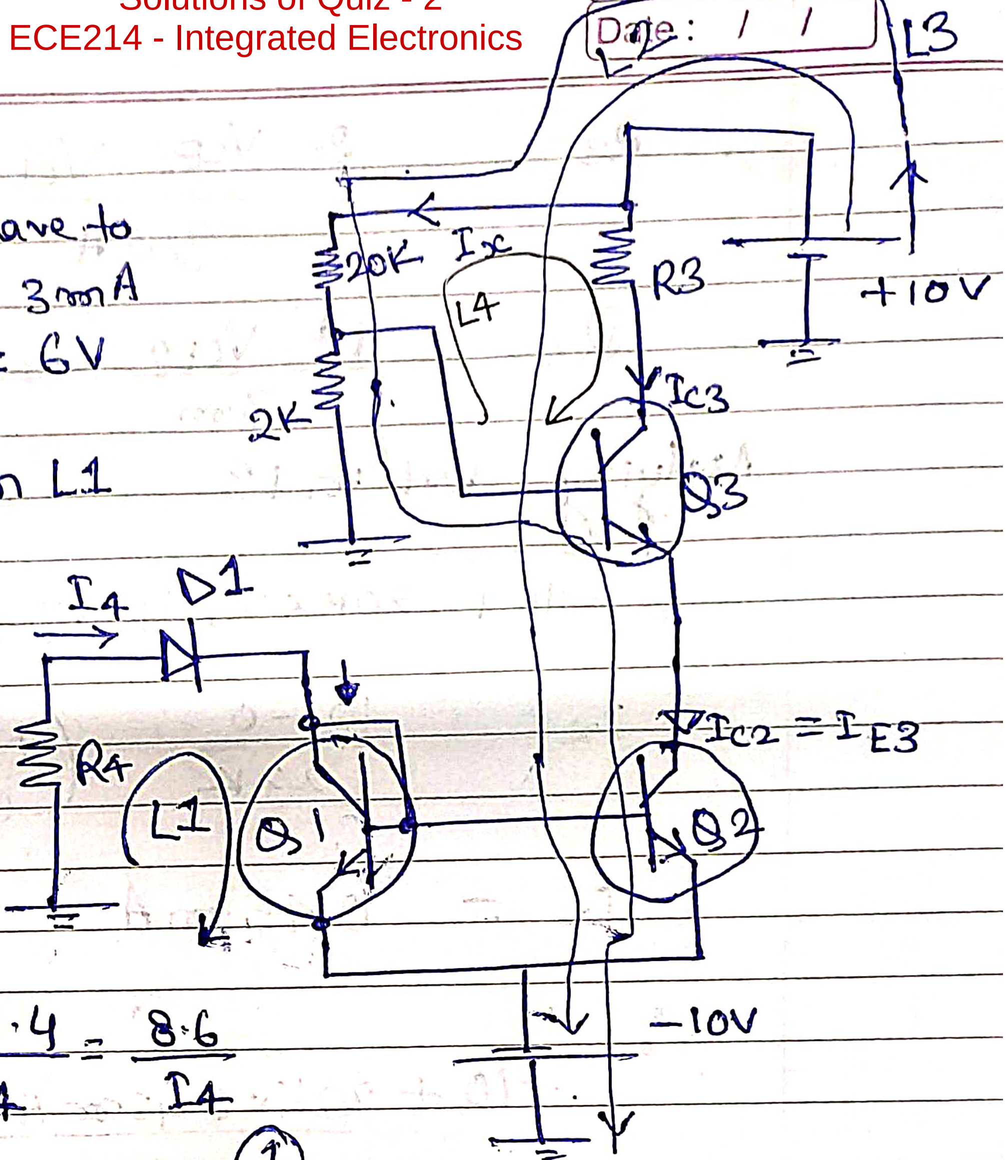
Q1) a)

For Q3 we have to set $I_{C3} = 3\,mA$
$V_{CE3} = 6V$



Applying KVL in L1

$-R_4 I_4 - 0.7 - V_{BE1} + 10 = 0$

$\therefore R_4 = \frac{10 - 0.7 - 0.7}{I_4}$

$\therefore R_4 = \frac{10 - 1.4}{I_4} = \frac{8.6}{I_4}$ — (1)

Since Q1 and Q2 are perfectly matched and they are forming a current mirror

$\therefore I_{C1} = I_{C2}$

Neglecting base current

$I_4 \approx I_{C1} = I_{C2} = I_{E3} \approx I_{C3} = 3\,mA$

$\therefore R_4 = \frac{8.6}{3m} \simeq 2.87\,K\Omega$

Now, Applying KVL in L2

$-10 + 3mA \times R_3 + V_{CE3} + V_{CE2} - 10 = 0$

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$\therefore R_3 = \dfrac{20 - V_{CE3} - V_{CE2}}{3mA} = \dfrac{20 - 6 - V_{CE2}}{3m}$

$\therefore R_3 = \dfrac{14 - V_{CE2}}{3m}$ —— (2)

Applying KVL in L3

$-10 + 20K \times I_x + 0.7 + V_{CE2} - 10 = 0$

$I_x = \dfrac{10 - 0}{22K}$ (Neglecting base currents)

$I_x = 0.45 mA$

$\therefore$

$-10 + 20K \times 0.45mA + 0.7 + V_{CE2} - 10 = 0$

$\therefore V_{CE2} = 20 - 9.09 - 0.7$

$\therefore V_{CE2} = 10.21 V$ —— (3)

$\therefore$ by (2) & (3)

$R_3 = \dfrac{14 - 10.21}{3m} = 1.26 k\Omega$

$\boxed{\begin{array}{l} \therefore R_4 = 2.87 k\Omega \\ \& \ R_3 = 1.26 k\Omega \end{array}}$ Ans

Q.1.(b) for Q_3 to remain in active region

$$V_{CE3} > 0.2V$$

From L2

$$-10 + I_{C3}R_3 + V_{CE3} + 10.21 - 10 = 0$$

$$\therefore I_{C3}R_3 + V_{CE3} = 20 - 10.21$$

From, L1

$$I_4 = \frac{10 - 1.4}{R_4}$$

$\because I_4 = I_{C3}$

$$\therefore \frac{8.6}{R_4} \cdot R_3 + V_{CE3} = \boxed{9.79} \quad \text{— (1)}$$

Hence, $V_{CE3} = 9.79 - 8.6 \frac{R_3}{R_4}$

$\therefore$ For Q_3 to remain in active region

$$9.79 - 8.6 \frac{R_3}{R_4} > 0.2$$

$$\frac{R_3}{R_4} < \frac{9.79 - 0.2}{8.6}$$

$$\therefore \boxed{\frac{R_3}{R_4} < 1.12}$$

Here, we see that at a particular R4

Q3 collector current will be biased according to the current mirror, which will be independent of R3.

However, as per R3, V_{CE3} will change.

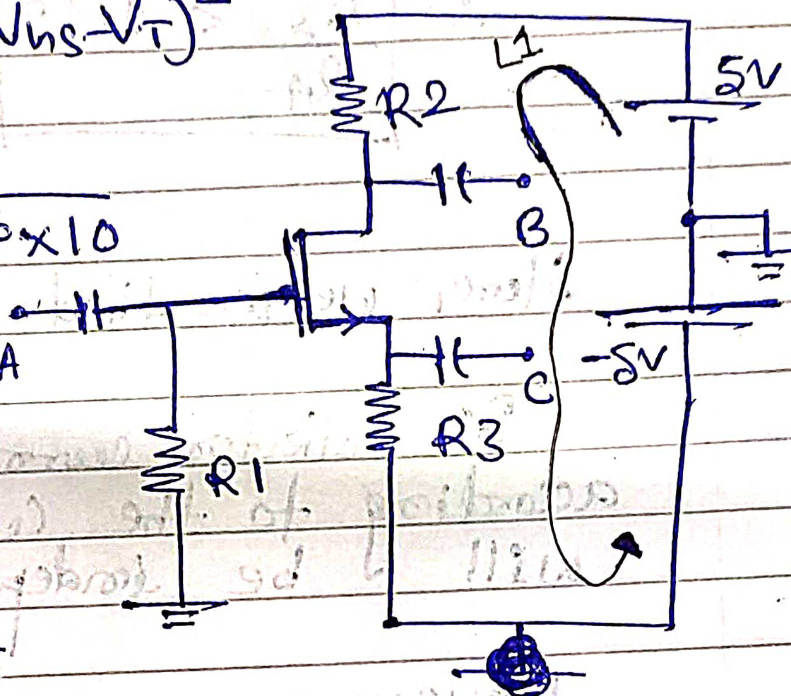
$\therefore$ Range of R4 will be

$$\boxed{R_4 > \frac{R_3}{1.12}}$$

Q. 2. (a.)

$I_D = 0.1 mA$

$0.1 = \frac{1}{2} \mu_n C_{ox} (W/L)(V_{GS} - V_T)^2$



$V_{GS} - V_T = \frac{0.1m}{\frac{1}{2} \times 80 \times 10^{-6} \times 10}$

$V_{GS} - V_T = \frac{10(4+4)}{4}$

$\therefore V_{GS} - V_T = 0.25$

$\therefore V_{GS} = 0.25 + V_T = 1.25V$

$V_G - V_S = 1.25$

$\therefore V_S = V_G - 1.25 = 0 - 1.25 = -1.25$

$\therefore$ ~~$\frac{V_S - 0}{R_3}$~~ $\therefore \frac{V_S + 5}{R_3} = 0.1mA$

$\therefore \frac{5 - 1.25}{R_3} = 0.1$

$R_3 = \frac{4.75}{0.1m} = 4.75 k\Omega.$

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Applying KVL in L1

$$-5 + 0.1R_2 + V_{DS} + 4.75 \times 0.1 - 5 = 0$$

$V_{DS} = 10 - 0.475 - 0.1R_2$

$V_{DS} = 9.525 - 0.1R_2$

For the mos to remain in active saturation

$V_{DS} > V_{GS} - V_T$

$V_{DS} \geq 0.25$

9.525.

$$-5 + I_D R_2 + V_{DS} + 4.75 I_D - 5 = 0$$

$$I_D(R_2 + 4.75) + V_{DS} = 10$$

$$0.1\,mR_2 + 4.75 \times 0.1\,m + V_{DS} = 10$$

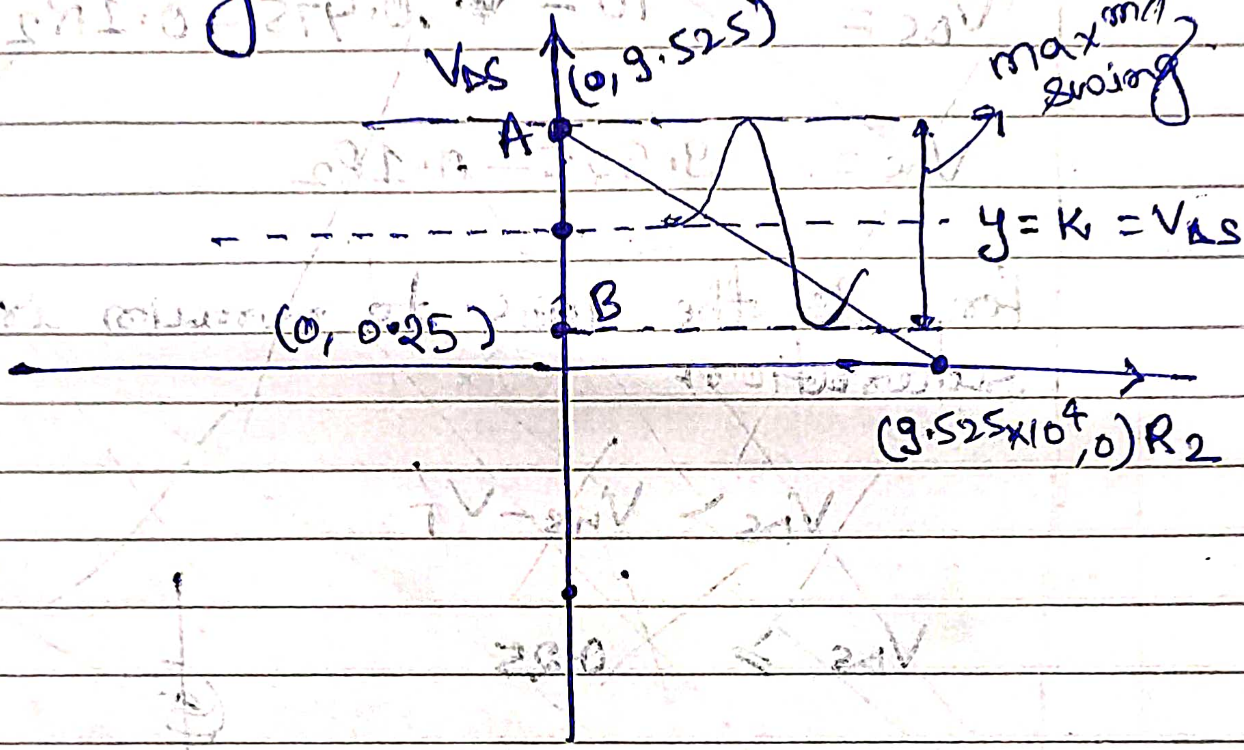
$$0.1\,mR_2 + V_{DS} = 10 - 0.475 = 9.525$$

$$0.1 \times 10^{-3} R_2 + V_{DS} = 9.525$$

or,

$$V_{DS} = -10^{-4}R_2 + 9.525$$

Plotting V_{DS} wrt R_2



$$y = mx + c$$

m → Slope, c → intercept

Since, for the MOS to remain in saturation mode

$$V_{DS} \geq V_{GS} - V_T \geq 0.25$$

∴ for a maximum possible swing at $I_D = 0.1\,mA$ the respective R_2 should come on the mid-point of A and B.

$\therefore K = \frac{9.525 + 0.25}{2} \approx 4.887$

$\therefore R_2 = \frac{9.525 - 4.887}{10^{-4}}$

$\therefore$ ~~$R_2 \approx 4.64 \times 10^4$~~

$\therefore$ ~~$R_2 = 46.35$~~

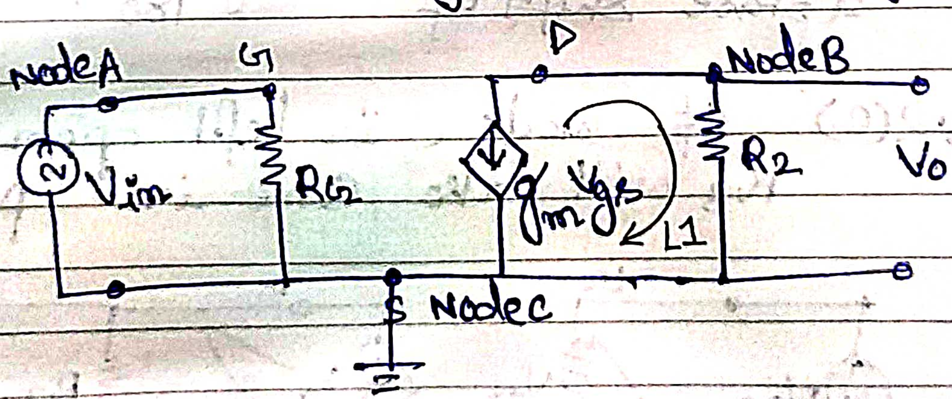
$\therefore \boxed{R_2 = 46.375 \text{ k}\Omega}$

Q. 2. b) Given that

$I_D = 0.1\text{mA}, \; R_2 = 46.375 \text{ k}\Omega$

If node C is grounded, C_3 will bypass R_3 for AC signals.

Hence drawing the small signal model.



~~V_{gs}~~ $V_{gs} = V_{in}$

In L1, $V_o = -g_m V_{gs} R_2$

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$$V_o = -g_m V_{in} R_2$$

$$\therefore \quad A_v = -g_m R_2$$

Now, $g_m = \dfrac{\partial I_D}{\partial V_{GS}}$

$$\therefore g_m = \frac{2 I_D}{V_{ov}} = \frac{2 \times 0.1m}{0.25}$$

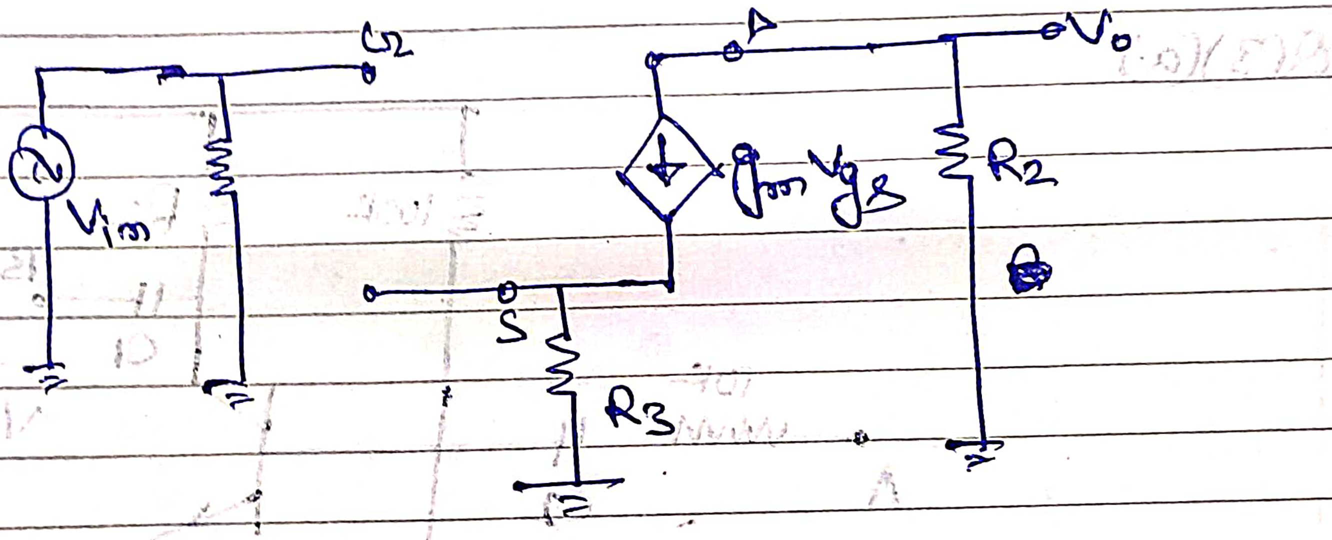
$$\therefore g_m = 0.8 \, mS$$

$$A_v = -0.8 \times 10^{-3} \times 46.375 \times 10^{3}$$

$$\boxed{A_v = -37.1}$$

where, minus sign indicate a phase shift of 180°.

Q.2(C.) If node C is left open then R_3 will also come in picture



$V_o = -g_m V_{gs} R_2$

$V_g = V_{in}$; $V_s = R_3 \cdot g_m V_{gs}$

$V_{gs} = V_g - V_s = V_{in} - R_3 g_m V_{gs}$

$\therefore\ V_{gs}(1+g_m R_3) = V_{in}$

$\therefore\ V_o = \dfrac{-g_m R_2 V_{in}}{1+g_m R_3}$

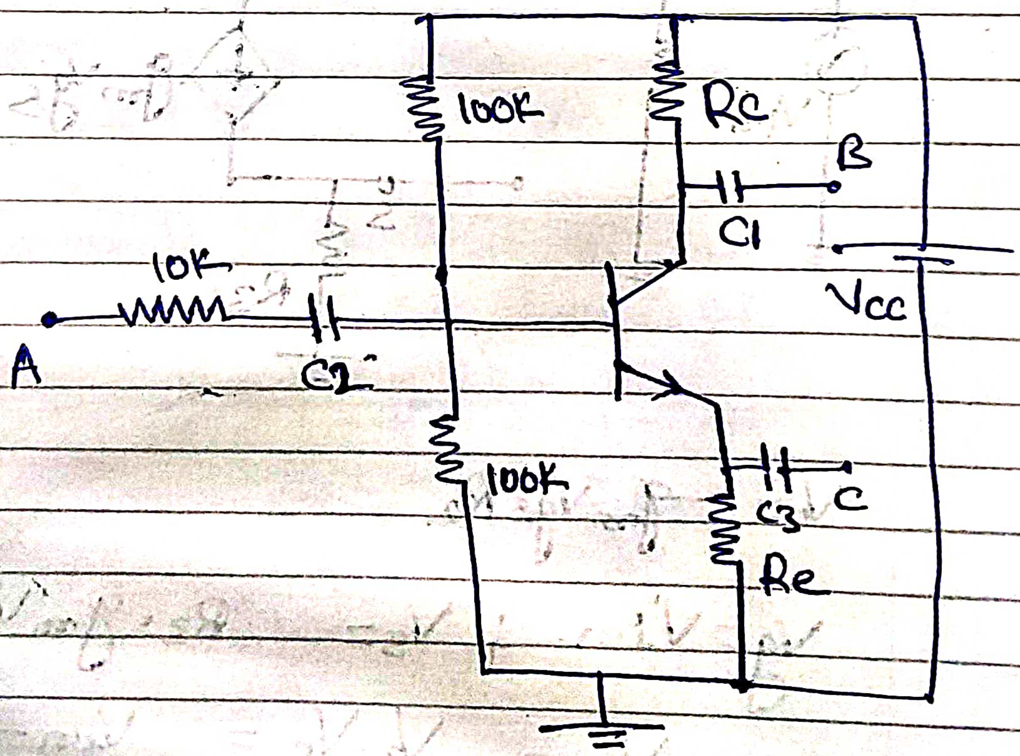
$\therefore\ A_V = \dfrac{-g_m R_2}{1+g_m R_3}$ —— (1)

$\therefore$ from (1) we see that

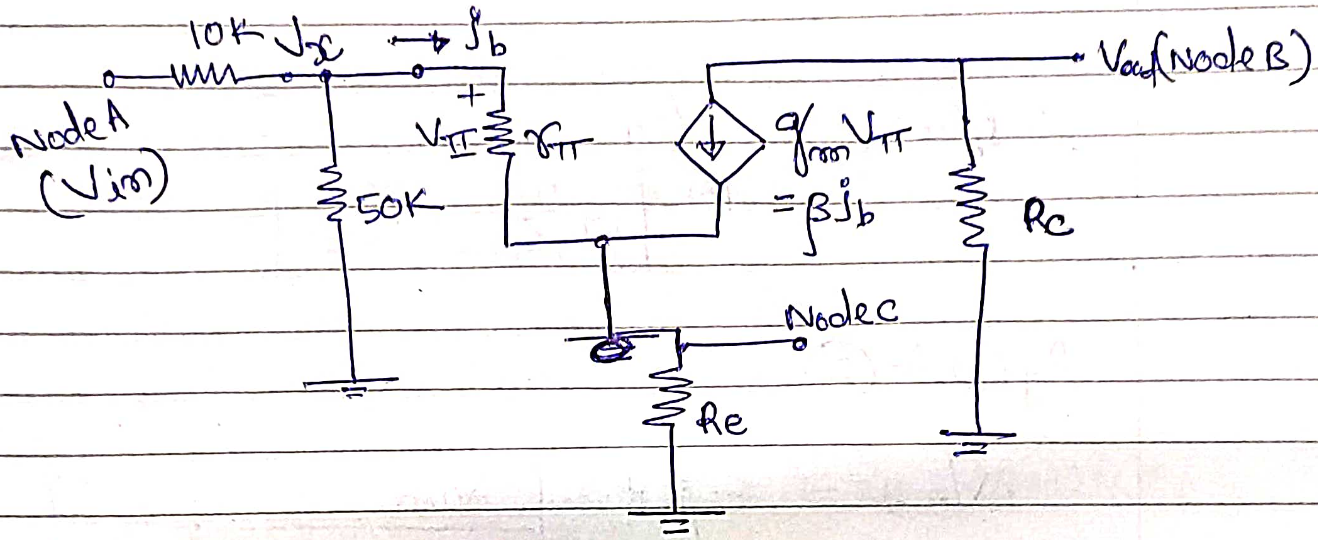
in Node C is left open R_3 will not be bypassed and hence,

overall gain will reduce by a factor of $(1+g_m R_3)$.

Q(3)(a.)



Drawing small signal model (neglecting r_o).



For part a : Node C is grounded.

∴ R_e will be bypassed by C_3 for AC signals.

Now, Voltage gain = $\frac{V_{out}}{V_{in}}$

$V_{out} = -\beta i_b R_c$ —— (I)

$\frac{V_{in} - V_x}{10K} = \frac{V_x}{50K} + i_b$

$\frac{V_x - 0}{r_\pi} = i_b \Rightarrow V_x = +r_\pi i_b$

∴ $\frac{V_{in} - r_\pi i_b}{10K} = \frac{r_\pi i_b}{50K} + i_b$

∴ $\frac{V_{in}}{10K} = \left[1 + \frac{r_\pi}{50K} + \frac{r_\pi}{10K}\right] i_b$

10k

$$\therefore i_b = \frac{V_{in}}{10K\left[1+\frac{r_\pi}{50K}+\frac{r_\pi}{10K}\right]} \quad \text{— (2)}$$

By (1) & (2)

$$V_{out} = -\beta R_C \cdot \left[\frac{V_{in}}{10K\left(1+\frac{r_\pi}{50K}+\frac{r_\pi}{10K}\right)}\right]$$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{-\beta R_C}{P} = A_{VS}$$

where, $P = 10K\left(1+\frac{r_\pi}{50K}+\frac{r_\pi}{10K}\right)$

Now, $r_\pi = \frac{V_T}{I_B} = \beta\left(\frac{V_T}{I_C}\right)$

and as per question, r_π will be constant for a given bias point.

$$\therefore \boxed{\frac{[A_{VS}]_{max}}{[A_{VS}]_{min}} = \frac{150}{50} = 3.}$$

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(b) Here, node C is open, hence Re will be taken into Consideration while gain calculation

$\because V_{out} = -\beta i_b R_C$

Applying KCL at node x

$$\frac{V_{in}-V_x}{10K} = \frac{V_x}{50K} + i_b \quad \text{--- (1)}$$

$$\because V_x = [r_\pi + (\beta+1)R_e]\, i_b \quad \text{--- (2)}$$

by (1) & (2)

$$A_{vs} = \frac{V_{out}}{V_{in}} = \frac{-\beta R_C}{1 + \frac{r_\pi + (\beta+1)R_e}{50K} + \frac{r_\pi + (\beta+1)R_e}{10K}}$$

or, $$A_{vs} = \frac{-\beta R_C}{1 + \left(\frac{r_\pi + (\beta+1)R_e}{50K}\right)6}$$

$$= \frac{-R_C}{\frac{1}{\beta} + \left[\frac{1}{g_m} + R_e\right]\frac{6}{50K}} \quad \{\beta+1 \approx \beta\}$$

$\because$ At the given bias point

$$g_m = \frac{I_C}{V_T} = 19.3[illegible]\ A/V$$

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Also, for β_{max}, A_{vs} will be max.

$$\therefore \frac{[A_{vs}]_{max}}{[A_{vs}]_{min}} = \frac{\dfrac{-R_C}{\dfrac{1}{150} + [19.3 + R_e]\dfrac{6}{50K}}}{\dfrac{-R_C}{\dfrac{1}{50} + [19.3 + R_e]\cdot\dfrac{6}{50K}}}$$

$$\therefore \frac{(A_{vs})_{max}}{(A_{vs})_{min}} = \frac{\dfrac{1}{50} + (19.3 + R_e)\cdot\dfrac{6}{50K}}{\dfrac{1}{150} + (19.3 + R_e)\cdot\dfrac{6}{50K}} = 1.5$$

$$\therefore \boxed{R_e = 166.68\Omega}$$