24.11.2023

BJT Amplifier : DC and AC Analysis

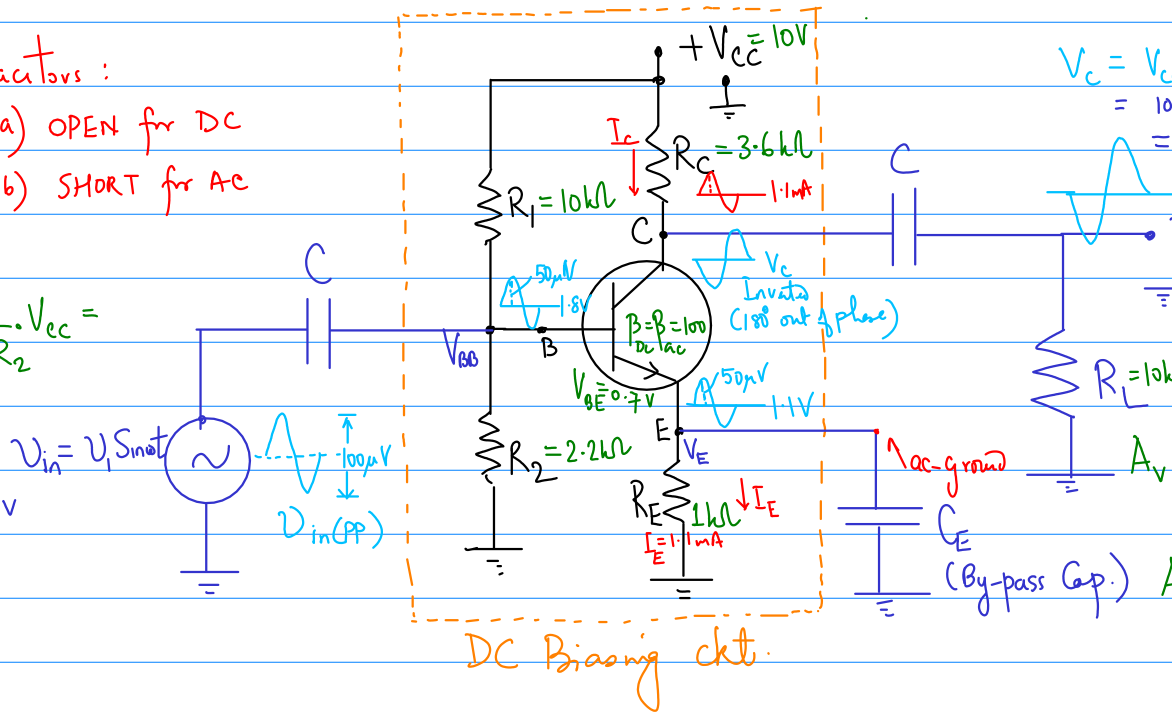
Common Emitter (CE) Amplifier Circuit :

Capacitors :

a) OPEN for DC

b) SHORT for AC

$V_{BB} = \frac{R_2}{R_1+R_2} \cdot V_{cc} =$



$V_c = V_{cc} - I_c R_c$

$= 10V - (1.1mA)(3.6k\Omega)$

$= 6.04V$

$v_o = v_2 \sin\omega t$

$R_L = 10k\Omega$

$v_1 = 100\mu V$ (pp)

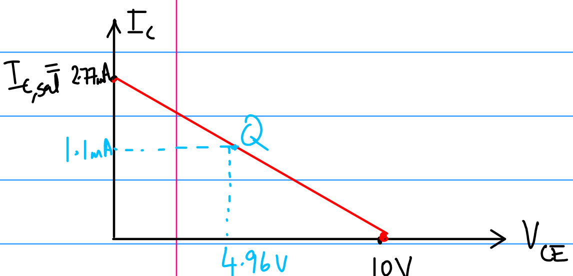
$v_2 = 100mV$ (pp)

$A_v = \frac{v_2}{v_1} = \frac{100mV}{100\mu V}$

$A_v = \frac{v_2}{v_1} = 1000$

$V_{CE} = 6.04 - 1.1V$

$V_{CE} = 4.96V$

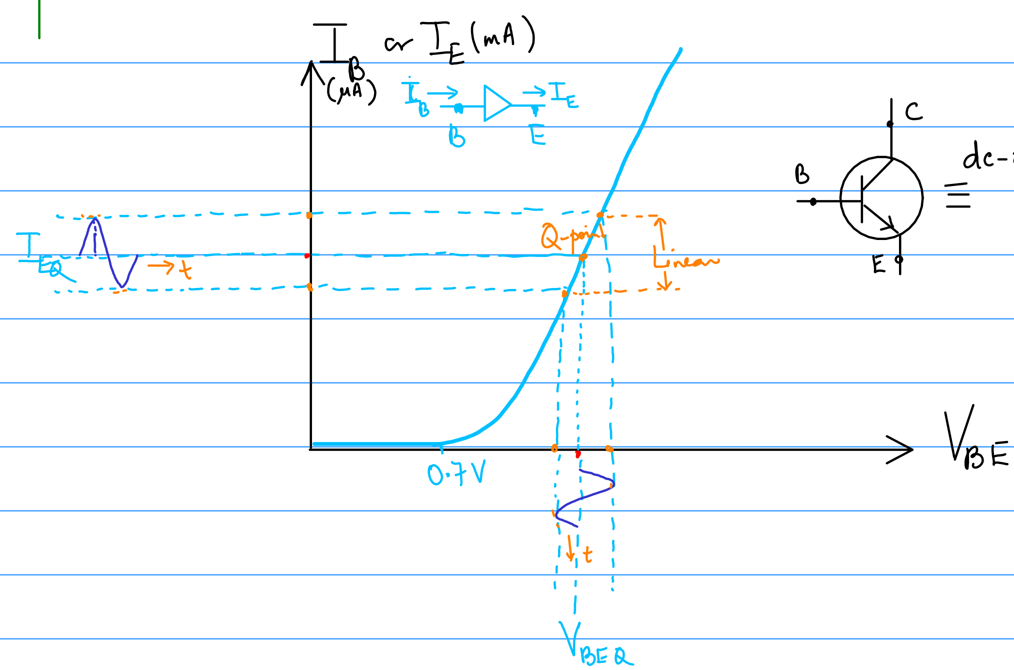


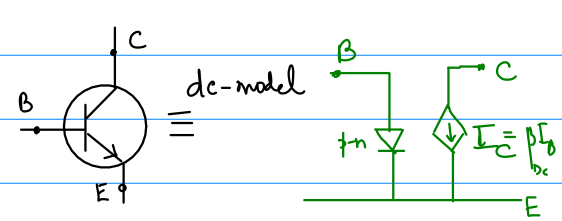
– Voltage gain = 1000

Input Characteristics :

$I_E = I_B + I_C$; $I_E \approx I_C$

$I_E \propto I_B$





at any instant of time 't';

$$\underbrace{i_E}_{\text{Total-Current}} = \underbrace{I_{EQ}}_{\text{DC-current}} + \underbrace{i_e}_{\text{ac-current}}$$

$$\underbrace{v_{BE}}_{\text{Total Base-Emitter voltage}} = \underbrace{V_{BEQ}}_{\text{DC}} + \underbrace{v_{be}}_{\text{ac}}$$

Here, we define ac-resistance of the base-emitter diode:

→ prime indicates that the resistance is within the transistor ie, virtual.

ac-Emitter Resistance $r_e' = \dfrac{v_{be}\ \text{(ac-voltage)}}{i_e\ \text{(ac-current)}}$

example at instant of time $\left.\begin{aligned} v_{be} &= 5\,mV \\ i_e &= 200\,\mu A \end{aligned}\right\}$ $r_e' = \dfrac{5\,mV}{200\,\mu A} = 25\,\Omega$

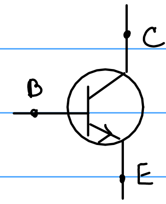
Note: There is a standard formula to determine the value of ac-emitter resistance (or, resistance of the base-emitter diode)

$$\boxed{r_e' = \frac{25\,mV}{I_E}}$$

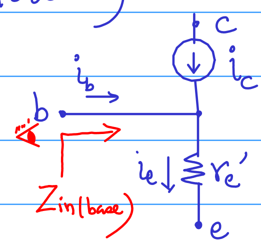
where, I_E is the dc emitter-current.

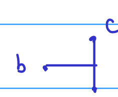
Transistor ac circuit Model:

1 T-model (Eber-Moll Model): Base-Emitter Diode → ac-emitter resistor



ac-equivalent ≡ ckt Model





(inverted T)

$i_e \approx i_b + i_c$

$i_e \approx i_c = \beta_{ac} i_b$

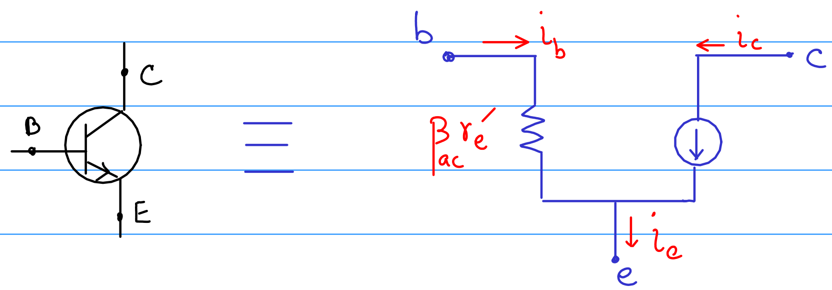
Input impedance as seen from the base terminal

$$Z_{in(base)} = \frac{v_{be}}{i_b} = \frac{i_e r_e'}{i_b} = \frac{i_c r_e'}{i_b} = \beta_{ac} r_e'$$

where, $\beta_{ac} = \dfrac{i_c}{i_b}$

$$\boxed{Z_{in(base)} = \beta_{ac} r_e'}$$

(2) **Π-Model :** (Visual representation of $Z_{in(base)}$)



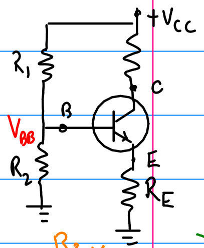
Note: Both the T- and Π-model are equivalent ac-circuit model of a BJT.

Analysis of a given CE Amplifier (Both DC & AC).

We apply superposition theorem:

That is, effect of each sources acting alone is added to get the total effect of all the sources acting simultaneously.

① DC-Analysis : DC-equivalent ckt.



- Mentally "OPEN" all the capacitors.
- Determine the operating point (Q-point).
  - V_{CEQ}, I_{CQ}.
- Determine $\underbrace{r_e'}_{\text{ac-emitter resistance}} = \dfrac{25mV}{I_E}$

$V_{BB} = \dfrac{R_2 V_{CC}}{R_1 + R_2}$

✓ $V_E = V_{BB} - V_{BE}$

✓ $I_E = \dfrac{V_E}{R_E}$

$I_C \approx I_E$

✓ $V_C = V_{CC} - I_C R_C$

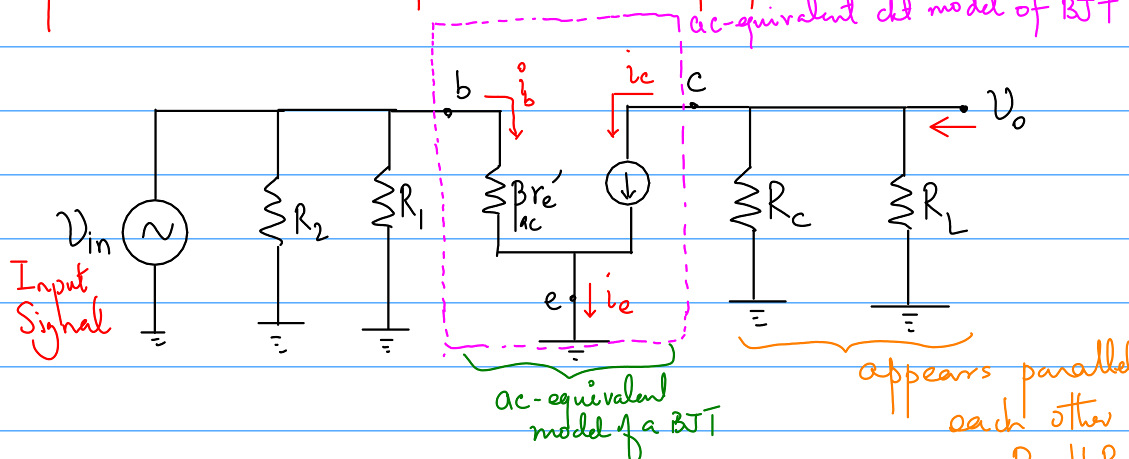
$V_{CE} = V_C - V_E$

Q-point (V_{CEQ}, I_{CQ})

② AC-Analysis :

- for all ac current, dc source acts as a 'SHORT'
- 'SHORT' all the capacitors
- Replace the BJT with equivalent ac-ckt model (ie, either T or π)!

ac-equivalent ckt. of the CE Amplifier :



$r_c = R_L \parallel R_c = \dfrac{R_L R_c}{R_L + R_c}$

$v_{in} = i_b \cdot Z_{in(base)} = i_b \beta_{ac} r_e'$

$v_o = i_c r_c$

We define voltage gain $A_v = \dfrac{v_o}{v_{in}} = \dfrac{\cancel{i_c} r_c}{\cancel{i_b \beta_{ac}} r_e'}$

Voltage Gain $\boxed{A_v = \dfrac{r_c}{r_e'}}$

$r_c = R_c \| R_L$

$r_e' = \dfrac{25\,mV}{I_E}$

From the given CE amplifier ckt.

$$r_c = \frac{R_L \cdot R_c}{R_L + R_c} = \frac{10k\Omega \times 3.6k\Omega}{10k\Omega + 3.6k\Omega}$$

$$r_c = \frac{36(k\Omega)^2}{13.6k\Omega} = 2.64\,k\Omega$$

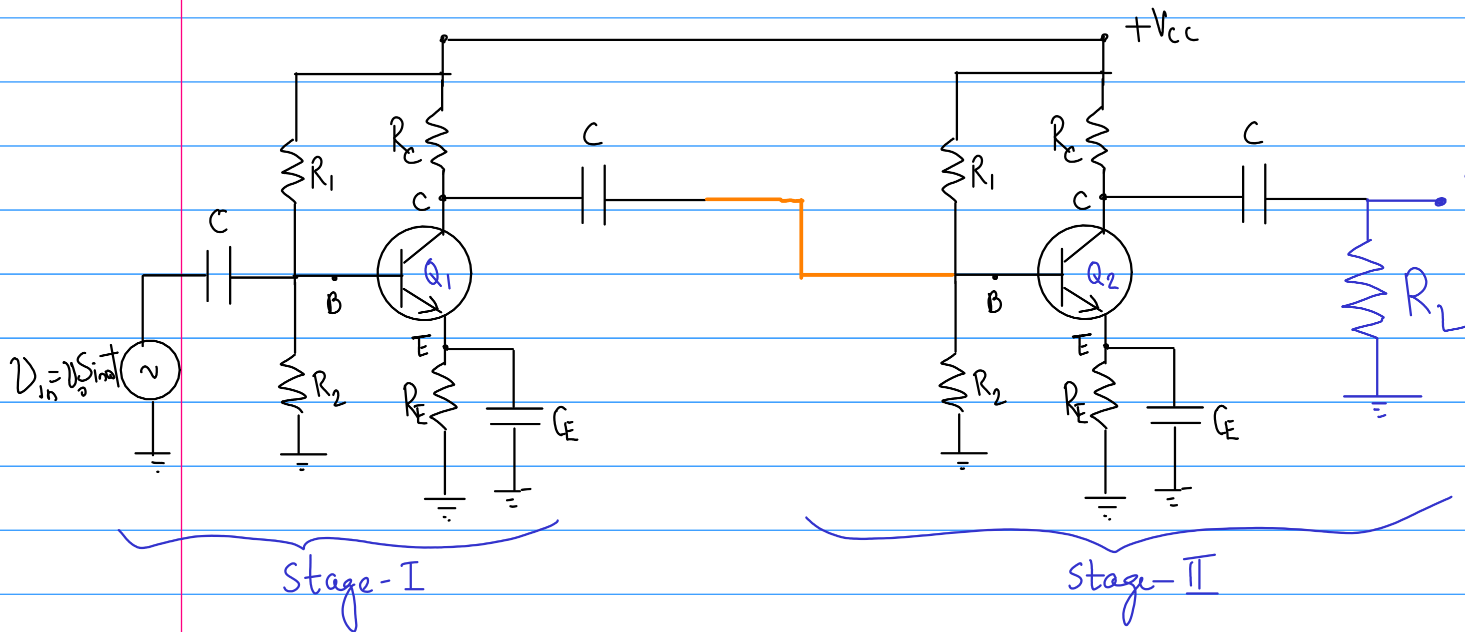
Now, $r_e' = \dfrac{25\,mV}{I_E} = \dfrac{25\,mV}{1.1\,mA} = 22.7\,\Omega$

Therefore, Voltage gain $A_v = \dfrac{r_c}{r_e'} = \dfrac{2.64\,k\Omega}{22.7\,\Omega}$

$$A_v = \frac{2640}{22.7} \approx 110$$

$\boxed{A_v = 110}$ $\Rightarrow$ If the amplitude of the input signal is $1\mu V$ then the amp. of output signal is $110\mu V$ (0.11 mV)

Multi-stage (eg. Two-stage) direct coupled CE Amplifier:



A_{v1} $\qquad\qquad$ A_{v2}

Overall voltage gain $A_v = A_{v_1} \cdot A_{v_2}$

Similarly, if there 'n' no. of stages, we have

$$A_v = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots\cdots A_{v_n}$$

Let $A_{v_1} = 100$ & $A_{v_2} = 200$

$$A_v = 100 \times 200 = 20000 = 2 \times 10^4$$

Also, voltage gain is defined in unit of decibel (dB)

$$A_v(\text{dB}) = 20 \log_{10} A_v$$

If $A_v = 100$ then

$$A_v(dB) = 20 \log_{10} 100 = 40dB$$

Similarly, if $A_v = 1000$

$$A_v(dB) = 20 \log_{10} 1000 = 60dB$$

For $A_v = 120dB$, $A_v = 10^6$

$$\Rightarrow \frac{v_o}{v_{in}} = 10^6$$

Determine A_v if the $A_v(\text{in} dB) = 3dB$

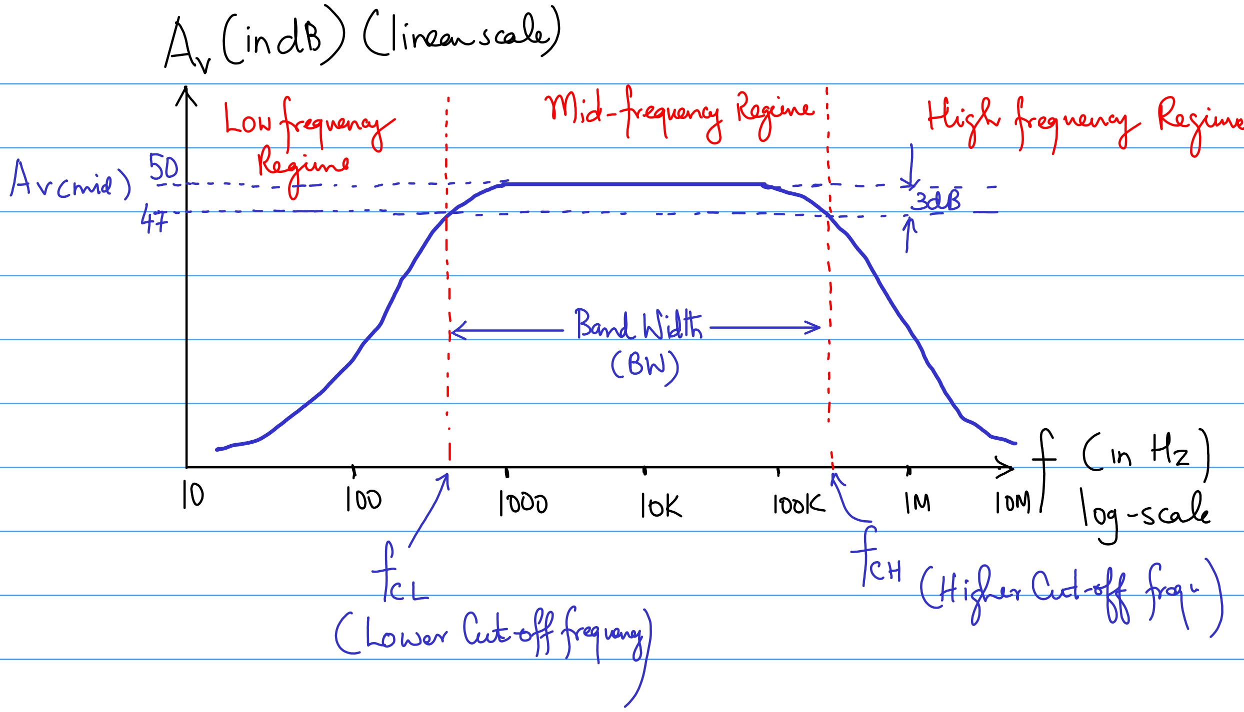
$$A_v = 1.414 = \sqrt{2}$$

$$\frac{v_o}{v_{in}} = \sqrt{2} \Rightarrow v_o = \sqrt{2}\, v_{in}$$

Determine A_v if the $A_v(\text{in} dB) = -3dB$

$$A_v = 0.707 = \frac{1}{\sqrt{2}}$$

$$\frac{v_o}{v_{in}} = \frac{1}{\sqrt{2}} \Rightarrow v_o = \frac{1}{\sqrt{2}} v_{in}$$



$$B.W = f_{CH} - f_{CL} \quad \text{— (1)}$$

$$(\text{Gain}) \times (B.W) = \text{Constant} \quad \text{— (2)}$$