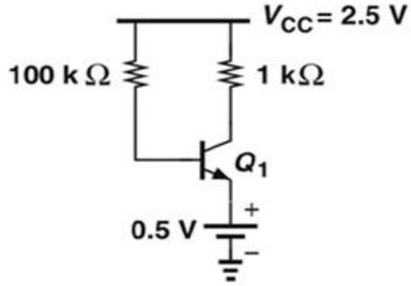
EE 101 Tutorial -4 BJT Amplifier (Solution)

1. Sol



$$V_{CC} - I_B(100\text{ k}\Omega) = V_{BE} + 0.5\text{ V}$$

$$V_{CC} - \frac{1}{\beta} I_C(100\text{ k}\Omega) = V_T \ln(I_C/I_S) + 0.5\text{ V}$$

$$I_C = \boxed{1.262\text{ mA}}$$

$$V_{BE} = \boxed{738\text{ mV}}$$

$$V_{CE} = V_{CC} - I_C(1\text{ k}\Omega) - 0.5\text{ V}$$

$$= \boxed{738\text{ mV}}$$

Q_1 is operating at the edge of saturation.

2. Sol.

(a)

$$V_{CE} \geq V_{BE} \text{ (in order to guarantee operation in the active mode)}$$

$$V_{CC} - I_C(2\text{ k}\Omega) \geq V_{BE}$$

$$V_{CC} - I_C(2\text{ k}\Omega) \geq V_T \ln(I_C/I_S)$$

$$I_C \leq 886\ \mu\text{A}$$

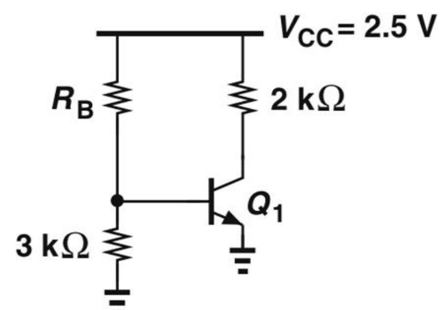
$$\frac{V_{CC} - V_{BE}}{R_B} - \frac{V_{BE}}{3\text{ k}\Omega} = I_B = \frac{I_C}{\beta}$$

$$\frac{V_{CC} - V_T \ln(I_C/I_S)}{R_B} - \frac{V_T \ln(I_C/I_S)}{3\text{ k}\Omega} = \frac{I_C}{\beta}$$

$$R_B\left(\frac{I_C}{\beta} + \frac{V_T \ln(I_C/I_S)}{3\text{ k}\Omega}\right) = V_{CC} - V_T \ln(I_C/I_S)$$

$$R_B = \frac{V_{CC} - V_T \ln(I_C/I_S)}{\frac{I_C}{\beta} + \frac{V_T \ln(I_C/I_S)}{3\text{ k}\Omega}}$$

$$R_B \geq \boxed{7.04\text{ k}\Omega}$$



(b)

$$\frac{V_{CC} - V_{BE}}{R_B} - \frac{V_{BE}}{3\text{ k}\Omega} = I_B = \frac{I_C}{\beta}$$

$$I_C = \beta \frac{V_{CC} - V_T \ln(I_C/I_S)}{R_B} - \beta \frac{V_T \ln(I_C/I_S)}{3\text{ k}\Omega}$$

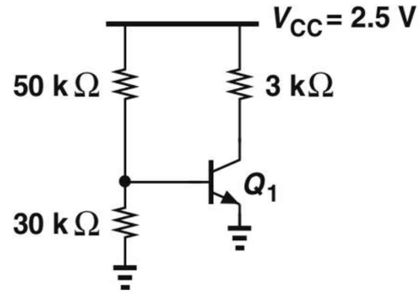
$$I_C = 1.14\text{ mA}$$

$$V_{BE} = 735\text{ mV}$$

$$V_{CE} = V_{CC} - I_C(2\text{ k}\Omega) = 215\text{ mV}$$

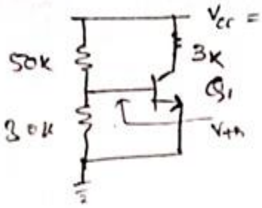
$$V_{BC} = V_{BE} - V_{CE} = \boxed{520\text{ mV}}$$

3.



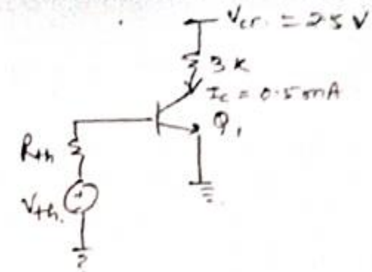
Sol.

Q. 3



Sol^n.

(a)



Given, $I_c = 0.5\ mA$.

$\beta = 100$

find I_s

$\rightarrow R_{th} = 30\ k \parallel 50\ K$

$= \left(\frac{30 \times 50}{80}\right) K = \boxed{18.75\ K}$

$\rightarrow V_{th} = \left(\frac{30}{30+50}\right) \times 2.5 = \boxed{0.9375}$

$\rightarrow I_c = \beta I_B$

$\Rightarrow I_B = 0.005\ mA$

$\rightarrow (V_{th} - V_{BE}) = I_B \times R_{th}$

$0.9375 - V_{BE} = 0.5 \times 10^{-5} \times 18.75 \times 10^3$

$\boxed{V_{BE} = 0.84375\ V}$

$\Rightarrow$

$\Rightarrow I_c = I_s\left(e^{V_{BE}/V_T}\right)$

$\Rightarrow I_s = \frac{I_c}{e^{(V_{BE}/V_T)}}$

$= \frac{0.5 \times 10^{-3}}{e^{(V_{BE}/0.025)}}$

$I_s = 4.03 \times 10^{-15}\ mA$.

(b) At the edge of saturation — $V_{BE} = V_{CE}$ (Soft saturation not allowed.)

$V_{CE} = 2.5 - I_c(3K)$

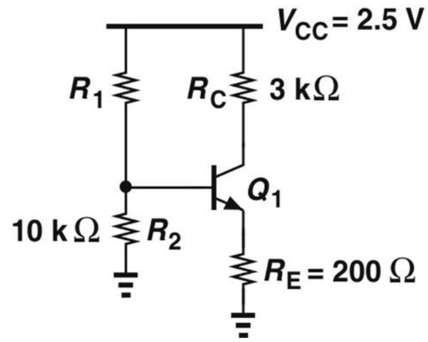
$I_c = \beta I_B = \beta\left(\frac{V_{th} - V_{BE}}{R_{th}}\right)$

$V_{BE} = 2.5 - \beta\left(\frac{V_{th} - V_{BE}}{R_{th}}\right) \times (3K)$

$\Rightarrow \boxed{V_{BE} = 0.83\ V}$

$I_s = \frac{I_c}{e^{V_{BE}/V_T}} = 7.84 \times 10^{-15}\ mA$.

4.



Sol. (a)

$$I_C = 0.25\ \text{mA}$$
$$V_{BE} = 696\ \text{mV}$$
$$\frac{V_{CC} - V_{BE} - I_E R_E}{R_1} - \frac{V_{BE} + I_E R_E}{R_2} = I_B = \frac{I_C}{\beta}$$
$$R_1 = \frac{V_{CC} - V_{BE} - \frac{1+\beta}{\beta} I_C R_E}{\frac{I_C}{\beta} + \frac{V_{BE} + \frac{1+\beta}{\beta} I_C R_E}{R_2}}$$
$$= \boxed{22.74\ \text{k}\Omega}$$

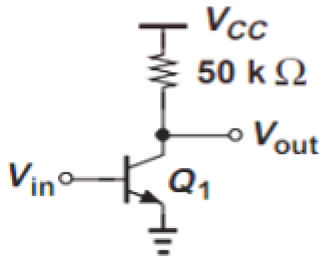
(b) First, consider a 5 % increase in R_E.

$$R_E = 210\ \Omega$$
$$\frac{V_{CC} - V_{BE} - I_E R_E}{R_1} - \frac{V_{BE} + I_E R_E}{R_2} = I_B = \frac{I_C}{\beta}$$
$$\frac{V_{CC} - V_T \ln(I_C/I_S) - \frac{1+\beta}{\beta} I_C R_E}{R_1} - \frac{V_T \ln(I_C/I_S) + \frac{1+\beta}{\beta} I_C R_E}{R_2} = I_B = \frac{I_C}{\beta}$$
$$I_C = 243\ \mu\text{A}$$
$$\frac{I_C - I_{C,nom}}{I_{C,nom}} \times 100 = \boxed{-2.6\ \%}$$

Now, consider a 5 % decrease in R_E.

$$R_E = 190\ \Omega$$
$$I_C = 257\ \mu\text{A}$$
$$\frac{I_C - I_{C,nom}}{I_{C,nom}} \times 100 = \boxed{+2.8\ \%}$$

5. So



$A_V = g_m R_C = 20$

$\frac{I_C R_C}{V_T} = 20 \Rightarrow I_C = \frac{20 V_T}{R_C}$

$I_C = 0.0104 mA$

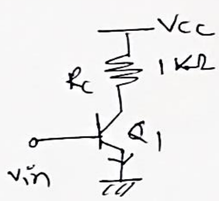
$V_{CC} - (50k\Omega)(0.0104mA) = V_{BE}$

$\Rightarrow V_{CC} - 50 \times 0.0104 V = 0.8 V$

$\Rightarrow V_{CC} = 1.32 V$

6. Sol.

6



Given $I_C = I_S e^{\frac{V_{BE}}{2V_T}}$.

$I_C = 1mA$.

$A_V = ?$

Now we know that $A_V = g_m R_{out}$ (from small signal analysis)

$A_V = g_m R_C$.

We also know that $g_m = \frac{\partial I_C}{\partial V_{BE}}$

$g_m = \frac{I_S}{2V_T} e^{\frac{V_{BE}}{2V_T}}$

$g_m = \frac{I_C}{2V_T}$.

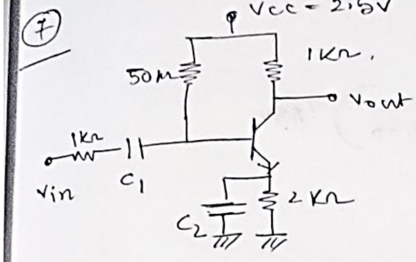
$\therefore A_V = \frac{I_C}{2V_T} \times R_C$

$A_V = \frac{1\times10^{-3}}{2\times 26\times10^{-3}} \times 1\times10^{3}$

$\boxed{A_V = 19.23}$.

7. Sol.

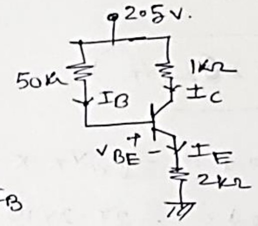
7



Given $\beta = 100$.

$I_S = 6 \times 10^{-16}$ A., $V_A = \infty$.

Lets first do the Dc analysis of the circuit,



$I_E = I_B + I_C$

$I_E = \frac{I_C}{\beta} + I_C$

$$\boxed{I_E = I_C\left(1+\frac{1}{\beta}\right)} \quad \text{—(1)}$$

Then, Apply KVL,

$$2.5 = (50 \times 10^3) I_B + V_{BE} + (2 \times 10^3) I_E.$$

$$\Rightarrow 2.5 = (50 \times 10^3)\frac{I_C}{\beta} + V_T \ln\left(\frac{I_C}{I_S}\right) + (2 \times 10^3) I_C\left(1+\frac{1}{\beta}\right)$$

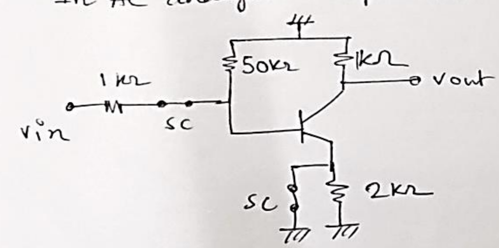
solving this Transedental equation we will get,

$$I_C = 708\,\mu A$$

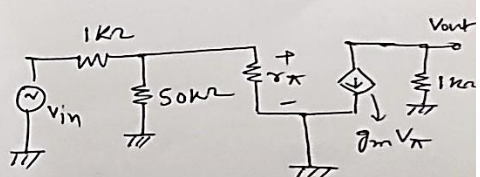
Now, $g_m = \frac{I_C}{V_T} = \frac{708 \times 10^{-6}}{26 \times 10^{-3}} = 27.2 \times 10^{-3}$ S.

Now to get the voltage gain lets do the Ac analysis

In Ac analysis capacitor will provide less reactance path,



small signal model $\Longrightarrow$

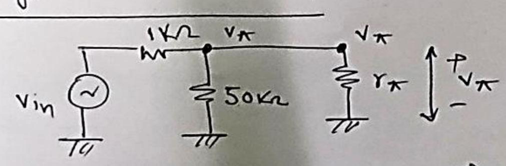


Lets work on output side loop, Apply KCL

$$g_m V_\pi = -\frac{V_{out}}{1 \times 10^3}$$

$$\boxed{V_{out} = -g_m V_\pi \times 10^3} \text{—(2)}$$

Lets go to input side loop:-



Apply Nodal analysis,

$$\frac{V_{in} - V_\pi}{1 \times 10^3} = \frac{V_\pi}{50 \times 10^3} + \frac{V_\pi}{r_\pi}$$

$$\Rightarrow V_{in} = 10^3\left(\frac{1}{10^3} + \frac{1}{50 \times 10^3} + \frac{1}{r_\pi}\right) V_\pi$$

$r_\pi = \frac{\beta}{g_m} = \frac{100}{27.2\times10^{-3}} = 3676.470.$

$$v_{in} = 10^3\left(\frac{1}{10^3} + \frac{1}{56\times10^3} + \frac{1}{3676.470}\right) v_\pi$$

$v_{in} = 1.262\, v_\pi$

using ②, $v_{out} = -g_m v_\pi \times 10^3$

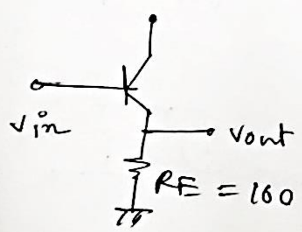
$$v_{out} = -27.2\times10^{-3}\times10^3\times\frac{v_{in}}{1.292}$$

$$\frac{v_{out}}{v_{in}} = -\frac{27.2\times10^{-3}\times10^3}{1.262} = -21.55.$$

$\boxed{A_v = -21.55}$

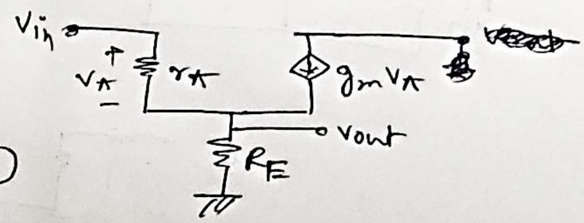
8. Sol.

⑧



Given $A_v = 0.8$.

Lets do the small signal modeling of the ckt,



KVL,

$v_{in} = v_\pi + v_{RE}$ — ①

$v_{RE} = v_{out}$ — ②

KCL, $\frac{v_\pi}{r_\pi} + g_m v_\pi = I_E \Rightarrow \frac{v_\pi}{r_\pi} + g_m v_\pi = \frac{v_{out}}{R_E}$

∴ $\cancel{v_{in} = v_\pi + \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E} \Rightarrow v_\pi = \left(\frac{r_\pi}{\beta+1}\right)\frac{v_{out}}{R_E}.$

From (1) & (3),

$$V_{in} = V_\pi + V_{out}$$

$$\Rightarrow V_{in} = \left(\frac{r_\pi}{\beta+1}\right)\frac{V_{out}}{R_E} + V_{out}$$

$$\Rightarrow \boxed{A_V = \frac{V_{out}}{V_{in}} = \frac{1}{1+\left(\frac{r_\pi}{\beta+1}\right)\frac{1}{R_E}}} \xrightarrow{\text{upon}}$$ simplification.

Let $\beta \gg 1$

$\therefore \beta+1 \rightarrow \beta$.

$$\boxed{A_V = \frac{1}{1+\left(\frac{r_\pi}{\beta}\right)\frac{1}{R_E}}}$$

We know that,

$$r_\pi = \frac{\beta}{g_m} \Rightarrow \frac{r_\pi}{\beta} = \frac{1}{g_m}$$

Therefore,

$$A_V = \frac{1}{1+\frac{(1/g_m)}{R_E}}$$

$$\boxed{A_V = \frac{R_E}{R_E + 1/g_m}}$$

$$\therefore A_V = \frac{R_E}{R_E + 1/g_m}$$

Again,

$$g_m = \frac{I_c}{V_T}$$

$$V_T = 26\times10^{-3}.$$

$$\Rightarrow 0.8 = \frac{100}{100 + \frac{V_T}{I_c}}.$$

upon solving,

$$\boxed{I_c = 1.04\ mA.}$$