C1 Slot

Monday DA1 key

STUDENT'S NAME	
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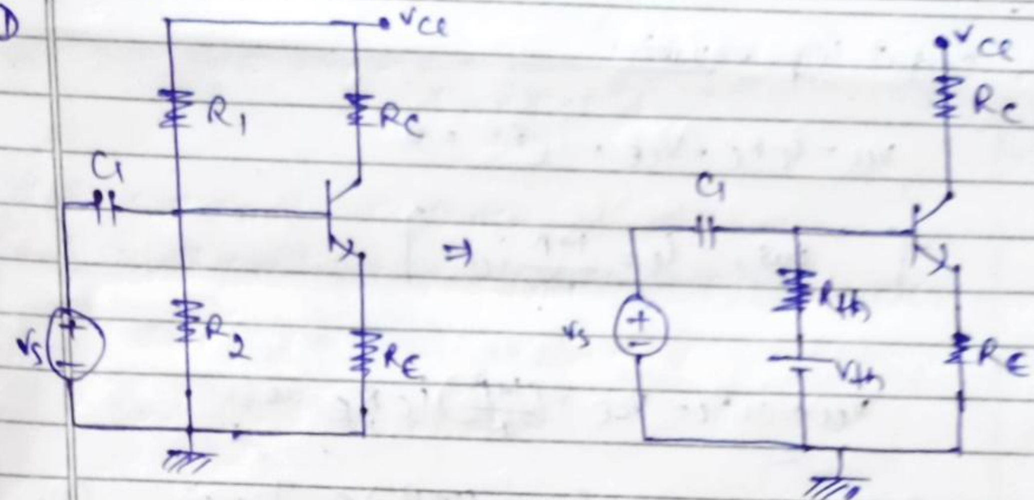
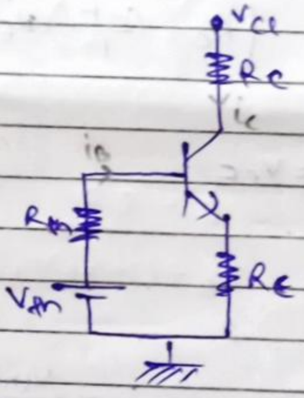
(1)



(a) DC analysis ⇒ short circuit AC sources & capacitors are open circuited.



$$\left[\because V_{th} = \frac{R_2 V_{CC}}{R_1 + R_2} \qquad R_{th} = \frac{R_1 R_2}{R_1 + R_2} \right]$$

input loop equation,

$$V_{th} - i_B R_{th} - V_{BE} - i_E R_E = 0 \qquad (\because i_E = (1+\beta) i_B)$$

$$V_{th} - i_B R_{th} - V_{BE} - (1+\beta) i_B R_E = 0$$

$$i_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) R_E}$$

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Output loop equation,

$$V_{CC} - i_C R_C - V_{CE} - i_E R_E = 0$$

$$\left[\text{But, } i_E = \frac{1+\beta}{\beta} i_C \right]$$

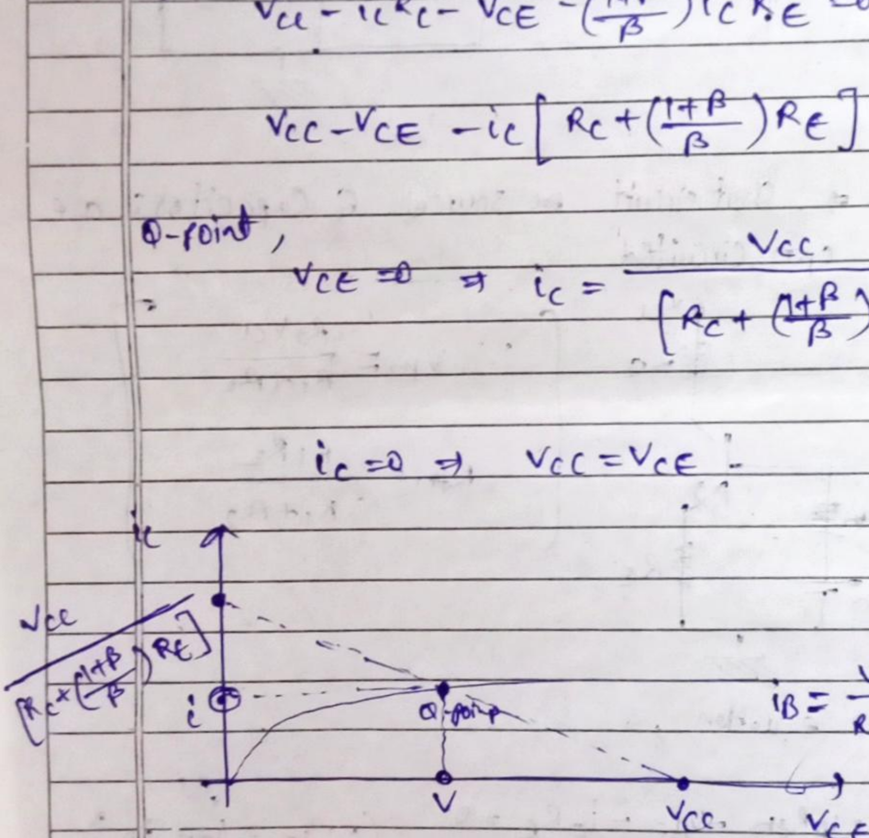
$$V_{CC} - i_C R_C - V_{CE} - \left(\frac{1+\beta}{\beta}\right) i_C R_E = 0$$

$$V_{CC} - V_{CE} - i_C \left[R_C + \left(\frac{1+\beta}{\beta}\right) R_E \right] = 0 \quad \text{— (1)}$$

Q-point,

$$V_{CE} = 0 \Rightarrow i_C = \frac{V_{CC}}{\left[R_C + \left(\frac{1+\beta}{\beta}\right) R_E \right]}$$

$$i_C = 0 \Rightarrow V_{CC} = V_{CE}$$



$$i_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) R_E}$$

$$i = \beta i_B \Rightarrow i = \frac{\beta (V_{th} - V_{BE})}{(R_{th} + (1+\beta) R_E)}$$

Substitute 'i' in eq (1),

$$V_{CC} - V = i \left(R_C + \left(\frac{1+\beta}{\beta}\right) R_E \right)$$

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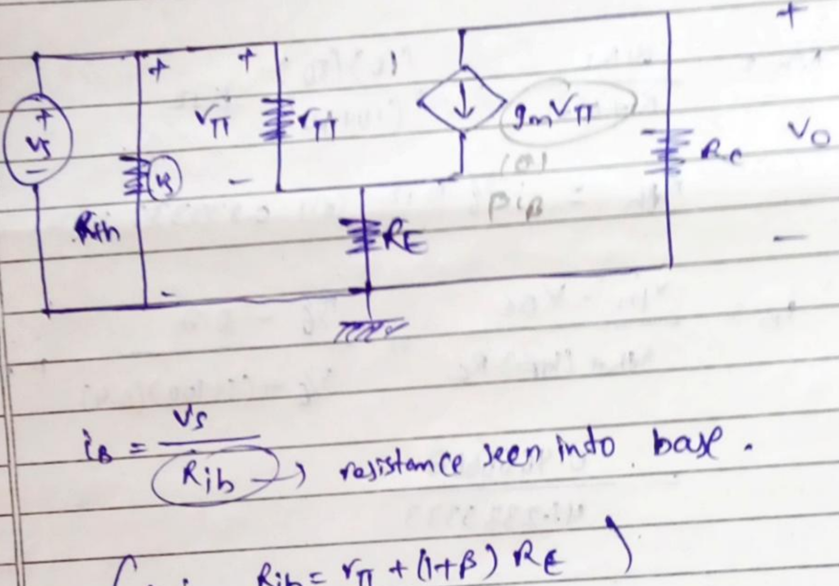
$$V = V_{CC} - \frac{\beta(V_{th} - V_{BE})}{(R_{th} + (1+\beta)R_E)} \cdot \left(R_C + \left(\frac{1+\beta}{\beta}\right) R_E\right)$$

(b) Short circuit DC sources
Short circuit coupling capacitor } AC analysis
Open circuit load capacitor

Small signal eq. model ⇒



$$i_B = \frac{v_s}{R_{ib}}$$ → resistance seen into base.

$$\left(\because \; R_{ib} = r_\pi + (1+\beta) R_E \right)$$

$$i_B = \frac{v_s}{(r_\pi + (1+\beta) R_E)}$$

$$v_0 = -\beta i_B R_C \Rightarrow -\beta \left[\frac{v_s}{r_\pi + (1+\beta) R_E}\right] R_C$$

$$\frac{v_0}{v_s} = \frac{-\beta R_C}{(r_\pi + (1+\beta) R_E)} = A_V$$

(c). from ((a) & (b))

$$i_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) R_E}$$

$$V_{th} = \frac{R_2 V_{CC}}{R_1 + R_2} \Rightarrow \frac{10(10)}{(10+50)} = \frac{10(10)}{60}$$

$$V_{th} = 10/6 \text{ V (or) } 1.666667 \text{ V}$$

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(10)(50)}{(10+50)} \text{ k}\Omega$$

$$R_{th} = 5/6 \text{ k}\Omega \text{ (or) } 0.833333 \text{ k}\Omega$$

$$i_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) R_E} \Rightarrow \frac{10/6 - 0.7}{5/6 + (1+100)(0.4)} \text{ mA}$$

$$= \frac{0.9666667}{41.2333333}$$

$$i_B = 0.0234438165 \text{ mA}$$

$$i_C = \beta i_C \Rightarrow i_C = 2.34438165 \text{ mA}$$

$$r_\pi = \frac{V_T}{i_B} \Rightarrow \frac{0.026}{0.0234438165} \text{ k}\Omega$$

$$r_\pi = 1.10903444 \text{ k}\Omega$$

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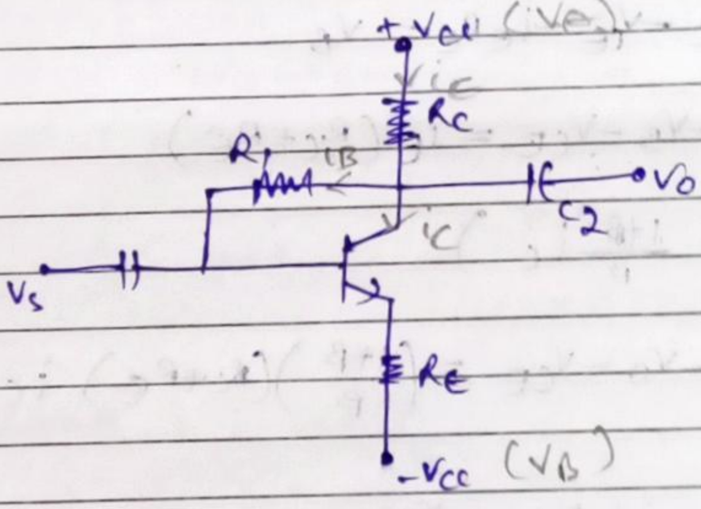
$$A_V = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E} \quad (\because \text{from (b)})$$

$$= \frac{-(100)(2)}{1.1090344 + (101)0.4}$$

$$= \frac{-200}{41.5090344}$$

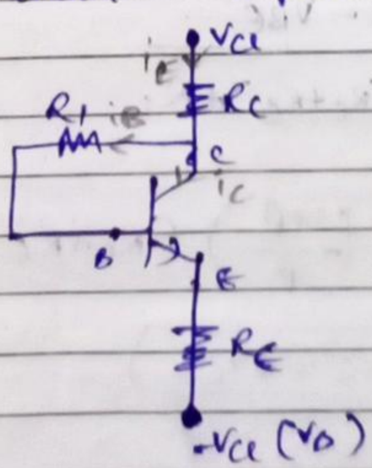
$$A_V = -4.8182282$$

(2)



(a) DC analysis

(Short circuit - AC voltages
open circuit - Capacitors)



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loop equation)

$$\Rightarrow V_A - i_E R_C - i_B R_1 - V_{BE} - i_E R_E = V_B$$

$$V_A - V_B - V_{BE} = i_E(R_C + R_E) + i_B R_1$$

$$V_A - V_B - V_{BE} = (1+\beta) i_B (R_C + R_E) + i_B R_1$$

$$i_B = \frac{V_A - V_B - V_{BE}}{(1+\beta)(R_C + R_E) + R_1} \quad -(1)$$

$$\Rightarrow V_A - i_E R_C - V_{CE} - i_E R_E = V_B$$

$$V_A - V_B - V_{CE} = i_E(R_C + R_E)$$

$$\left(\because i_E = \frac{1+\beta}{\beta} i_C\right)$$

$$V_A - V_B - V_{CE} = \left(\frac{1+\beta}{\beta}\right)(R_C + R_E)\, i_C \quad -(2)$$

$\Rightarrow V_A = V_{CC}$, $V_B = -V_{CC}$

substitute in eq (1), (2).

$$i_B = \frac{2V_{CC} - V_{BE}}{(1+\beta)(R_C + R_E) + R_1}$$

$$2V_{CC} - V_{CE} = \left(\frac{1+\beta}{\beta}\right) \cdot (R_C + R_E)\, i_C \quad -(3)$$

$i_C = 0 \Rightarrow \boxed{V_{CE} = 2V_{CC}}$

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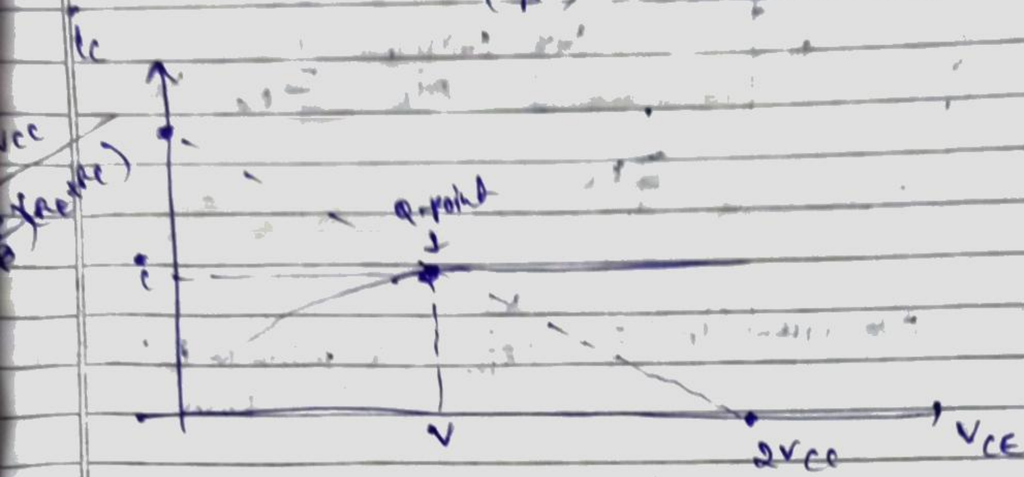
$$V_{CE} = 0 \Rightarrow i_C = \frac{2V_{CC}}{\left(\frac{1+\beta}{\beta}\right)(R_C + R_E)}$$



$$i_B = \frac{2V_{CC} - V_{BE}}{(1+\beta)(R_C+R_E) + R_1}$$

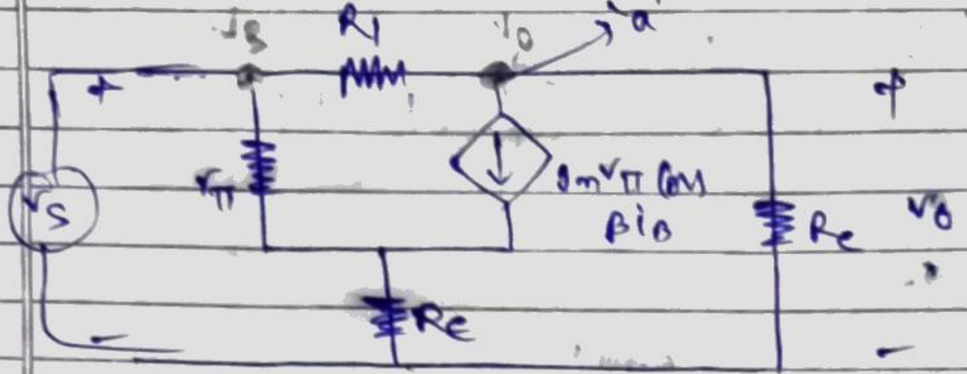
$$i_C = \beta i_B \Rightarrow \frac{\beta(2V_{CC} - V_{BE})}{(1+\beta)(R_C+R_E) + R_1} = i$$

Substitute 'i' in eq ③,

$$V \Rightarrow V_{CE} = 2V_{CC} - \left(\frac{1+\beta}{\beta}\right)(R_C+R_E)\left[\frac{\beta(2V_{CC} - V_{BE})}{(1+\beta)(R_C+R_E) + R_1}\right]$$

(b) Short circuit - DC sources, Coupling capacitor
& open circuit - load capacitor

DC → analysis



Base current (i_B) $= \dfrac{v_s}{R_{ib}}$ → resistance looked into base.

$$i_B = \frac{V_s}{(r_\pi + (1+\beta)R_E)}$$

$$g_m v_\pi \text{ (or) } \beta i_B = \frac{\beta V_s}{r_\pi + (1+\beta) R_E}$$

KCL at node 'a',

$$\frac{v_s - V_0}{R_1} = g_m v_\pi + \frac{V_0}{R_C}$$

$$\frac{V_s - V_0}{R_1} = \frac{\beta V_s}{r_\pi + (1+\beta)R_E} + \frac{V_0}{R_C}$$

$$V_0\left[\frac{1}{R_C} + \frac{1}{R_1}\right] = -V_s\left[\frac{\beta}{r_\pi + (1+\beta)R_E} - \frac{1}{R_1}\right]$$

$$V_0\left[\frac{R_1 + R_C}{\cancel{R_1} R_C}\right] = -V_s\left[\frac{\beta R_1 - (r_\pi + (1+\beta)R_E)}{\cancel{R_1}(r_\pi + (1+\beta)R_E)}\right]$$

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$$\frac{V_o}{V_s} \Rightarrow \frac{-[\beta R_1 - (r_\pi + (1+\beta)R_E)]R_C}{(R_1+R_C)[r_\pi + (1+\beta)R_E]}$$

$$A_V = \frac{-R_C[\beta R_1 - (r_\pi + (1+\beta)R_E)]}{(R_C+R_1)[r_\pi + (1+\beta)R_E]}$$

(c) Q-point (v, i) $\quad$ ($\because$ from (a))

$$V = 2V_{CC} - \left(\frac{1+\beta}{\beta}\right)(R_C+R_E)\left[\frac{\beta(2V_{CC} - V_{BE})}{(1+\beta)(R_C+R_E)+R_1}\right]$$

$$= 2(10) - \left(\frac{101}{100}\right)(11)\left[\frac{100(20-0.7)}{(101)(11)+100}\right]$$

$$V = 20 - 11.11\left[\frac{1930}{1211}\right]$$

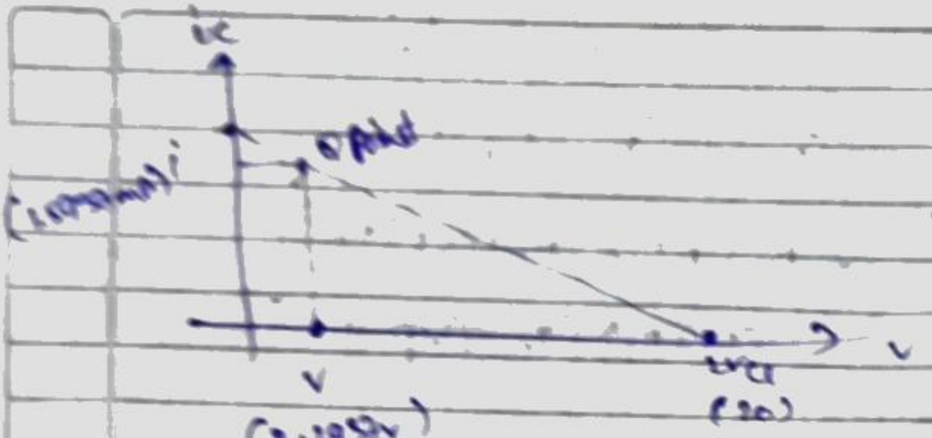
$$= 20 - 17.70627581$$

$$V = 2.293724195 \text{ V}$$

$$i = \frac{\beta(2V_{CC} - V_{BE})}{(1+\beta)(R_C+R_E)+R_1} \Rightarrow \frac{100(20-0.7)}{(101)(11)+100}$$

$$= 1930/1211$$

$$i = 1.593724195 \text{ mA}$$



voltage gain (A_v) → ($\because$ from (B))

$$A_v = \frac{-R_C\left[\beta R_1 - \left(r_\pi + (1+\beta)R_C\right)\right]}{(R_C+R_1)\left[r_\pi + (1+\beta)R_C\right]}$$

$$i_B = \frac{2V_{CC} - V_{BE}}{(1+\beta)(R_C+R_E)+R_1} \quad (\because \text{from DC analysis})$$

$$= \frac{20-0.7}{(101)(11)+100} \text{ mA}$$

$$= \frac{19.3}{1211}$$

$$i_B = 0.0159372419 \text{ mA}$$

$$r_\pi = \frac{V_T}{i_B} \rightarrow \frac{0.026}{0.0159372419} \text{ k}\Omega$$

$r_\pi = 1.63139897 \ k\Omega$

Substitute in A_v

$$A_v = \frac{-R_C\left[\beta R_1 - (r_\pi + (1+\beta)R_C)\right]}{(R_C+R_1)\left[r_\pi + (1+\beta)R_C\right]}$$

$$\Rightarrow \frac{-10\left[100(100) - (1.63139897 + (101)10)\right]}{(110)\left[1.63139897 + 1010\right]}$$

$$= \frac{-8988.3686}{11127.9454}$$

$$A_v = -0.807729395$$

(d) Q-point (v, i)

$$v = V_{CC} - \left(\frac{1+\beta}{\beta}\right)(R_C + R_E)\left[\frac{\beta(V_{CC} - V_{BE})}{(1+\beta)(R_C+R_E) + R_1}\right]$$

$\because$ as $-V_{CC} = 0$, $2V_{CC}$ in 1(c) becomes V_{CC}

$$= 10 - \left(\frac{101}{100}\right)(11)\left[\frac{100(10-0.7)}{(101)(11)+100}\right]$$

$$= 10 - 11.11\left[\frac{930}{1211}\right] \Rightarrow 10 - 8.53203963$$

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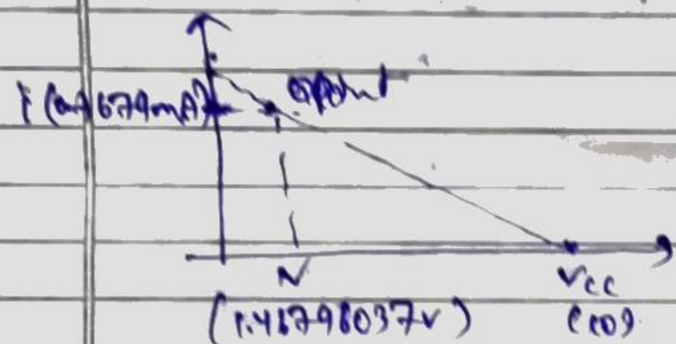
$V = 1.46796037\ V$

$$i = \frac{\beta(V_{CC} - V_{BE})}{(1+\beta)(R_E+R_C)+R_1}$$

$$\Rightarrow \frac{100(10-0.7)}{(101)(11)+100} = \frac{930}{1211}$$

$i = 0.767960363\ mA$



$$i_B = \frac{i_C}{\beta} \Rightarrow \frac{i}{\beta} = 0.00767960363\ mA$$

$$r_\pi = \frac{V_T}{i_B} \Rightarrow \frac{0.026}{0.00767960363}$$

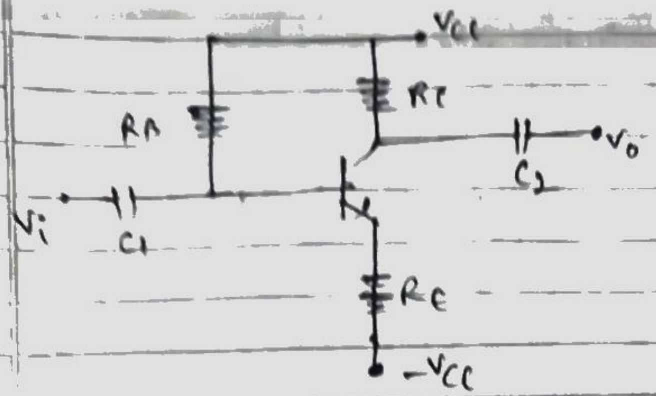
$r_\pi = 3.3855914\ k\Omega$

$$A_V = \frac{-R_C[\beta R_1 - (r_\pi + (1+\beta)R_E)]}{(R_C+R_1)[r_\pi + (1+\beta)R_E]}$$

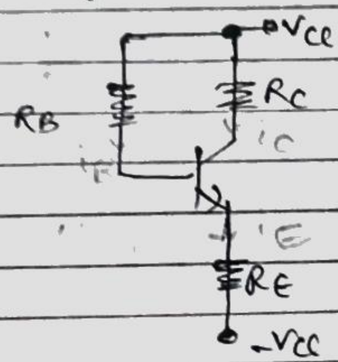
$$\Rightarrow \frac{-10[100(100) - (3.3855914 + (101)10)]}{(110)[3.3855914 + 1010]} = \frac{-8986.6144}{11147.2415}$$

$A_V = -0.806173833$

(3)



(a) DC analysis,



input loop equation,

$$V_{CC} - R_B i_B - V_{BE} - i_E R_E = -V_{CC}$$

$$2V_{CC} - R_B i_B - V_{BE} - (1+\beta) i_B R_E = 0$$

$$i_B = \frac{2V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

Output loop equation,

$$V_{CC} - i_C R_C - V_{CE} - \frac{(1+\beta)}{\beta} i_C R_E = -V_{CC}$$

$$2V_{CC} - V_{CE} = i_C \left[R_C + \left(\frac{1+\beta}{\beta}\right) R_E \right] \quad \text{—} \ (1)$$

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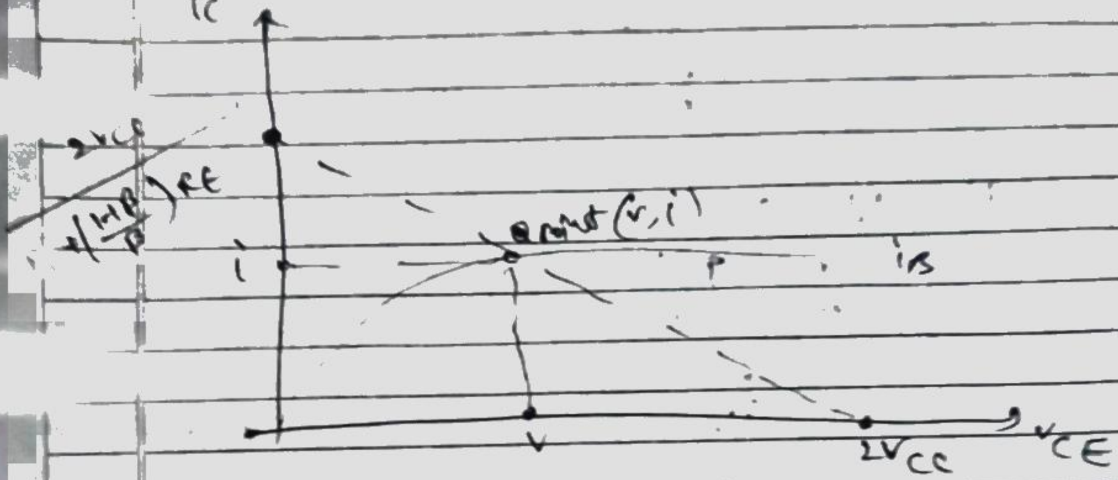
$i_C = 0 \Rightarrow V_{CE} = 2V_{CC}$

$V_{CE} = 0 \Rightarrow i_C = \dfrac{2V_{CC}}{\left[R_C + \left(\frac{1+\beta}{\beta}\right)R_E\right]}$



$i_B = \dfrac{2V_{CC} - V_{BE}}{R_B + (1+\beta)R_E}$

$i = \beta i_B \Rightarrow i = \dfrac{\beta(2V_{CC} - V_{BE})}{(R_B + (1+\beta)R_E)}$

Substitute 'i' in eq (1)

$V = 2V_{CC} - \dfrac{\beta(2V_{CC} - V_{BE})}{(R_B + (1+\beta)R_E)}\left(R_C + \left(\frac{1+\beta}{\beta}\right)R_E\right)$

(b) short circuit - DC voltages, C_1.
open circuit - C_2

DC analysis

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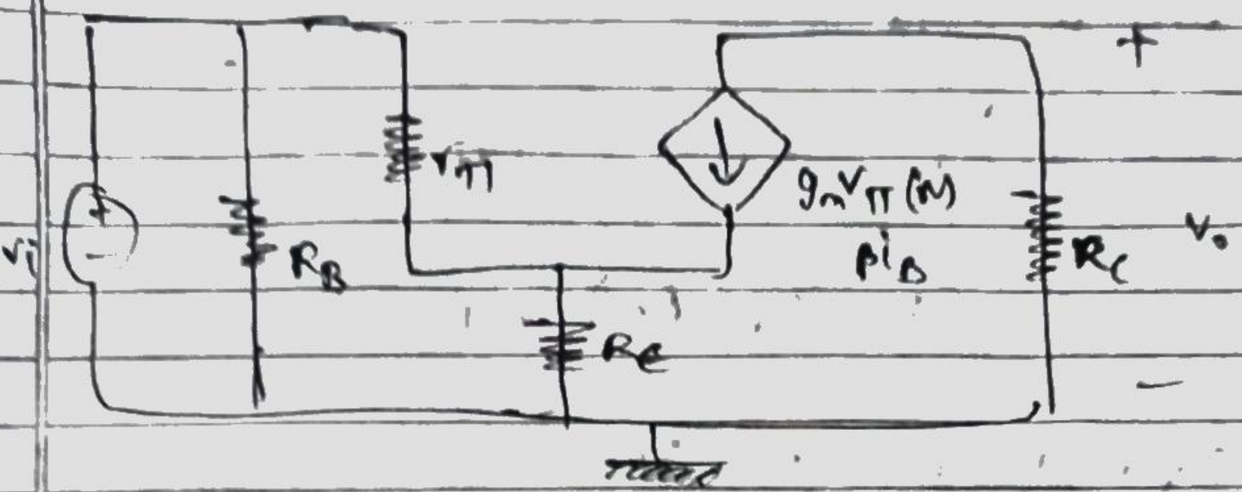


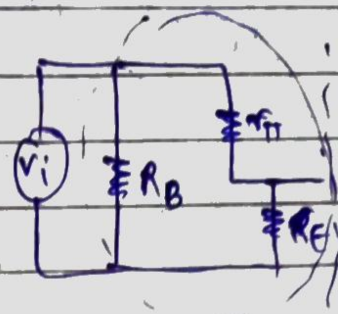
$$i_B = \frac{V_i}{R_{ib}} \Rightarrow i_B = \frac{V_i}{r_\pi + (1+\beta)R_E}$$

Case (i) $v_o = -\beta i_B R_C$ (∵ for $V_A = \infty$)

$$= -\beta\left[\frac{V_i}{r_\pi + (1+\beta)R_E}\right]R_C$$

$$A_v = v_o/v_i = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}$$

(c) Input resistance (V_i / i_{in})



$$\Rightarrow \frac{v_i}{i_{in}} = R_{ib} \parallel R_B$$

(i/p) resist $= (r_\pi + (1+\beta)R_E) \parallel R_B$

Output resistance (v_o / i_c) $\Rightarrow$

$$v_o / i_c = \frac{\cancel{-g_m V_\pi} R_C}{\cancel{-g_m V_\pi}}$$

o/p resistance $= R_C$

(d) $A_v = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$ (∵ from (b))

$$i_B = \frac{2V_{CC} - V_{BE}}{R_B + (1+\beta)R_E} = \frac{40 - 0.7}{500 + (101)1} \text{ mA}$$

$$i_B = \frac{39.3}{601} \text{ mA} \Rightarrow i_B = 0.065391015 \text{ mA}$$

$$r_\pi = V_T / i_B \Rightarrow \frac{0.026}{0.065391015} \text{ k}\Omega$$

$$r_\pi = 0.399608142 \text{ k}\Omega$$

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$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E}$$

$$= \frac{-100(5)}{0.39700814 + (101)1}$$

$$= \frac{-500}{101.397608}$$

$$A_v = -4.93108279$$

(e)

$i_B = 0.065391015$ mA (∵ from (d))

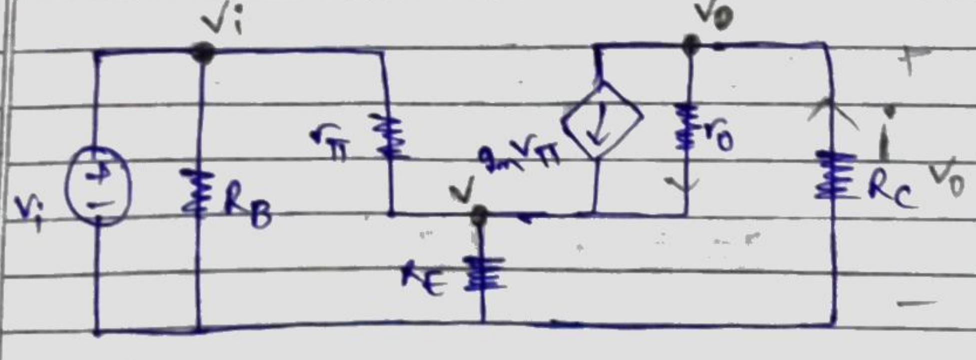
$i_C = \beta i_B \Rightarrow i_C = 6.5391015$ mA

$V_A = 100$ V

$$r_o = V_A / i_C = \frac{100}{6.5391015} \text{ k}\Omega$$

$$r_o = 15.2926209 \text{ k}\Omega$$

Small signal eq. model ⇒



$v_\pi = V_i - V$

$$\rightarrow \frac{V_i - V}{r_\pi} + g_m v_\pi + \frac{V_0 - V}{r_0} = \frac{V}{R_E}$$

$$\frac{V_i - V}{r_\pi} + g_m (V_i - V) + \frac{V_0 - V}{r_0} = \frac{V}{R_E}$$

$$V_i \left[g_m + \frac{1}{r_\pi}\right] + V_0 \left[\frac{1}{r_0}\right] = V \left[\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_0} + g_m\right]$$

$$V = \frac{V_i \left[g_m + 1/r_\pi\right] + V_0 \left[1/r_0\right]}{\left(1/R_E + 1/r_\pi + 1/r_0 + g_m\right)}$$

at output $\rightarrow$

$$V_0 = -i R_C$$

$$= -\left[\frac{V_0 - V}{r_0} + g_m v_\pi\right] R_C$$

$$= -\left[\frac{V_0 - V}{r_0} + g_m (V_i - V)\right] R_C$$

$$\rightarrow -\left[V_0 - V + g_m r_0 (V_i - V)\right]\left(\frac{R_C}{r_0}\right)$$

$$\rightarrow -(V_0 - V)\left(\frac{R_C}{r_0}\right) - g_m r_0 (V_i - V)\left[\frac{R_C}{r_0}\right]$$

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$$* \Rightarrow -(v_0 - v)\frac{R_E}{r_0}$$

$$\Rightarrow -\left(v_0 - \frac{v_i(g_m + 1/r_\pi) + v_0(1/r_0)}{1/R_E + 1/r_\pi + 1/r_0 + g_m}\right)\frac{R_E}{r_0}$$

$$\Rightarrow -\left[\frac{\frac{v_0}{R_E} + \frac{v_0}{r_\pi} + \cancel{\frac{v_0}{r_0}} + g_m v_0 - v_i g_m - \frac{v_i}{r_\pi} - \cancel{\frac{v_0}{r_0}}}{1/R_E + 1/r_\pi + 1/r_0 + g_m}\right]\frac{R_E}{r_0}$$

$$\Rightarrow \frac{-v_0\left[\frac{1}{R_E} + \frac{1}{r_\pi} + g_m\right] + v_i\left[g_m + \frac{1}{r_\pi}\right]}{1/R_E + 1/r_\pi + 1/r_0 + g_m}\left[\frac{R_E}{r_0}\right]$$

$$** \Rightarrow -g_m \cancel{r_0}(v_i - v)\frac{R_E}{\cancel{r_0}}$$

$$\Rightarrow -g_m R_E\left[v_i - \frac{v_i(g_m + 1/r_\pi) + v_0(1/r_0)}{1/R_E + 1/r_\pi + 1/r_0 + g_m}\right]$$

$$\Rightarrow -g_m R_E\left[\frac{\frac{v_i}{R_E} + \cancel{\frac{v_i}{r_\pi}} + \frac{v_i}{r_0} + \cancel{g_m v_i} - \cancel{v_i g_m} - \cancel{\frac{v_i}{r_\pi}} - \frac{v_0}{r_0}}{1/R_E + 1/r_\pi + 1/r_0 + g_m}\right]$$

$$\Rightarrow \frac{-g_m R_E\left[1/R_E + 1/r_0\right]v_i}{1/R_E + 1/r_\pi + 1/r_0 + g_m} + \frac{g_m R_E v_0}{r_0(1/R_E + 1/r_\pi + 1/r_0 + g_m)}$$

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$$v_o = -(v_o - v)\frac{R_c}{r_o} - g_m r_o (v_i - v)\frac{R_c}{r_o}$$

$$v_o = \frac{-v_o\left[\frac{1}{R_E} + \frac{1}{r_\pi} + g_m\right]\left(\frac{R_c}{r_o}\right)}{\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m} + \frac{v_i\left[g_m + \frac{1}{r_\pi}\right]\left[\frac{R_c}{r_o}\right]}{\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m}$$

$$- \frac{g_m R_c\left[\frac{1}{R_E} + \frac{1}{r_o}\right]v_i}{\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m} + \frac{g_m R_c v_o}{r_o\left[\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right]}$$

$$v_o + \frac{v_o\left[g_m + \frac{1}{r_\pi} + \frac{1}{R_E}\right]\left(\frac{R_c}{r_o}\right)}{\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m} - \frac{v_o\left[g_m R_c\right]}{r_o\left(\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right)}$$

$$= \frac{v_i\left[g_m + \frac{1}{r_\pi}\right]\left(\frac{R_c}{r_o}\right)}{\left(\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right)} - \frac{v_i g_m R_c\left[\frac{1}{R_E} + \frac{1}{r_o}\right]}{\left(\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right)}$$

$$\frac{v_o\left[\frac{r_o}{R_E} + \frac{r_o}{r_\pi} + 1 + g_m r_o + g_m R_c + \frac{R_c}{r_\pi} + \frac{R_c}{R_E} - g_m R_c\right]}{r_o\left[\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right]}$$

$$= \frac{v_i\left[\cancel{\frac{g_m R_c}{r_o}} + \frac{R_c}{r_\pi r_o} - \cancel{\frac{g_m R_c}{r_o}} - \frac{g_m R_c}{R_E}\right]}{\left[\frac{1}{R_E} + \frac{1}{r_\pi} + \frac{1}{r_o} + g_m\right]}$$

$$A_V = \frac{V_o}{V_i}$$

$$\Rightarrow \frac{r_o\left[\frac{R_C}{r_\pi r_o} - \frac{g_m R_C}{R_E}\right]}{\left(\frac{r_o}{R_E} + \frac{r_o}{r_\pi} + 1 + g_m r_o + \frac{R_C}{r_\pi} + \frac{R_C}{R_E}\right)}$$

$r_o = 15.2926209\ k\Omega$

$r_\pi = 0.397608142\ k\Omega$

$g_m = {i_C}/{V_T} = \frac{6.5391015}{0.026}\ mA/V$

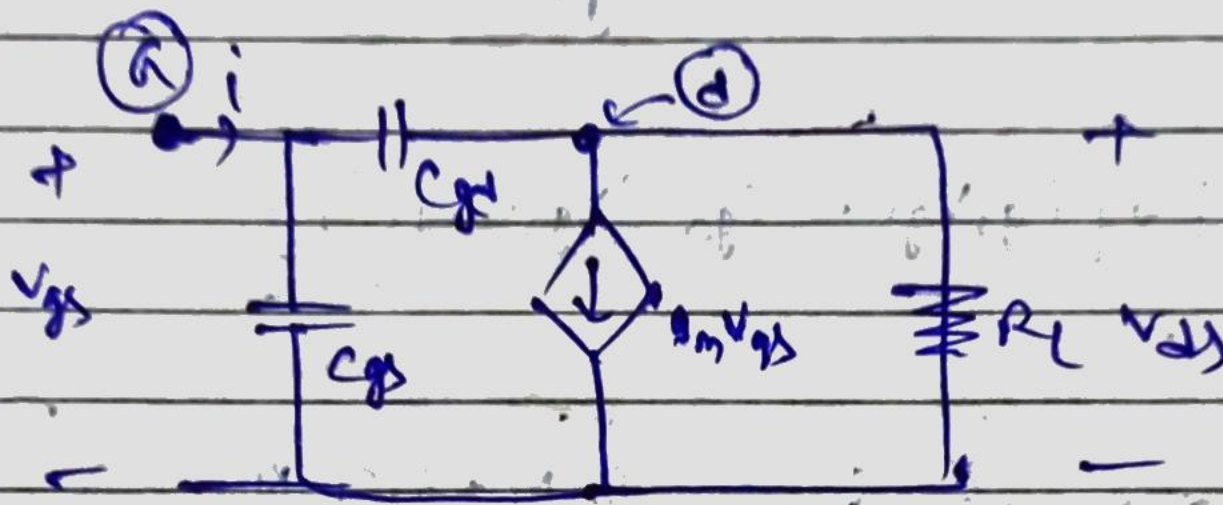
$g_m = 251.503904\ mA/V$

$$A_V = \frac{12.5751952 - 19230.7693}{(15.2926209 + 38.4615386 + 1 + 3846.15386 + 12.5751952 + 5)}$$

$$= \frac{-19218.1941}{3918.48321}$$

$$A_V = -4.90449826$$

(4)



KCL at node 'd',

$$\frac{v_{gs} - v_{ds}}{\left(\frac{1}{j\omega C_{gd}}\right)} = g_m v_{gs} + \frac{v_{ds}}{R_L}$$

$$j\omega C_{gd}(v_{gs} - v_{ds}) = g_m v_{gs} + \frac{v_{ds}}{R_L}$$

$$(g_m - j\omega C_{gd}) V_{gs} = -\left(\tfrac{1}{R_L} + j\omega C_{gd}\right) V_{ds}$$

$$V_{ds} = \frac{-(g_m - j\omega C_{gd})}{\left(\tfrac{1}{R_L} + j\omega C_{gd}\right)} V_{gs}$$

$$V_{ds} = \frac{-(g_m R_L - j\omega C_{gd} R_L)}{(1 + j\omega R_L C_{gd})} V_{gs}$$

KCL at node 'G',

$$i = \frac{V_{gs}}{\left(\tfrac{1}{j\omega C_{gs}}\right)} + \frac{V_{gs} - V_{ds}}{\left(\tfrac{1}{j\omega C_{gd}}\right)}$$

$$= j\omega \left[C_{gs} V_{gs} + C_{gd} (V_{gs} - V_{ds}) \right]$$

$$= j\omega \left[C_{gs} V_{gs} + C_{gd} \left(V_{gs} + \frac{g_m R_L - j\omega C_{gd} R_L}{1 + j\omega R_L C_{gd}} V_{gs} \right) \right]$$

$$= j\omega \left[C_{gs} + C_{gd} \underbrace{\left(1 + \frac{g_m R_L - j\omega C_{gd} R_L}{1 + j\omega R_L C_{gd}} \right)}_{} \right] V_{gs}$$

~~Miller Capacitance (C_M) =~~

~~$C_M = C_{gd} [1+$~~

$g_m R_L , 1 >> j\omega C_{gd} R_L$

$$i = j\omega \left[\underbrace{C_{gs} + C_{gd}\left(1 + \frac{g_m R_L}{1}\right)}_{C_M} \right] v_{gs}$$

miller capacitance $(C_M) \Rightarrow$

$$C_M = C_{gd}(1 + g_m R_L)$$

$\rightarrow \quad i = j\omega \{C_{gs} + C_M\} v_{gs}$

output current, $(i_d) \Rightarrow$

$$i_d = -g_m v_{gs}$$

$$A_i = \frac{i_d}{i} \Rightarrow \frac{-g_m \cancel{v_{gs}}}{j\omega [C_{gs} + C_M] \cancel{v_{gs}}}$$

Cutoff frequency $(f_T) \Rightarrow$

$$\left|\frac{i_d}{i}\right| = 1 \Rightarrow$$

$$\frac{g_m}{\omega (C_{gs} + C_M)} = 1$$

$$f_T = \frac{g_m}{2\pi (C_{gs} + C_M)}$$

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Cut off frequency (f_T) →

$|A_i| = 1$ ⇒

$$\frac{g_m}{\omega_T(C_{gs} + C_M)} = 1$$

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_M)}$$