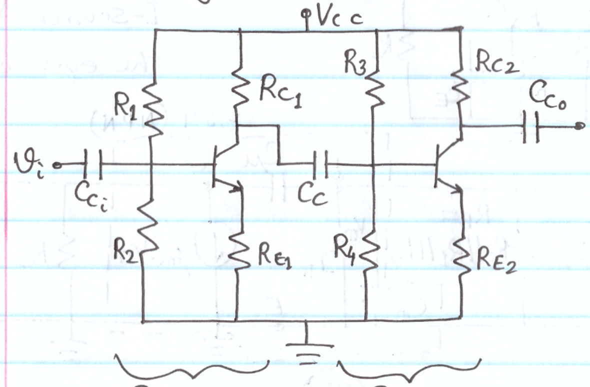
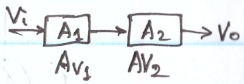
$$f_{3db} = \frac{1}{2\pi (R_B || r_\pi)(C_\pi + C_M)} \quad \text{(LPF like)}$$

(BJT) ext. ckt.

16. Two-stage amplifier: Obtains a larger gain w/o bandwidth reduction & phase preservation ($\phi = 0^\circ$)



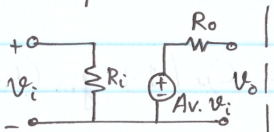




Stage 1 $\phi_1 = 180^\circ$ | Stage 2 $\phi_2 = 180^\circ$

Gain: $A_V = |A_{V_1}| \cdot |A_{V_2}|$ $\quad \phi = \phi_1 + \phi_2$

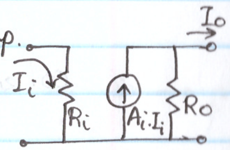
17. Equivalent 2-port networks:

a) V-amp.



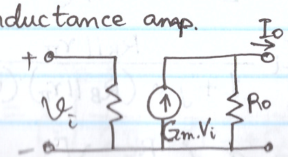

$V_{in} \rightarrow V_{out}$

b) I-amp.



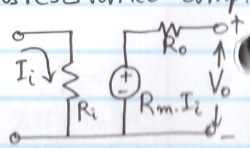

$I_{in} \rightarrow I_{out}$

c) Transconductance amp.




$V_{in} \rightarrow I_{out}$

d) Transresistance amp.




$I_{in} \rightarrow V_{out}$

# Tutorial (BJTs)

1. Calculate $\beta$, $\alpha$ & $I_C$ if $I_B = 10.2\mu A$ & $I_E = 0.9 mA$

Sol$^n$. $I_E = (1+\beta) I_B$

$$\Rightarrow \beta = \frac{I_E}{I_B} - 1 = \frac{0.9 \times 10^{-3}}{10.2 \times 10^{-6}} - 1 = 87.23 \quad \text{(Ans)}$$

No unit

Now, $\alpha = \frac{\beta}{1+\beta} = \frac{87.23}{87.23+1} = 0.988$ ← No unit (Ans)

And, $I_C = \alpha . I_E = (0.988)(0.9 \times 10^{-3}) = 0.889\ mA$ (Ans)

2. Find $r_o$ if $V_A = 190V$ & $I_C = 2.2mA$

Sol$^n$. $r_o = \frac{V_A}{I_C} = \frac{190}{2.2 \times 10^{-3}} = 86.363\ k\Omega$ (Ans)

3. Find $I_C$ at $V_{CE} = 12V$. Given, $I_C = 1.3\ mA$ @ $V_{CE} = 1.5V$ & $V_A = 200V$. Assume $V_{BE_{on}} = 0.7V$ is constant.

Sol$^n$. We know, $I_C = \left[I_S . \left(e^{\frac{V_{BE}}{V_T}}\right)\right]\left(1 + \frac{V_{CE}}{V_A}\right) = I_o . \left(1 + \frac{V_{CE}}{V_A}\right)$

$$\Rightarrow 1.3 \times 10^{-3} = I_o . \left(1 + \frac{1.5}{200}\right)$$

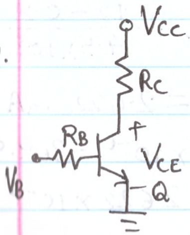
$$\Rightarrow I_o = 1.29 \times 10^{-3}\ A$$

$\therefore$ At $V_{CE} = 12V$,

$$I_C = 1.29 \times 10^{-3}\left(1 + \frac{12}{200}\right)$$

$$= 1.367\ mA \quad @ V_{CE} = 12V \quad \text{(Ans)}$$

4.




Let, $V_{CC} = 5V$, $V_B = 2.2V$, $R_C = 4.2k\Omega$, $R_B = 220k\Omega$, $\beta = 150$, $V_{BE(on)} = 0.7V$.

Calculate $I_B$, $I_C$, $V_{CE}$ & $P_{transistor}$.

Sol$^n$: $I_B = \dfrac{V_B - V_{BE(on)}}{R_B} = \dfrac{2.2-0.7}{220\times10^{-3}} = 6.818\,\mu A$ (Ans)

$I_C = \beta . I_B = 6.818\times10^{-6}\times150 = 1.022\,mA$ (Ans)

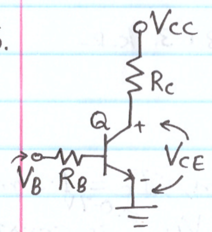
$V_{CE} = V_{CC} - I_C . R_C = 5-[(1.022\times10^{-3})(4.2\times10^{+3})]$

$= 0.707\,V$, Forward active mode (Ans)

$P_{transistor} = I_B . V_{BEon} + I_C . V_{CE}$

$= (6.818\times10^{-3})(0.7) + (1.022\times10^{-3})(0.707)$

$= 5.495\,mW$ (Ans)

5. 


Calculate $I_B, I_C, I_E, V_{CE}$, if $V_{BEon} = 0.7V$, $\beta = 110$, $V_{CEsat} = 0.2V$ & $V_B = 1.5V$ to $7V$, $V_{CC} = 12V$, $R_B = 240k\Omega$, $R_C = 4.5k\Omega$.

Sol$^n$: $I_{B\,@V_B=1.5V} = \dfrac{V_B - V_{BEon}}{R_B} = \dfrac{1.5-0.7}{240\times10^3} = 3.333\,\mu A$ (Ans)

$I_{B\,@V_B=7V} = \dfrac{7-0.7}{240\times10^3} = 26.25\,\mu A$ (Ans)

$I_{C_{1.5V}} = \beta . I_B = 110\times3.333\times10^{-6} = 366.630\,\mu A$ (Ans)

$V_{CE} = V_{CC} - I_C R_C \Rightarrow V_{CE} > 0.2V$

$I_{C_{7V}} \Rightarrow$ Transistor is likely in saturation mode.

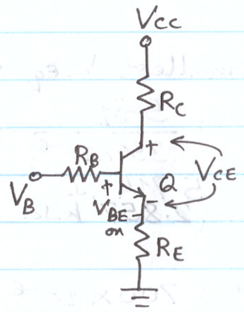
$\therefore I_{C_{7V}} = \dfrac{V_{CC} - V_{CEsat}}{R_C} = \dfrac{12-0.2}{4.5\times10^3}$

$= 2.622\,mA$ (Ans)

$I_{E_{1.5V}} = (1+\beta) I_B = (1+110)3.333\times10^{-6} = 369.963\,\mu A$ (Ans)

$I_{E_{7V}} = I_B + I_C = 26.25\times10^{-6} + 2.622\times10^{-3}$

$= 2.648\,mA$ (Ans)

6. 


$V_{CC} = 15V$, $V_B = 9V$, $R_B = 33k\Omega$, $R_C = 0.5k\Omega$, $R_E = 1.5k\Omega$, $\beta = 80$, $V_{BE(on)} = 0.7V$. Calculate: $I_B, I_C, I_E$ & $V_{CE}$. (quiescent point parameters)

Sol$^n$: $I_B = \dfrac{V_B - V_{BE(on)}}{R_B + (1+\beta)R_E} = \dfrac{9-0.7}{33\times10^3 + (1+80)\times1.5\times10^3}$

$= 53.721\,\mu A$ (Ans)

$I_C = \beta . I_B = 80\times53.721\times10^{-6}$

$= 4.297\,mA$ (Ans)

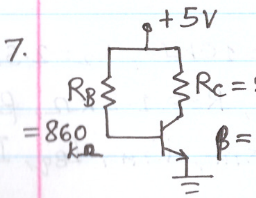
$I_E = (1+\beta) I_B = (1+80)\times53.721\times10^{-6}$

$= 4.351\,mA$ (Ans)

$V_{CE} = V_{CC} - I_C . R_C - I_E . R_E$

$= 15 - (4.297\times10^{-3})(0.5\times10^3) - (4.351\times10^{-3}\times1.5\times10^3)$

$= 6.325\,V$ (Ans)

7. 


Find a new $R_C$ such that the q-pt will be in the range $V_{CEq} = 1$ to $3V$. What is the actual range of $V_{CEq}$ for the new $R_C$?

Assume, $V_{BEon} = 0.7V$ (Si)

Sol$^n$: $I_{Bq} = \dfrac{V_{CC} - V_{BEon}}{R_B} = \dfrac{5-0.7}{860\times10^3} = 5\,\mu A$

For $\beta = 70$, $I_{Cq} = \beta . I_{Bq} = 70\times5\times10^{-6} = 350\,\mu A$

For $\beta = 140$, $I_{Cq} = 140\times5\times10^{-6} = 700\,\mu A$

Largest $I_{cq}$ leads to smallest $V_{CEq}$ & vice-versa

For $\beta=70$, $R_C = \dfrac{V_{CC}-V_{CEq}}{I_{cq}} = \dfrac{5-3}{350\times10^{-6}} = 5.714\,k\Omega$ (Ans)

For $\beta=140$, $R_C = \dfrac{5-1}{700\times10^{-6}} = 5.714\,k\Omega$ (Ans)

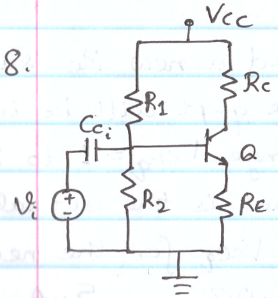
Nominal $I_{cq_{nom.}} = \dfrac{350\times10^{-6}+700\times10^{-6}}{2} = 525\,\mu A$

Nominal $V_{CEq_{nom.}} = \dfrac{1+3}{2} = 2\,V$

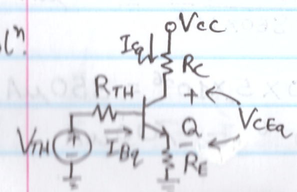
Nominal $R_{c_{nom.}} = \dfrac{V_{CC}-V_{CEq_{nom.}}}{I_{cq}} = \dfrac{5-2}{525\times10^{-6}} = 5.714\,k\Omega$

For $I_{cq} = 350\,\mu A$, (@$\beta=70$) $V_{CEq} = V_{CC} - I_{cq}.R_C$
$= 5-[(350\times10^{-6})(5.714\times10^{3})]$
$= 3V$ (Ans)

For, $I_{cq} = 700\,\mu A$, (@$\beta=140$) $V_{CEq} = 5-[(700\times10^{-6})(5.714\times10^{3})]$
$= 1V$ (Ans)

8. 


$V_{CC}=6V$, $R_1 = 10k\Omega$, $R_2 = 2.5k\Omega$, $R_E = 220\,\Omega$, $R_C = 1.2k\Omega$, $\beta=160$. Calculate $R_{TH}$, $V_{TH}$, $I_{Bq}$, $I_{cq}$, & $V_{CEq}$.

Sol$^n$. 


$R_{TH} = R_1 // R_2 = \dfrac{10k\times2.5k}{10k+2.5k} = 2\,k\Omega$ (Ans)

$V_{TH} = \dfrac{R_2}{R_1+R_2}.V_{CC} = \dfrac{2.5k}{10k+2.5k}\times6 = 1.2V$ (Ans)

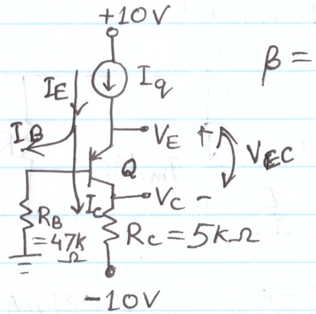
Assume, $V_{BE_{on}} = 0.7V$

$I_{Bq} = \dfrac{V_{TH}-V_{BE_{on}}}{R_{TH}+(1+\beta)R_E} = \dfrac{1.2-0.7}{2\times10^{3}+(1+160)220} = 13.361\,\mu A$ (Ans)

$I_{cq} = \beta.I_{Bq} = 160\times13.361\times10^{-6} = 2.137\,mA$ (Ans)

$I_{Eq} = (1+\beta)I_{Bq} = 2.151\,mA$

$V_{CEq} = V_{CC} - I_{cq}.R_C - I_{Eq}.R_E = 6-[(2.137\times10^{-3})(1.2\times10^{3}) + (2.151\times10^{-3})(220)]$
$= 2.960V$ (Ans)

9. 


$\beta=60$, $I_q = 1.2mA$. Find $V_C$ & $V_E$ & $V_{EE}$

Sol$^n$. $I_E = 1.2\,mA$; $I_c = \underbrace{\left(\dfrac{\beta}{1+\beta}\right)}_{\alpha} I_E = \dfrac{50}{1+50}\times1.2\times10^{-3}$
$= 1.176\,mA$

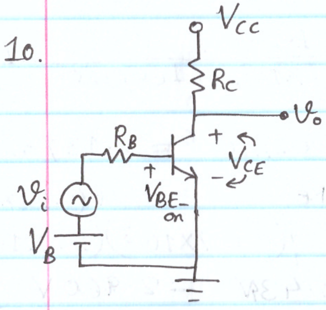
$V_C = I_C.R_C + V_{EE}$
$= (1.176\times10^{-3})(5\times10^{3}) - 10 = -3.12V$ (Ans)

$I_B = \dfrac{I_C}{\beta} = \dfrac{1.176\times10^{-3}}{60} = 19.6\,\mu A$

$V_E = I_B.R_B + V_{BE_{on}} = (19.6\times10^{-6})(47\times10^{3}) + 0.7$
$= 1.621\,V$ (Ans)

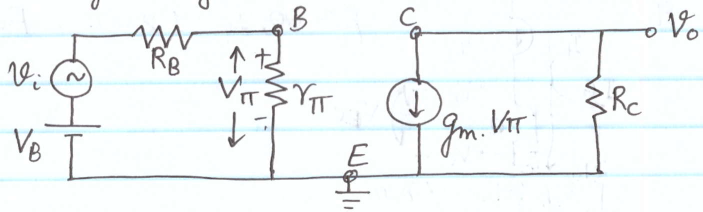
$V_{EC} = V_E - V_C = 1.621-(-3.12)$
$= 4.74V$ (Ans)

10.




$V_{cc} = 6V$, $V_B = 2V$, $R_B = 640\,k\Omega$, $R_C = 12\,k\Omega$, $V_{BEon} = 0.7V$, $\beta = 90$. Draw the small signal hybrid-$\pi$ model. Find q-pt values, $g_m$, $r_\pi$. Calculate small-signal V-gain.

Sol$^n$: Small signal hybrid-$\pi$ model:




$$I_{Bq} = \frac{V_B - V_{BEon}}{R_B} = \frac{2-0.7}{640\times10^3} = 2.031\,\mu A \quad \text{(Ans)}$$

$$I_{cq} = \beta . I_{Bq} = 90 \times 2.031\times10^{-6} = 182.812\,\mu A \quad \text{(Ans)}$$

$$V_{CEq} = V_{cc} - I_{cq}.R_C = 6 - [182.812\times10^{-6}\times 12\times10^3] = 3.806\,V \quad \text{(Ans)}$$

$$I_{Eq} = I_{Bq} + I_{cq} = 2.031\mu + 182.812\mu A = 184.843\mu A \text{ (Ans)}$$

$$g_m = \frac{I_{cq}}{V_T} = \frac{182.812\times10^{-6}}{0.026} = 7.031\,mA/V \quad \text{(Ans)}$$

Assume $V_T = 26\,mV$

$$r_\pi = \frac{\beta . V_T}{I_{cq}} = \frac{90\times0.026}{182.812\times10^{-6}} = 12.800\,k\Omega \quad \text{(Ans)}$$

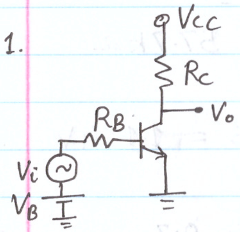
$$\frac{V_o}{V_i} = A_V = -g_m . R_C\left(\frac{r_\pi}{r_\pi + R_B}\right) \qquad [\because A_V = -g_m.V_\pi R_C]$$

$$= -(7.031\times10^{-3})\times(12\times10^3)\times\left(\frac{12.8\times10^3}{12.8\times10^3 + 640\times10^3}\right)$$

$$= -1.654 \quad \text{(Ans)}$$

No unit

11.




$V_{cc} = 7V$, $V_B = 1V$, $V_A = 200V$, $\beta = 120$, $R_C = 15\,k\Omega$, $V_{BEon} = 0.7V$, $R_B = 120\,k\Omega$. Calculate $g_m$, $r_\pi$, $r_o$ & $A_V$.

$r_o$ must be shown in hybrid-$\pi$

Sol$^n$:
$$g_m = \frac{I_{cq}}{V_T} = \frac{\beta . I_{Bq}}{V_T} = \frac{\beta . \left(\frac{V_B - V_{BEon}}{R_B}\right)}{V_T}$$

$$= \frac{\cancel{120}\times\left(\frac{1-0.7}{\cancel{120}\times10^3}\right)}{0.026} = 11.538\,mA/V \quad \text{(Ans)}$$

$$r_\pi = \frac{\beta . V_T}{I_{cq}} = \frac{120\times0.026}{\cancel{120}\times\left(\frac{1-0.7}{\cancel{120}\times10^3}\right)} = 10.4\,k\Omega \quad \text{(Ans)}$$

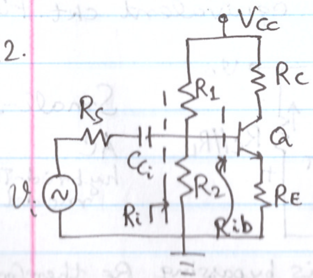
$$r_o = \frac{V_A}{I_{cq}} = \frac{200\times10^3}{0.3} = 666.666\,k\Omega \quad \text{(Ans)}$$

$$A_V = \frac{V_o}{V_i} = -g_m\left(\frac{r_\pi}{r_\pi + R_B}\right)(r_o // R_C)$$

$$= -(11.538\times10^{-3})\left(\frac{10.4k}{10.4k + 120k}\right)(666.666k // 15k)$$

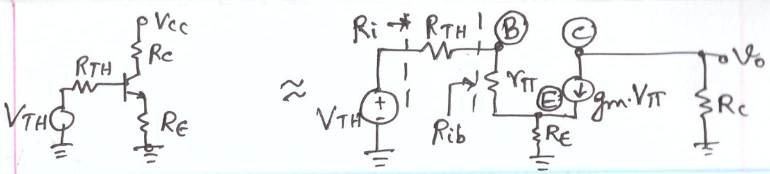
$$= -13.499 \quad \text{(Ans)}$$

12.




$V_{cc} = 5V$, $R_C = 5.6\,k\Omega$, $R_E = 0.6\,k\Omega$, $\beta = 120$, $R_1 = 250\,k\Omega$, $R_2 = 75\,k\Omega$, $V_A = \infty$, $R_S = 0.5\,k\Omega$ & $V_{BEon} = 0.7V$.

Find: $R_{ib}$ & $R_i$.




Sol$^n$ $R_{TH} = R_1 // R_2 = \frac{250k \times 75k}{250k + 75k} = 57.7 k\Omega$

$$V_{TH} = \frac{R_2}{R_1+R_2} V_{cc} = \frac{75k}{75k+250k} \cdot 5 = 1.154V$$

$$I_{Bq} = \frac{V_{TH} - V_{BEon}}{R_{TH} + (1+\beta)R_E} = \frac{1.154 - 0.7}{57.7 - (120+1)(0.6k)} = 3.48 \mu A$$

$$I_{cq} = \beta . I_{cq} = 120 \times 3.48 \times 10^{-6} = 0.418 \text{ mA}$$

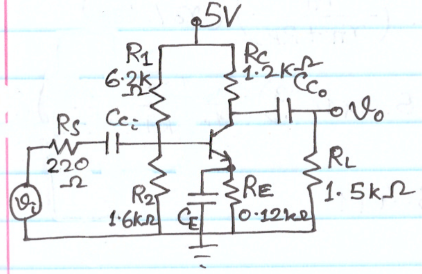
$$g_m = \frac{I_{cq}}{V_T} = \frac{0.418 \times 10^{-3}}{0.026} = 16.08 \text{ mA/V}$$

$$r_\pi = \frac{\beta . V_T}{I_{cq}} = \frac{120 \times 0.026}{0.418 \times 10^{-3}} = 7.46 k\Omega$$

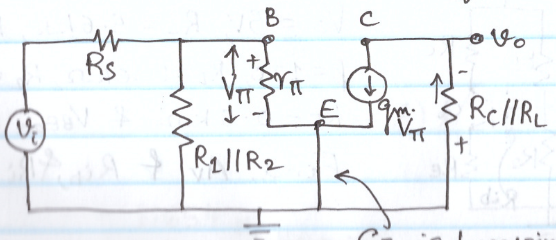
$\times$ $V_o = -g_m . V_\pi . R_c$

$$R_{ib} = r_\pi + (1+\beta) R_E = 7.46k\Omega + (1+120)(0.6 \times 10^3)$$
$$= 80.1 \ k\Omega$$ (Ans)

$$R_i = R_1 || R_2 + R_{ib} = 57.7k + 80.1k = 137.8 \ k\Omega$$ (Ans)

13. 

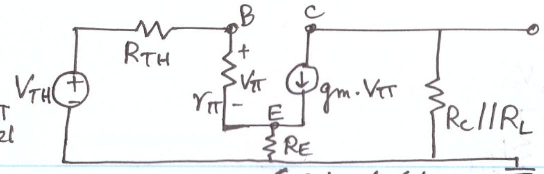

$\beta = 200$, $r_o = \infty$
Find small signal hybrid-π parameters after drawing an equivalent ckt. Find Av

Sol$^n$ 


Small-signal AC hybrid-π model

CE is bypassing RE, therefore a short.

Small Signal DC hybrid-π model




Assume $V_\pi = V_{BEon} = 0.7V$ & $V_T = 26 mV$

$$R_{TH} = R_1 // R_2 = \frac{6.2k \cdot 1.6k}{6.2k + 1.6k} = 1.271 k\Omega$$

$$V_{TH} = \frac{R_2}{R_1+R_2} V_{cc} = \frac{1.6k}{6.2k + 1.6k} \cdot 5 = 1.025V$$

$$I_{Bq} = \frac{V_{TH} - V_{BE on}}{R_{TH} + (1+\beta)R_E} = \frac{1.025 - 0.7}{1.271k + (1+200)0.12k}$$
$$= 12.799 \ \mu A$$

$$I_{cq} = \beta . I_{Bq} = 200 \times 12.799 \times 10^{-6} = 2.559 mA$$
$$I_{cq} = (1+\beta) I_{Bq} = 2.572 \ mA$$ (Ans)

$$V_{CEq} = V_{cc} - I_{cq} . R_c - I_{Eq} . R_E$$
$$= 5 - (2.559m)(1.2k) - (2.572m)(0.12k)$$
$$= 1.620 V$$ (Ans)

$$r_\pi = \frac{\beta . V_T}{I_{cq}} = \frac{200 \times 0.026}{2.559 \times 10^{-3}} = 2.032 k\Omega$$

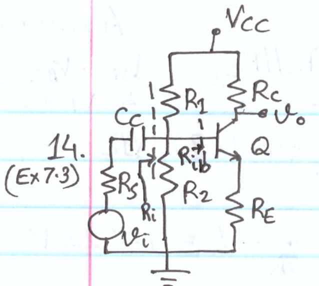
$$g_m = \frac{I_{cq}}{V_T} = \frac{2.559 \times 10^{-3}}{0.026} = 98.423 \ mA/V$$ (Ans)

$$A_v = -g_m . \left[\frac{R_1 || R_2 || r_\pi}{(R_1||R_2||r_\pi) + R_s}\right](R_c // R_L)$$

$$= -98.423m \left[\frac{6.2k || 1.6k // 2.032k}{(6.2k || 1.6k // 2.032k) + 220}\right](1.2k // 1.5k)$$

$= -$ (Ans)

14. (Ex 7.3)




$R_S = 0.1\,k\Omega$, $R_1 = 20k$, $R_2 = 2.2k$, $R_E = 0.1k$, $R_C = 2k$, $C_C = 47\mu F$, $V_{CC} = 10V$, $V_{BEon} = 0.7V$, $\beta = 200$, $V_A = \infty$.

Find $\tau_S$ & $f_C$ & $A_{v_{mid\text{-}band}}$.

Sol$^n$:

$$\tau_S = (R_i + R_S).C_C$$

$$f_C = \frac{1}{2\pi\tau_S}$$

$$R_{TH} = R_1 // R_2 = \frac{20k \cdot 2.2k}{20k + 2.2k} = 1.98\,k\Omega$$

$$V_{TH} = \frac{R_2}{R_1 + R_2} \cdot V_{CC} = \frac{2.2k}{20k + 2.2k} \cdot 10 = 0.990\,V$$

$$I_{Bq} = \frac{V_{TH} - V_{BEon}}{R_{TH} + (1+\beta)R_E} = \frac{0.990 - 0.7}{1.98k + (1+200)\,0.1k} = 13.2\,\mu A$$

$$I_{cq} = \beta \cdot I_{Bq}$$

$$I_{cq} = 200 \cdot 13.2\mu = 2.636\,mA$$

$$r_\pi = \frac{\beta \cdot V_T}{I_{cq}} = \frac{200 \times 0.026}{2.636m} = 1.97\,k\Omega$$

$$g_m = \frac{I_{cq}}{V_T} = \frac{2.636m}{0.026} = 101.4\,mA/V$$

$$R_{ib} = r_\pi + (1+\beta).R_E = 1.97k + (1+200)\,0.1k = 22.1\,k\Omega$$

$$R_B = R_1 // R_2 = 1.98\,k\Omega$$

$$R_i = R_B // R_{ib} = \frac{1.98k \cdot 22.1k}{1.98k + 22.1k} = 1.817\,k\Omega$$

$$\therefore \tau_S = (R_i + R_S).C_C = (1.817k + 0.1k) \cdot 47\mu = 90.099\,ms$$ (Ans)

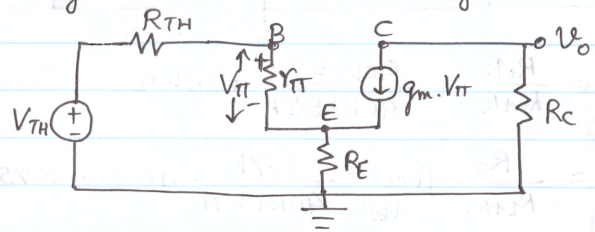
$$f_C = \frac{1}{2\pi\tau_S} = \frac{1}{2\pi \times 90.099m} = 1.77\,Hz$$ (Ans) (High I/P pass)

$$A_{v_{mid\text{-}band}} = \frac{-\beta \cdot R_C}{r_\pi + (1+\beta)R_E} \cdot \frac{R_i}{R_i + R_S}$$

$$= \frac{-(200)(2k)}{1.97k + (1+200)(0.1k)} \cdot \frac{1.817k}{1.817k + 0.1k}$$

$$= -17.2$$ (Ans)

DC hybrid-π model: Small-signal




AC hybrid-π model: Small signal