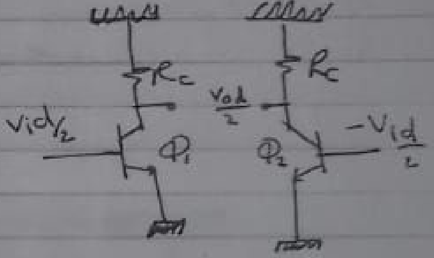


$$r_{\pi_1} = r_{\pi_2} = r_{\pi} = \beta \frac{V_T}{I_{C_1}}$$

$$= 200 * \frac{0.025}{0.458} = \boxed{10.92\,k\Omega}$$

Half - Circuit Concept

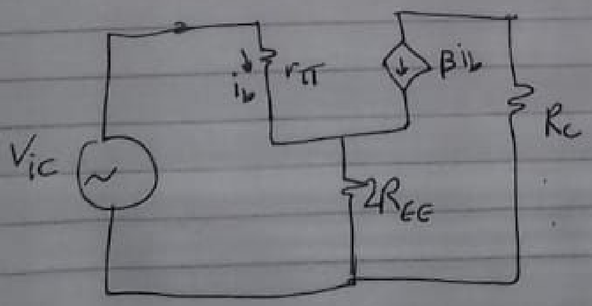


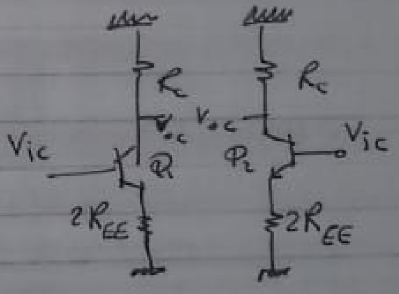


$$A_{dM} = \frac{V_{od}/2}{V_{id}/2} = \frac{V_{od}}{V_{id}} = \frac{-\beta i_b R_c}{i_b r_\pi} = \frac{-\beta R_c}{r_\pi}$$

$$A_{dM} = -\frac{200 * 10 * 10^3}{10.92 \times 10^3} = \boxed{-183.15}$$

③ The Common Mode gain:





$$A_{CM} = \frac{V_{oc}}{V_{ic}} = \frac{-\beta \cancel{i_b} R_c}{\cancel{i_b} r_\pi + (1+\beta)\cancel{i_b}\, 2R_{EE}}$$

$$A_{CM} = \frac{-\beta R_c}{r_\pi + 2R_{EE}(1+\beta)} = \frac{-200 \times 10}{10.92 + 2(130.29)(1+200)}$$

$$\boxed{A_{CM} = -0.038}$$

(9) $$CMRR = \left| \frac{A_{dM}}{A_{cM}} \right| = \left| \frac{183.15}{0.038} \right| = 4797.39$$

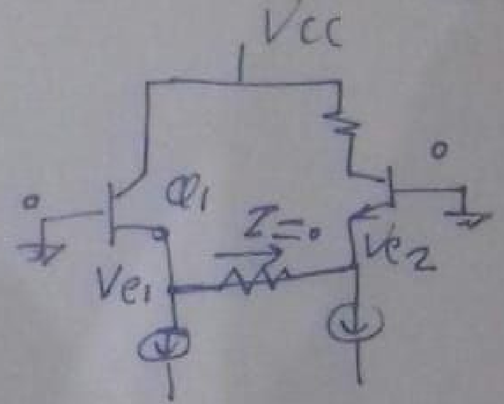
$$CMRR(dB) = 20 \log 4797.39 = \boxed{73.62\ dB}$$

...*~~~~~~~~*...

Scanned with CamS

* $I_{E_1} = 1mA$, $I_{E_2} = 1mA$

①



Note:- D.C Analysis

$V_{e_1} = -0.7V$

$V_{e_2} = -0.7V$

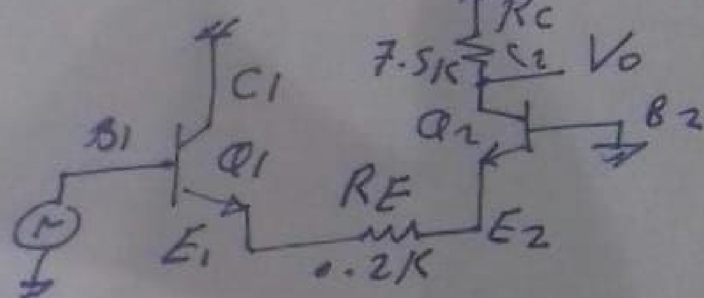
$\therefore I = 0$

$\therefore I_{E_1} = 1mA \cong I_{C_1}$

$\therefore I_{E_2} = 1mA \cong I_{C_2}$

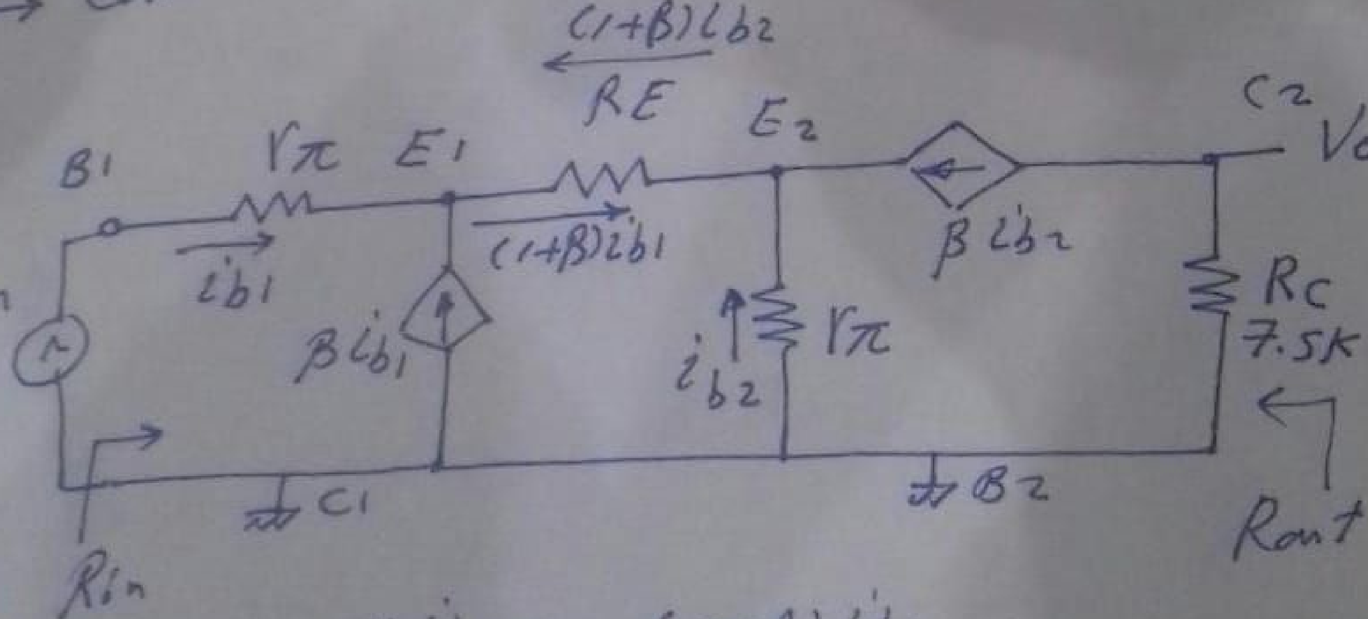
$r_{\pi_1} = r_{\pi_2} = \beta \dfrac{V_T}{I_C} = 100 \times \dfrac{0.025}{1mA} = 2.5 k\Omega$

A.C Analysis



$Q_1 \rightarrow$ Common-Collector

$Q_2 \rightarrow$ Common-Base



$(1+\beta) i_{b2} = -(1+\beta) i_{b1}$

$\therefore \boxed{i_{b2} = -i_{b1}}$

$$A_V = \frac{V_o}{V_{in}} \Rightarrow$$

$$V_o = -\beta i_{b2} R_C = +\beta i_{b1} R_C$$

$$\boxed{V_o = \beta i_{b1} R_C} \quad 1$$

$$\ast \quad V_{in} = i_{b1} r_\pi + (1+\beta) i_{b1} R_E - \overset{-i_{b1}}{i_{b2}} r_\pi$$

$$V_{in} = [r_\pi + (1+\beta) R_E + r_\pi] i_{b1}$$

$$\boxed{V_{in} = (2 r_\pi + (1+\beta) R_E) i_{b1}} \quad 2$$

$$1 \div 2 \quad A_V = \frac{V_o}{V_{in}} = \frac{\beta R_C}{2 r_\pi + (1+\beta) R_E}$$

$$A_V = \frac{100 \times 7.5}{2 \times 2.5 + 101 \times 0.2} = \frac{750}{5 + 101 \times 0.2} = --$$

$$\ast \quad R_{in} = \frac{V_{in}}{i_{b1}} \Rightarrow \text{from } 2$$

$$R_{in} = 2 r_\pi + (1+\beta) R_E = 2 \times 2.5 + 101 \times 0.2$$

$$= \quad k\Omega$$

$$\ast \quad R_{out} = R_C = 7.5\, k\Omega$$

As $V_{in} = 0$ $\;i_{b1} = 0$, $i_{b2} = 0$

$\therefore \beta i_{b2} = 0$ (open)

Problem (5)

The differential amplifier shown in figure (7) uses the current mirror current source M3 and M4 with $K = 0.5\,mA/V^2$ and $V_{A_3} = V_{A_4} = 120V$. If $V_{A_1} = V_{A_2} = \infty$, Calculate:

1) The differential mode gain A_{dm}.
2) The common mode gain A_{CM}.
3) The CMRR in decibel (dB).

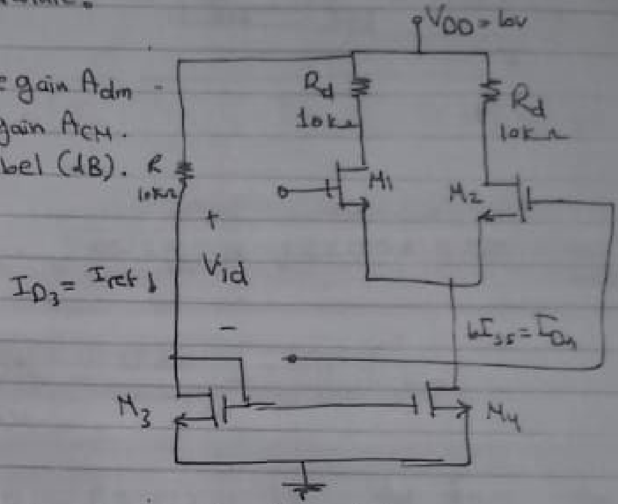


Figure (7)

Solution

① DC Analysis $\rightarrow$ Condition for Saturation $V_{DS} > V_{GS} - V_T$

For M_3 $\quad V_{GS_3} = V_{DS_3} \Rightarrow \therefore M_3$ is in saturation

K.V.L $\quad 10 = 10\, I_{D_3} + V_{DS_3} = 10\, I_{D_3} + V_{GS_3}$

$$\boxed{\therefore I_{D_3} = \frac{10 - V_{GS_3}}{10} = 1 - 0.1 V_{GS_3}} \quad \#①$$

Known $\quad I_{D_3} = \frac{K}{2}(V_{GS_3} - V_T)^2$

$$1 - 0.1 V_{GS_3} = \frac{0.5}{2}(V_{GS_3} - 1)^2$$

$$4 - 0.4 V_{GS_3} = V_{GS_3}^2 - 2V_{GS_3} + 1$$

$$V_{GS_3}^2 - 1.6 V_{GS_3} - 3 = 0 \Rightarrow V_{GS_3} = \begin{cases} 2.71 & \checkmark > V_T \\ -1.11 & \times \end{cases}$$

$\boxed{V_{GS_3} = 2.71\ V}$

$\boxed{\text{Sub in } ①}$ $\boxed{I_{D_3} = 1 - 0.1(2.71) = 0.729\ mA}$

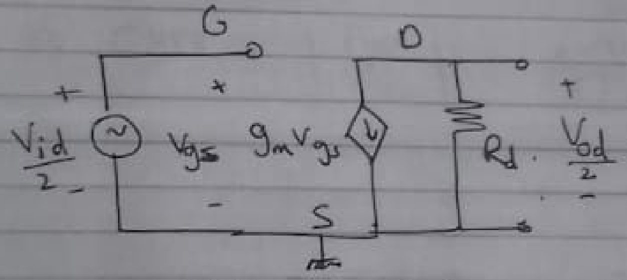
$\therefore V_{GS_4} = V_{GS_3} \Rightarrow \therefore \boxed{I_{D_4} = I_{D_3} = 0.729 mA}$

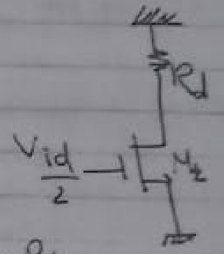
$V_{GS_1} = V_{GS_2} \Rightarrow \boxed{I_{D_1} = I_{D_2} = \frac{I_{ss}}{2} = \frac{0.729}{2} = 0.365 mA}$

$g_{m_1} = g_{m_2} = g_m = \sqrt{2KI_{D_1}} = \sqrt{2 \times 0.5 \times 0.365} = 0.6041$ mA/V

$R_{SS} = r_{ds_4} = \frac{V_{A_4}}{I_{D_4}} = \frac{120 v}{0.729 mA} = \boxed{164.61\ K\Omega}$

1) Differential mode gain (A_{dm}) . $V_{i_1} = \frac{V_{id}}{2}$ & $V_{i_2} = -\frac{V_{id}}{2}$





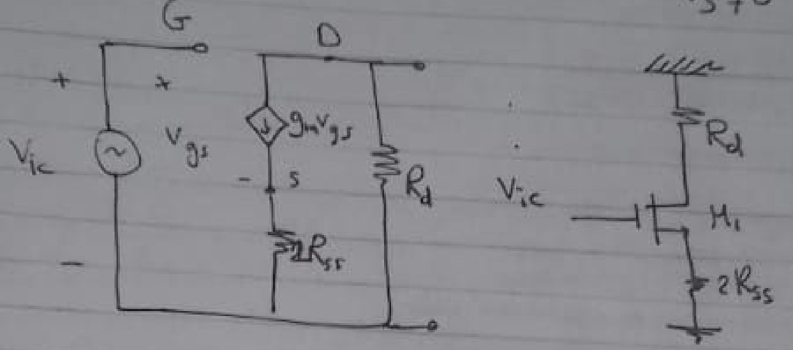
$A_{dm} = \frac{V_{od}/2}{V_{id}/2} = \frac{V_{od}}{V_{id}} = \frac{-g_m V_{gs} R_d}{V_{gs}} = -g_m R_d$

$\boxed{A_{dm} = -0.6041 * 10 = -6.041}$

Scanned with CamScanner

2) Common mode gain (A_{cm}) , $V_{i_1} = V_{ic}$, $V_{i_2} = V_{ic}$

$V_s \neq 0$



$$A_{CM} = \frac{V_{oc}}{V_{ic}} = \frac{-g_m V_{gs} R_d}{V_{gs} + 2R_{ss} g_m V_{gs}} = \frac{-g_m R_d}{1 + 2R_{ss} g_m}$$

$$\boxed{A_{CM} = \frac{-0.6041 * 10}{1 + 2(164.61)(0.6041)} = -0.0302}$$

3) $$CMRR = \left| \frac{A_{dM}}{A_{CM}} \right| = \frac{6.041}{0.0302} = 199.88$$

$$CMRR(dB) = 20 \log 199.88 = \boxed{46.02\ dB}$$

... * ——— * ...