Module – 3
Unit – 3
Small Signal BJT Amplifiers

Review Questions:

1. Define $h$ – parameters for a transistor. Why are these called hybrid parameters? What are their units?
2. Out of four $h$ – parameters, two are most important. Which are these? And why the other two have less significance?
3. $h_i$ and $Z_i$ both represent input impedance in $h$ - and $Z$ systems of parameters but they are most equal. Why?
4. What are $r$ – parameters and how are they superior to $h$ – parameters?
5. Common – base (CB) amplifier has limited applications. Why?
6. Among BJT amplifiers, common-emitter amplifier is most favoured. Give reasons.
7. What is an emitter follower? Discuss its main applications.
8. What are, in general, performance parameters of an amplifier?
Problems:

3.1 Calculate dynamic emitter resistance $r'_e$ (also called ac emitter resistance) of the transistor in the circuit of fig. ($V_{BE} = 0.7V$)
Solution:-

The dynamic emitter resistance, $r'_e$, is expressed as,

$$r'_e = \frac{25\text{mV}}{I_E}$$

Where $I_E$ is dc emitter current.

The dc emitter current in the circuit (i.e, voltage drop across resistor $R_E$, divided by the resistance) is

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{5 - 0.7}{4.3\times10^3} = 1\text{mA}$$

Therefore,

$$r'_e = \frac{25\text{mV}}{1\text{mA}} = 25\Omega$$

That is,

$$r'_e = 25\Omega$$
3.2 How much is the voltage gain of the amplifier (fig) if the dynamic emitter resistance, $r'_e$, is 25 $\Omega$. The current gain of the transistor is 80.

How much is input impedance of the amplifier.

The coupling and bypass capacitors may be assumed of negligible impedance at the signal frequency. Take $V_{BE} = 0.7V$
Solution:-

The voltage gain $A_v$, for a common emitter amplifier with resistor $R_E$ by-passed is

$$A_v = \frac{r_c}{r'_c}$$

Where $r_c$ is effective (ac) impedance seen by the collector and it is

$$r_c = R_c \parallel R_L = 5k \parallel 5k = 2.5 \, \text{kΩ}$$

And $r'_c = 25\Omega$ (given)

Therefore,

$$A_v = \frac{2.5 \times 10^3 \, \Omega}{25\Omega} = 100$$

First we find out impedance between base (point A in Fig 3.2) and ground, $Z_{(\text{base})}$ and we know, it is given by

$$Z_{(\text{base})} = \beta \cdot r'_c$$

$$= 80 \times 25$$

or $Z_{(\text{base})} = 2 \, \text{kΩ}$

And, input impedance of the amplifier $Z_{(\text{amp})}$ is,

$$Z_{(\text{amp})} = R_B \parallel Z_{(\text{base})}$$

Where $R_B$ is effective biasing resistance, and

$$R_B = R_1 \parallel R_2 = 12k \parallel 6k = 4 \, \text{kΩ}$$

Therefore,

$$Z_{(\text{amp})} = 4k \parallel 2k$$

or $Z_{(\text{amp})} = 1.33 \, \text{kΩ}$
3.3 Calculate the value of resistor $R_C$ so that the voltage gain of the amplifier in fig is 100. Capacitors $C_1$, $C_2$, and $C_3$ may be assumed short at signal frequency.
Solution:-

In case, $R_E$ is by-passed, the voltage gain $A_v$ of the amplifier is,

$$A_v = \frac{r_c}{r'_e}$$

Where $r_c$ is the effective (ac) resistance seen by the collector of the transistor, and $r'_e$ is the dynamic resistance of the emitter.

We know,

$$r'_e = \frac{25 \text{mV}}{I_E}$$

Now,

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{12.0 - 0.7}{5 \times 10^3} = 2.26 \text{mA}$$

Therefore,

$$r'_e = \frac{25 \text{mV}}{2.26 \text{mA}} \approx 11 \Omega = 0.011 \text{k}

And,

$$R_c = R_o \left| R_L = \frac{4R_c}{R_c + 4}$$

Where resistances have been taken in kΩ

Therefore,
\[ A_v = \frac{r_c}{r'_c} \]

\[ = \left( \frac{4R_c}{R_c + 4} \right) \frac{1}{0.011} \]

As \( A_v = 100 \) (given), \( R_c \) (in k\( \Omega \)) is,

\[ 100 = \frac{4R_c}{(R_c + 4)(0.011)} \]

or \( R_c = 1.51 k\Omega \)
3.4 Find out the smallest value of load $R_L$ in the amplifier circuit shown in fig so that the voltage gain is at least 40. The dynamic emitter resistance of the transistor is 25 $\Omega$. The coupling and by-pass capacitors may be assumed short at signal frequency.
Solution:-

The voltage gain of the common emitter amplifier with resistor $R_E$ by-passed (see fig.) is expressed as

$$A_v = \frac{r_c}{r_e} = 40 \ (\text{required gain})$$

Where $r_c$ is effective ac impedance seen by the collector, Which is

$$r_c = R_C || R_L = \frac{R_c R_L}{R_c + R_L}$$

Taking resistances in kΩ

$$r_c = \frac{3R_L}{3 + R_L}$$

And,

$$A_v = \left( \frac{3R_L}{3 + R_L} \right) \frac{1}{25 \times 10^{-3}} = 40$$

or $R_L = 1.5 kΩ$
The silicon transistor in the common-base amplifier has the current gain $\alpha$ of 0.98. Find the input impedance and voltage gain of the amplifier in Fig. \((V_{BE} = 0.7V)\)
Solution:-

The dc voltage sources have to be grounded for ac analysis of the amplifier. Then the input impedance of the CB amplifier (in fig.) is

\[ Z_{(amp)} = R_E \parallel r'_e \approx r'_e \]

Where \( r'_e \) is dynamic emitter resistance and \( r'_e \ll R_E \)

Also,

\[ r'_e = \frac{25mV}{I_E} \]

Where \( I_E \) is dc emitter current in the circuit

\[ I_E = \frac{|V_{EE} - V_{BE}|}{R_E} \]

or, \( I_E = \frac{9 - 0.7}{6 \times 10^3} = 1.38 \ mA \)

Therefore,

\[ r'_e = \frac{25mV}{1.38mA} \approx 18\Omega \]

Thus, the input impedance \( Z_{(amp)} \) is,

\[ Z_{(amp)} = r'_e = 18\Omega \]

The low value of input impedance is the main reason for limited applications of CB amplifier.

The voltage gain of CB amplifier is expressed as,

\[ A_v = \frac{\alpha r_e}{r'_e} \]

Since, \( r_e = R_C \parallel R_L = 4k \parallel 4k = 2k\Omega = 2000 \ \Omega \)

Then,

\[ A_v = \frac{0.98 \times 2000}{18} = 108.8 \]

\[ A_v = 108.8 \]
3.6 The transistor in the amplifier circuit shown in fig, has h – parameters, $h_{ie} = 2k\Omega$ and $h_{fl} = 80$. The values of $h_{be}$ and $h_{re}$ are negligible. Calculate the voltage gain and input impedance $Z_{i(amp)}$ of the amplifier. Capacitors $C_1$, $C_2$, and $C_3$ may be assumed short at signal frequency due to small impedances.
Solution:-

The magnitude of voltage gain with h-parameters $h_{oe}$ and $h_{re}$ dropped, and emitter resistance $R_E$ by-passed by capacitor $C_3$ is

$$A_v = \frac{h_{fe} \cdot Z_i}{h_{ie}}$$

$$= \frac{80 \times 3k\Omega}{2k\Omega} = 120$$

Because the ac load at collector, $Z_l$, is

$$Z_l = R_C \parallel R_L = 6k \parallel 6k = 3k\Omega$$

Further, the impedance between base and ground, $Z_{i(base)}$, is,

$$Z_{i(base)} = h_{ie} = 2k\Omega$$

And, input impedance of amplifier, $Z_{i(amp)}$ is,

$$Z_{i(amp)} = R_1 \parallel R_2 \parallel Z_{i(base)}$$

$$= 20k \parallel 20k \parallel Z_{i(base)}$$

$$= 10k \parallel Z_{i(base)}$$

$$= 10k \parallel 2k$$

$$= 1.6k\Omega$$

or $Z_{i(amp)} = 1.6k\Omega$
3.7 For the amplifier circuit shown in fig. calculate the voltage gain and input impedance of the amplifier when by-pass capacitor $C_3$ is removed from the circuit.
Solution:-

With by-pass capacitor $C_3$ (in fig.) removed, the gain of a amplifier falls and input impedance of the amplifier increases.

In case $R_E$ is not by-passed, the magnitude of voltage gain $A_V$ is

$$A_V = \frac{Z_i}{R_E} = \frac{3k}{2k} = 1.5$$

And,

$$Z_{(\text{base})} = h_{ie} + (1 + h_{ie}) R_E$$
$$= 2k + (1 + 80) \times 2k$$

Or, $Z_{(\text{base})} = 164 \text{ k}\Omega$

And, input impedance of amplifier, $Z_{(\text{amp})}$ is

$$Z_{(\text{amp})} = R_1 \parallel R_2 \parallel Z_{(\text{base})}$$
$$= 20k \parallel 20k \parallel 164k$$
$$= 10k \parallel 164k = 9.4 \text{ k}\Omega$$

or $Z_{(\text{amp})} = 9.4 \text{ k}\Omega$
The emitter follower (common collector amplifier) shown in fig. uses a transistor with h-parameters $h_{ie} = 4.5 \, \text{k}\Omega$, $h_{re} = 120$. Other parameters $h_{oe}$ and $h_{re}$ have negligible effect on amplifier performance. Calculate voltage gain and input impedance of the amplifier. The coupling and by-pass capacitors may be assumed short at signal frequency.
Solution:-

Neglecting the effect of $h_{oe}$ and $h_{re}$ on amplifier performance, the voltage gain of emitter follower may be expressed as,

$$|A_v| = \frac{h_{fe} \times Z_e}{h_{ic} + h_{fe} \cdot Z_e}$$

Where $Z_e$ is the effective load seen by the emitter, and it is

$$Z_e = R_E \parallel R_L = 3k \parallel 6k = 2 \text{k}\Omega$$

And using $h_{ic} \approx h_{fe}$ and $h_{ic} = h_{re}$,

We have,

$$A_v = \frac{h_{fe} \times Z_e}{h_{ic} + h_{fe} \cdot Z_e}$$
$$= \frac{120 \times 2 \text{k}\Omega}{4 \text{k}\Omega + (120 \times 2 \text{k}\Omega)} = \frac{240}{244}$$

$$A_v = 0.98$$

The input impedance as seen at the base w.r.t ground is,

$$Z_{i(base)} = h_{ic} \cdot Z_e = h_{re} \cdot Z_e$$
$$= 120 \times 2 \text{k}\Omega = 240 \text{k}\Omega$$

The input impedance of the amplifier (that is, after taking the effect of biasing resistors),

$$Z_{i(amp)} = R_B \parallel Z_{i(base)}$$

And the effective base resistance $R_B$ is,

$$R_B = R_1 \parallel R_2 = 60 \text{k} \parallel 30 \text{k} = 20 \text{k}\Omega$$

Therefore,

$$Z_{i(amp)} = 20 \text{k} \parallel 240 \text{k} = 18.46 \text{k}\Omega$$

or $Z_{i(amp)} = 18.46 \text{k}\Omega$