Solution for Q.2 (a)

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Step 1 - under DC operating conditions

$$V_{TH} = \frac{V_{cc} \cdot R_2}{R_1 + R_2} = \frac{14 \times 30K}{120K + 30K} = 2.8\ V \longrightarrow ①$$

$$R_{TH} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{120K \cdot 30K}{120K + 30K} = 24\ K\Omega \longrightarrow ②$$

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E} = \frac{2.8 - 0.7}{24K + (101) \times 2.2K} = 8.53\ \mu A \longrightarrow ③$$

$$I_E = (1+\beta) I_B = (1 + 100) \times 8.53\mu = 0.861\ mA$$

$$r_e = \frac{26 mV}{I_E} = \frac{26 \times 10^{-3}}{0.861 \times 10^{-3}} = 30.198\ \Omega \longrightarrow ⑤$$

Step 2 - under AC operating conditions

Performing AC analysis on the common collector (cc) BJT amplifier we obtain following small signal parameters :-

$\therefore R_i$ or $Z_i = R_1 // R_2 // (1+\beta)(R_E + r_e)$

$\boxed{\text{Hence } R_i \text{ or } Z_i = 21.68\ K\Omega} \longrightarrow ①$

$\therefore R_o$ or $Z_o = R_E // r_e$

$\boxed{\text{Hence } R_o \text{ or } Z_o = 29.78\ \Omega} \longrightarrow ②$

$$\therefore A_V = \frac{R_E // R_L}{R_E // R_L + r_e}$$

$\boxed{\text{Hence } A_V = 0.9829}$

Step 3 - Lower cut-off frequency (f_L)

With only two capacitors Cin & Cout there are only two corner frequencies f_{L_1} & f_{L_2} present as shown :-

$$\therefore f_{L_1} = \frac{1}{2\pi [R_{sig} + R_i] C_{in}} = \frac{1}{2\pi [1K + 21.68K] \times 0.1 \times 10^{-6}}$$

$\boxed{\text{Hence } f_{L_1} = 70.174 \text{ Hz}}$ ⟶ ①

$$\therefore f_{L_2} = \frac{1}{2\pi [R_o + R_L] C_{out}} = \frac{1}{2\pi [29.78 + 8.2K] \times 0.1 \times 10^{-6}}$$

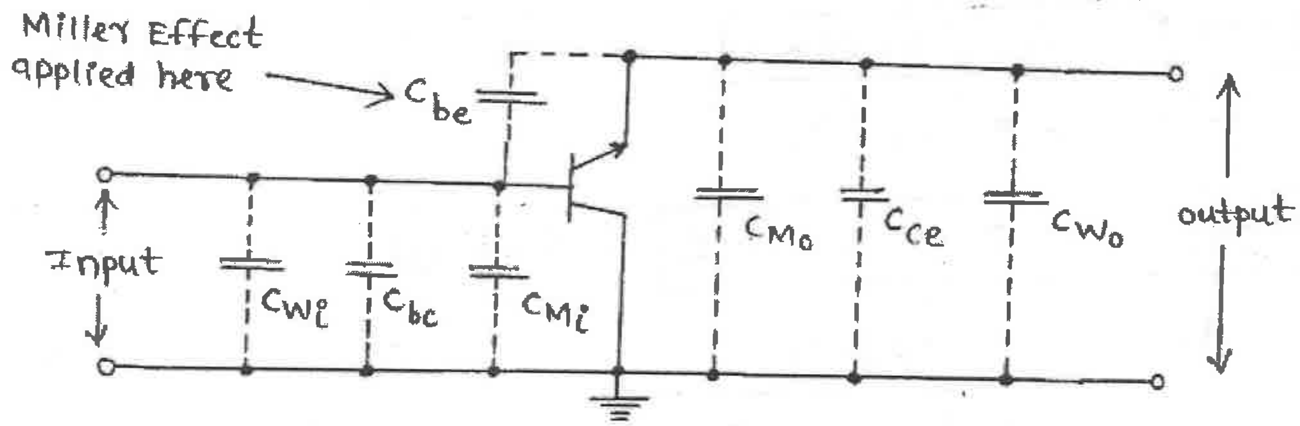
$\boxed{\text{Hence } f_{L_2} = 193.38 \text{ Hz}}$ ⟶ ②

Thus $f_L = \max[f_{L_1}, f_{L_2}]$ as it is the last corner frequency encountered when the amplifier frequency response moves from lower frequency range to mid-band range.

$\boxed{\text{Hence } f_L = 193.38 \text{ Hz}}$

Step 4 - Calculate input & output capacitance (C_i & C_o)

For common collector (CC) BJT configuration the stray/parasitic & wiring capacitances with Miller Effect are as :-



$$C_{Mi} = C_{be}[1 + |A_v|] = [1 + 0.9829] \times 30 \times 10^{-12}$$

$\boxed{\text{Hence } C_{Mi} = 59.487 \text{ pF}}$ ⟶ ①

$$C_{M_o} = C_{be}\left[\frac{1+|A_v|}{|A_v|}\right] = \left[1+\frac{1}{0.9829}\right]\times 30\times10^{-12}$$

$$\boxed{\text{Hence } C_{M_o} = 60.52\ pF} \longrightarrow ②$$

$$\therefore\ C_i = C_{wi} + C_{bc} + C_{Mi} = 8pF + 20pF + 59.487\ pF$$

$$\boxed{\text{Hence } C_i = 87.487\,pF} \longrightarrow ③$$

$$\therefore\ C_o = C_{W_o} + C_{ce} + C_{M_o} = 10pF + 12pF + 60.52\,pF$$

$$\boxed{\text{Hence } C_o = 82.52\,pF} \longrightarrow ④$$

Step 5 – Higher cut-off frequency (f_H)

With two capacitances C_i & C_o at input & output side there are two corner frequencies f_{H_1} & f_{H_2} present as shown :-

$$\therefore\ f_{H_1} = \frac{1}{2\pi[R_{sig}/\!/R_i]C_i} = \frac{1}{2\pi[1K/\!/21.68K]\times 87.487\times10^{-12}}$$

$$\boxed{\text{Hence } f_{H_1} = 1.903\,MHz} \longrightarrow ①$$

$$\therefore\ f_{H_2} = \frac{1}{2\pi[R_o/\!/R_L]C_o} = \frac{1}{2\pi\,[29.78/\!/8.2K]\times 82.52\times10^{-12}}$$

$$\boxed{\text{Hence } f_{H_o} = 65.004\,MHz} \longrightarrow ②$$

Always select $f_H = \min[f_{H_1}, f_{H_2}]$ since it is the first high corner frequency encountered by amplifier frequency response before it moves from mid-band range to high frequency.

$$\boxed{\text{Hence } f_H = 1.903\,MHz}$$

Solution for Q.4 (a)

Applying KVL in gate to source loop,

$$-V_{GSQ} - 2I_{DQ}R_S + V_{SS} = 0 \quad \text{——— (1)}$$

$$V_{GSQ} = V_{SS} - 2I_{DQ}R_S \quad \text{——— (2)}$$

$$V_{GSQ} = 12 - 20I_{DQ} \quad \text{——— (3)}$$

For E-MOSFET (N channel), drain current equa (I_{DQ}) is given by ~~I_{DQ}~~

$$I_{DQ} = k_n\left[V_{GSQ} - V_{GS(TH)}\right]^2 \quad \text{——— (4)}$$

where,

$$k_n = \frac{I_{D(ON)}}{\cancel{V_G}\left[V_{GS(ON)} - V_{GS(TH)}\right]^2}$$

$$\boxed{k_n = 2.67\,mA/V^2}$$

$\therefore$ ~~$I_{DQ} = 2.67\left[V_{GSQ}\right.$~~

$$\text{Hence, } I_{DQ} = 2.67\left[12 - 20I_{DQ} - 1.5\right]^2$$

$$I_{DQ} = 2.67\left[10.5 - 20I_{DQ}\right]^2 \quad \text{——— (5}$$

$$\therefore I_{DQ} = 2.67\left[400I_{DQ}^2 - 420I_{DQ} + 110.25\right] \quad \text{———}$$

Date ____
Page ____

$\therefore I_{DQ} = 294.36 - 1121.4 I_{DQ} + 1068 I_{DQ}^2$ ——— (7)

$\therefore 1068 I_{DQ}^2 - \cancel{113.4 I} \; 1122.4 I_{DQ} + 294.36$ ——— (8)

$I_{DQ1} = 0.54 \text{ A}$, $I_{DQ2} = 0.50 \text{ A}.$

$V_{GSQ1} = 12 - 20 (0.54 \cancel{\times 10^{3}}) = \cancel{11.98} \; 1.2 V$

$V_{GSQ2} = 2V.$

Since for E-MOSFET (N-channel) V_{GSQ} is greater than threshold voltage of $V_{GS(TH)}$ which means only correct value is +2V. & $I_{DQ} = 0.5 \text{ mA}$.

Applying KVL in drain to source loop,

$V_{DD} - I_{DQ}R_D - V_{DSQ} - 2I_{DQ}R_S + V_{SS} = 0$ ——— (9)

$\therefore V_{DSQ} = (V_{DD} + V_{SS}) - 2I_{DQ}R_S - I_{DQ}R_D$ ——— (10)

$\therefore \boxed{V_{DSQ} = 24 - I_{DQ}[R_D + 2R_S]}$ ——— (11)

$\therefore V_{DSQ} = 12.35 V$

$\boxed{\text{Hence } Q = [12.35 V, 0.5 \text{ mA}]}$

$g_m = 2\sqrt{k_n I_{DQ}}$

$g_m = 2\sqrt{2.67 \times 0.5} = 2.31 \text{ m℧}$

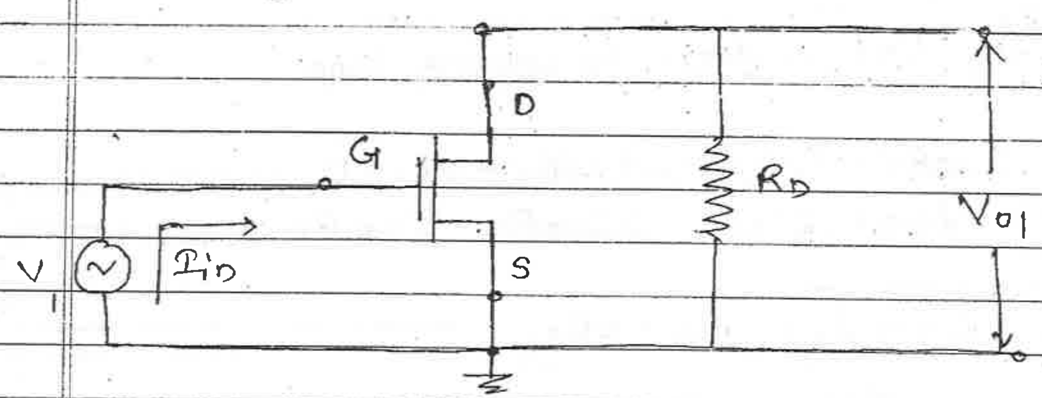
$\boxed{g_m = 2.31 \text{ m℧}}$

STEP II :- AC operating conditions (AC analysis

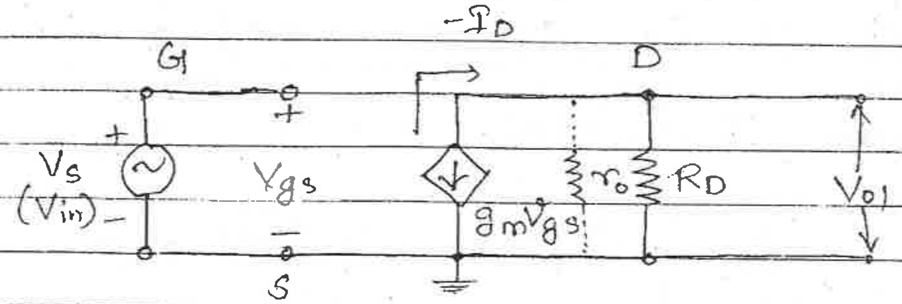
→ Remove all DC signal sources ($V_{DD} = -V_{SS} = 0$)
→ Short circuit all capacitors if present.

(a) Under differential mode of operation.

For differential mode of operation consider $V_1 = -V_2 = V_{in}$ where both i/p signals have same amplitude and frequency but are 180° out of pha with each other due to which emitter resistance is electrically shorted down to ground giving us following equivalent circuit for first stage.



Replace MOSFET by it's equivalent mathematical model.



Applying Ohm's law at o/p side,

$\therefore$ $V_{01} = -I_D R_D$ where $I_D = g_m V_{gs}$. ———— (1)

$\therefore$ $V_{01} = -g_m V_{gs} R_D$ ———— (2)

By observation $V_1 = V_{gs}$.

$\therefore$ $\frac{V_{01}}{V_i} = -g_m R_D$ ———— (3)

Note:- If MOSFET output impedance ~~(small R_o)~~ (r_o) is also present then the AC equivalent circuit contains this value of R_o parallal with externall connected drain resistance R_D giving V_{01}

$\frac{V_{01}}{V_1} = -g_m [R_D || r_o]$

$\therefore$ $V_{01} = -g_m R_D V_1$ ———— (4)

Similarly due to symmetrical configuration;

$V_{02} = -g_m R_D V_2$ ———— (5)

Subtracting $V_{01} - V_{02}$,

$V_{01} - V_{02} = -g_m R_D V_1 + g_m R_D V_2$

$\therefore$ $V_{01} - V_{02} = -g_m R_D [V_1 - V_2]$ ———— (6)

Date
Page

$$\frac{V_{o1} - V_{o2}}{V_1 - V_2} = -g_m R_D$$

By defination differential mode o/p voltage

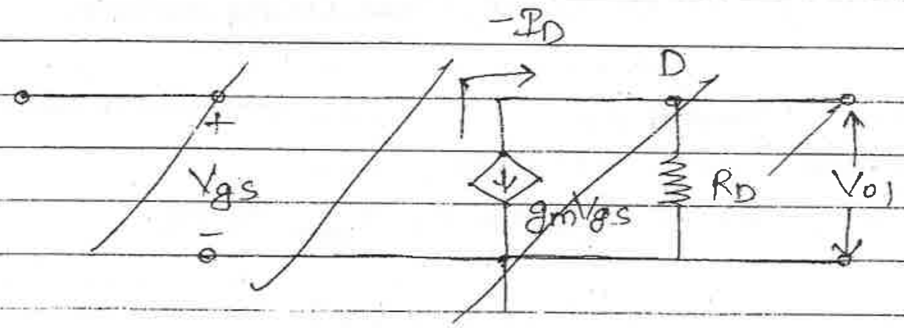
$V_{od} = V_{o1} - V_{o2}$ and differential mode i/p sig
$V_{id} = V_1 - V_2$ giving differential mode gain

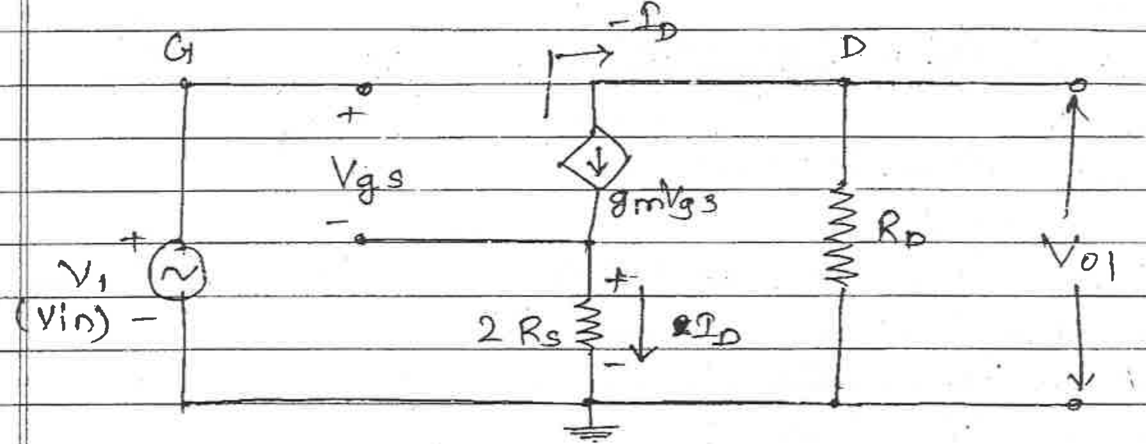
$$A_d = \frac{V_{od}}{V_{id}} = |g_m R_D| = \underline{7.683}$$

(b) For common mode of operation

Replace MOSFET by it's equivalent mathematical model.

For common mode of operation select $V_1 = V_2 = V$ where both i/p s/g are exactly inphase & of t same amplitude & frequency thereby makin appear as $2R_E$ for each individual stage giving following AC equivalent circuit for BJT Q_1.





By Ohm's law, at o/p side,

$V_{o1} = -I_D R_D$ where $I_D = g_m V_{gs}$ ——— (1)

$\therefore V_{o1} = -g_m V_{gs} R_D$ ——— (2)

Applying KVL @ the input gate to source loop,

$V_1 - V_{gs} - 2 I_D R_s = 0$ ——— (3)

where $I_D = g_m V_{gs}$

$\therefore V_1 = V_{gs} + g_m V_{gs} 2 R_s$ ——— (4)

$\therefore V_1 = V_{gs}\left[1 + 2 g_m R_s\right]$ ——— (5)

Usually R_s is extremely large hence $2g_m R_s >> 1$ giving $1 + 2g_m R_s$ approximatly equal to $2 g_m R_s$.

$\therefore V_1 = V_{gs}\left[2 g_m R_s\right]$

$\therefore \dfrac{V_{o1}}{V_1} = \dfrac{-g_m R_D}{2 g_m R_s} = \dfrac{-R_D}{2 R_s}$

By defination common mode o/p signal ~~Voc~~

Date

Page

$V_{oc} = \frac{V_{o1} + V_{o2}}{2}$ & common i/p signal

$V_{ic} = \frac{V_1 + V_2}{2}$ where since $V_1 = V_2$ & for

$V_{o1} = V_2$, common mode gain is defined as

$$A_c = \frac{V_{oc}}{V_{ic}}$$

$$\therefore A_c = \left| \frac{R_D}{2R_S} \right| = 0.165$$

$$CMRR = \frac{A_D}{A_c} = \frac{g_m R_D}{\left| \frac{R_D}{2R_S} \right|} = g_m R_D \times \frac{2R_S}{R_D}$$

$$= \cancel{g_m} = 2 g_m R_S$$

$$\boxed{CMRR = |2 g_m R_S|}$$

$$\boxed{CMRR = \frac{7.623}{0.165} = 46.2}$$

Solution for Q.4 (b)

Q.1 (a) – Voltage Series Feedback

Calculation of R_{if} :-

Applying KVL in the input loop :-

$\therefore \; V_s - V_i - V_f = 0 \longrightarrow (1)$

$\therefore \; V_s = V_i + V_f \longrightarrow (2)$

$\therefore \; V_s = V_i + \beta_v V_o \longrightarrow (3)$

$\therefore \; V_s = V_i + \beta_v A_v V_i \longrightarrow (4)$

$\therefore \; V_s = V_i [1 + \beta_v A_v] \longrightarrow (5)$

$\therefore \; V_s = I_i R_i [1 + \beta_v A_v] \longrightarrow (6)$

$\therefore \; \frac{V_s}{I_i} = R_i [1 + \beta_v A_v] \longrightarrow (7)$

$\boxed{\text{Hence } R_{if} = R_i [1 + \beta_v A_v]} \longrightarrow (8)$

Calculation of R_{of} :-

Applying KVL in the output loop :-

$\therefore \; V_K - I_K R_o - A_v V_i = 0 \longrightarrow (1)$

$\therefore \; V_K = I_K R_o + A_v V_i \longrightarrow (2)$

$\therefore \; V_K = I_K R_o - A_v V_f \longrightarrow (3)$

$\therefore \; V_K = I_K R_o - \beta_v A_v V_K \longrightarrow (4)$

$\therefore \; V_K + \beta_v A_v V_K = I_K R_o \longrightarrow (5)$

$\therefore \; V_K [1 + \beta_v A_v] = I_K R_o \longrightarrow (6)$

$\therefore \; \frac{V_K}{I_K} = \frac{R_o}{1 + \beta_v A_v} \longrightarrow (7)$

$$\boxed{\text{Hence } R_{of} = \frac{R_o}{1 + \beta_v A_v}} \longrightarrow (9)$$

Solution for Q.5 (b)

Q.1 (b) - 3 stage R-C Phase Shift oscillator

(i) $R_{TH} = R_1 /\!/ R_2 = 68K /\!/ 12K = 10.2\,K\Omega$

$V_{TH} = \frac{V_{CC} \cdot R_2}{R_1 + R_2} = \frac{12 \times 12K}{12K + 68K} = 1.8\,V$

$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta) R_E} = \frac{1.8 - 0.7}{10.2K + (1+350) \times 1.2K} = 2.55\,\mu A$

$I_C = \beta \cdot I_B = 2.55\mu \times 350 = 0.893\,mA$

$V_{CE} = V_{CC} - I_C [R_C + R_E] = 6.7313\,V$

$\boxed{\text{Hence } Q = [V_{CE}, I_C] = [6.7313\,V, 0.893\,mA]}$

(ii) $|A_V| = \frac{R_C}{r_e}$ where $r_e = \frac{26mV}{I_E} = 29.03\,\Omega$

$\boxed{\text{Hence } |A_V| = 161.88}$

(iii) $f_o = \frac{1}{2\pi RC\sqrt{6+4K}}$ where $K = \frac{R_C}{R}$

$\boxed{\text{Hence } f_o = 4.821\,KHz}$

(iv) Minimum starting voltage gain required for the sustained oscillations is given by $|A_V| \geq 29$ while the feedback network coefficient is $|\beta| \leq 1/29$

(v) Ideally each individual / idependent R-C network stage provides phase difference of 60° each hence for each individual R-C network we have :-

$$\left.\begin{aligned} \theta_1 &= 60^\circ \\ \theta_2 &= 120^\circ \\ \theta_3 &= 180^\circ \end{aligned}\right\} \quad \theta = \tan^{-1}\left[\frac{X_C}{R}\right] \quad \text{where } X_C = \frac{1}{2\pi f C}$$