UNIT 4

ANALYSIS AND DESIGN OF SMALL SIGNAL LOW FREQUENCY BJT AMPLIFIERS

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. What is meant by small signal for analyzing a BJT based amplifier?

Model Paper-I, Q1(g)

Ans:

The small amplitude A.C input signals applied to an amplifier are called small signals. These signals are assumed as voltage signals and are used to drive the large current signals. These signals are used for the analyzation of BJT amplifier when it is operating in active region. Their amplitude is less than 0.3 V. The output of an amplifier is not distorted because the signals used always lie in the active region.

Q2. Write the voltage and current equation for hybrid parameters.

Ans:

V-I equations for two port network are,

$$V_1 = h_{11}\, i_1 + h_{12}\, V_2$$

$$i_2 = h_{21}\, i_1 + h_{22}\, V_2$$

Where, h_{11}, h_{12}, h_{21} and h_{22} are the hybrid parameters.

Q3. Define the four h-parameters.

Ans:

Hybrid parameters or h-parameters are used to analyse the characteristics of BJT and FET amplifiers.

The h-parameters of an amplifier are defined as follows.

1. **Input Impedance, h_{11}:** It is the ratio of input voltage to input current i.e., $h_{11} = V_i/i_i$
2. **Output Admittance, h_{22}:** It is the ratio of output current to output voltage i.e., $h_{22} = i_i/V_o$
3. **Reverse Voltage Gain, h_{12}:** It is the ratio of input voltage to output voltage i.e., $h_{12} = V_i/V_o$
4. **Forward Current Gain, h_{21}:** It is the ratio of output current to input current i.e., $h_{21} = i_o/i_i$

Q4. What is the significance of h-parameters.

Model Paper-II, Q1(g)

Ans:

h-parameters plays a vital role in small signal frequency analysis of transistors. It determines the system performance by calculating output gain. They are also best suited for circuits having small voltages and small currents.

Q5. Draw the h-parameter equivalent circuits for CE and CB configuration.

Ans:

Low Frequency Hybrid Equivalent Circuit for CE Amplifier

Figure (1) shows the low frequency hybrid equivalent circuit for Common Emitter (CE) amplifier.

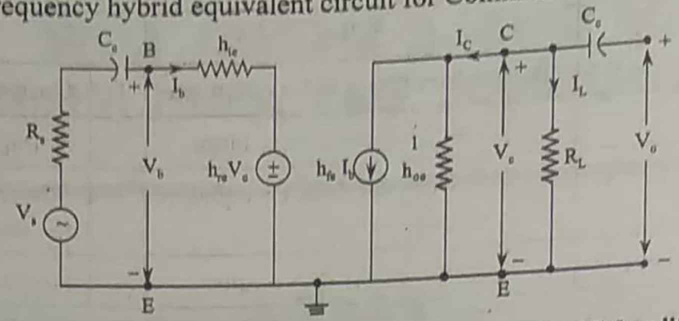


Figure (1): Low Frequency Hybrid Equivalent Circuit for CE Amplifier

Low Frequency Hybrid Equivalent Circuit for CB Amplifier

Figure (2) shows the low frequency hybrid equivalent circuit for Common Base (CB) amplifier.

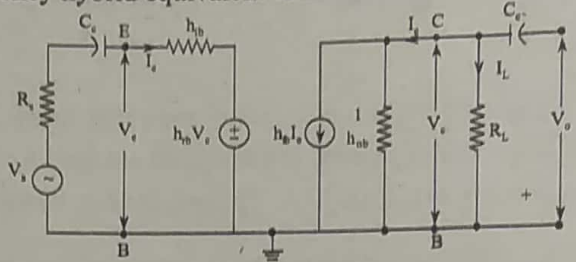


Figure (2): Low Frequency Hybrid Equivalent Circuit for CB Amplifier

Q6. List the benefits of h-parameters.

Ans: Model Paper-III, Q1(g)

Analyzing the circuits (i.e., transistor circuits) using h-parameters has following advantages,

1. h-parameters are very easy to measure.
2. These parameters can be easily determined using the transistor static characteristic curves.
3. In circuit analysis and design, these parameters are very convenient to use.
4. h-parameters in one configuration can be easily converted into other configuration.
5. These parameters are readily supplied by manufacturers.

Q9. Compare the characteristics of CE, CB and CC amplifiers.

Ans:

The comparison between characteristics of CE, CB and CC amplifiers is mentioned below.

	CE		CB		CC
1.	It has high current gain	1.	Current gain is less than one	1.	Current gain is large
2.	It has high voltage gain	2.	Voltage gain is very large	2.	Voltage gain is approximately one
3.	Since A_v and A_I are large, power gain is also high.	3.	Power gain is nearly equal to voltage gain	3.	Power gain is approximately equal to current gain
4.	The phase shift in output is 180°	4.	No phase shift in output	4.	No phase shift in output

Q10. A common emitter amplifier has an input resistance 2.5 kΩ and voltage gain of 200. If the input signal volume is 5 mV. Find the base current of the amplifier.

Ans:

Model Paper-II, Q1(h)

Given that,

For a common emitter amplifier,

Input resistance, $R_{in} = 2.5$ kΩ

Source voltage, $V_S = 5$ mV

Voltage gain, $A_V = 200$

Base current, $I_B = ?$

The voltage gain of common-emitter amplifier is defined by,

$$A_V = \beta \frac{R_{out}}{R_{in}}$$

Here,

$$R_{out} = R_C \text{ and } \beta = \frac{I_C}{I_B}$$

$$\Rightarrow \quad A_V = \frac{I_C R_C}{I_B R_{in}}$$

$$I_C \simeq I_E = \frac{V_S}{R_{in}} = \frac{5\times10^{-3}}{2.5\times10^{3}}$$

$$= 2\ \mu A$$

Assuming, $R_C = 1$ kΩ

$$I_B = \frac{2\times10^{-6}\times1\times10^{3}}{200\times2.5\times10^{3}}$$

$$= 4\times10^{-9}\ A$$

$\therefore$ $\boxed{\text{Base current, } I_B = 4 \text{ nA}}$

Q11. Why h-parameter model is not suitable for the analysis of high frequency response of the amplifier?

Ans:

Model Paper-III, Q1(h)

The h-parameter model is suitable only to analyze low frequency response of amplifiers. This analysis is carried out by neglecting the effect of shunt capacitance in the transistor due to instantaneous response to variations in input current or voltage. It is not suitable for the analysis of high frequency response of the amplifier because,

The values of h-parameters become complex at high frequencies.

At high frequencies the values of h-parameters change and hence it is required to analyze the transistor at each and every range of frequency. In practice, it is not possible to analyze the transistor at each and every range of frequency.

PART-B

ESSAY QUESTIONS WITH SOLUTIONS

4.1 TRANSISTOR HYBRID MODEL, DETERMINATION OF h-PARAMETERS FROM TRANSISTOR CHARACTERISTICS, TYPICAL VALUES OF h-PARAMETERS IN CE, CB AND CC CONFIGURATIONS, TRANSISTOR AMPLIFYING ACTION

Q12. Explain about h-parameters.

Ans:

Hybrid Parameters: A transistor is a non linear device. It is difficult to analyze the circuit by using mathematical relation. Hence by using two port network (circuit models) the amplifier circuits can be analyzed. Figure shows the two port network of amplifier.

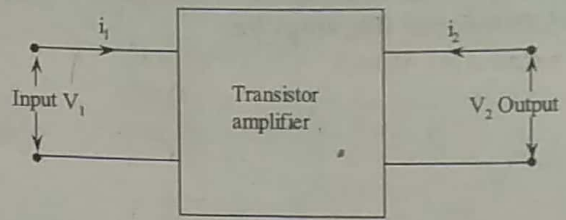


Figure: Two Port Network For Transistor Amplifier

Two port network consists of two ports as shown in figure. The most common parameters are h, y, z and g.

Hybrid parameters are used to analyze the transistor circuits and are defined as follows,

The equations of voltage and current in terms of h-parameters are,

$$V_1 = h_{11}\, i_1 + h_{12}\, V_2 \quad \text{... (1)}$$

$$i_2 = h_{21}\, i_1 + h_{22}\, V_2 \quad \text{... (2)}$$

Where,

V_1, V_2 – Input and output voltages

i_1, i_2 – Input and output currents.

Short circuiting the output port i.e., $V_2 = 0$

Then,

$$V_1 = h_{11}\, i_1$$

$$\Rightarrow \quad h_{11} = \frac{V_1}{i_1}$$

And,

$$i_2 = h_{21}\, i_1$$

$$\Rightarrow \quad h_{21} = \frac{i_2}{i_1}$$

Open circuiting the input port i.e., $i_1 = 0$

Then,

$$V_1 = h_{12}\, V_2$$

$$\Rightarrow \quad h_{12} = \frac{V_1}{V_2}$$

$$i_2 = h_{22}\, V_2$$

$$\Rightarrow \quad h_{22} = \frac{i_2}{V_2}$$

Therefore,

$$h_{11} = \frac{V_1}{i_1} \text{ – Input impedance in ohms}$$

$$h_{12} = \frac{V_1}{V_2} \text{ – Reverse voltage gain}$$

$$h_{21} = \frac{i_2}{i_1} \text{ – Forward current gain}$$

$$h_{22} = \frac{i_2}{V_2} \text{ – Output admittance in mho's}$$

3. Derive the expressions for current gain, voltage gain and input and output resistances of transistor amplifier using h-parameter model.

Ans: **Model Paper-I, Q8**

Figure (1) shows that the equivalent circuit of transistor amplifier using *h*-parameter model.

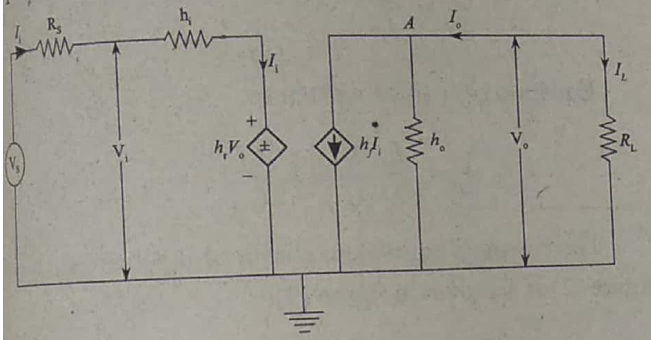


Figure (1) : Hybrid Equivalent Circuit

1. **Current Gain:** Current gain of an amplifier is defined as the ratio of output current to the input current.

$$A_i = \frac{I_o}{I_i} = \frac{-I_L}{I_i} \quad \text{... (1)}$$

From the figure (1), by applying KCL at node *A*, then,

$$h_f I_i + h_o V_o = -I_o \quad \text{... (2)}$$

Here, $V_o = I_o R_L$

$$\Rightarrow \quad h_f I_i + h_o (I_o R_L) = -I_o$$

$$\Rightarrow \quad h_f I_i = -(h_o R_L + 1) I_o$$

$$\Rightarrow \quad \frac{I_o}{I_i} = \frac{-h_f}{1+h_o R_L}$$

$$A_i = \frac{-h_f}{1+h_o R_L} \quad \text{... (3)}$$

$$\boxed{\therefore \text{ Current gain}(A_i) = \frac{-h_f}{1+h_o R_L}}$$

2. **Input Resistance:** It is defined as the ratio of input voltage to the input current.

$$R_i = \frac{V_i}{I_i} \quad \text{... (4)}$$

By applying KVL to the input loop of circuit shown in figure (1),

$$V_i = h_i I_i + h_r V_o \quad \text{... (5)}$$

Substituting equation (5) in equation (4),

$$\therefore \quad R_i = \frac{h_i I_i + h_r V_o}{I_i}$$

$$R_i = h_i + h_r \frac{V_o}{I_i}$$

Since, $V_o = I_o R_L$,

$$R_i = h_i + h_r \frac{I_o R_L}{I_i}$$

$$= h_i + h_r R_L \left(\frac{I_o}{I_i}\right)$$

$$R_i = h_i + h_r A_i R_L$$

Substituting A_i value in the above equation,

$$R_i = h_i + h_r \left(\frac{-h_f}{1+h_o R_L}\right) R_L$$

$$= h_i - \frac{h_r . h_f}{1+h_o R_L} . R_L$$

$$\boxed{\therefore \text{ Input resistance}(R_i) = h_i + \frac{h_r . h_f}{1+h_o R_L} . R_L}$$

3. **Voltage Gain:** Voltage gain of an amplifier is defined as the ratio of the output voltage to the input voltage.

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

Since $V_o = I_o R_L$

$$\Rightarrow \quad A_V = \frac{I_o R_L}{V_i}$$

$$= \frac{I_o R_L}{I_i R_i} = \frac{A_i R_L}{R_i}$$

$$\boxed{\therefore \text{ Voltage gain}(A_v) = \frac{A_i R_L}{R_i}} \quad \text{... (6)}$$

4. **Output Conductance:** Output conductance of an amplifier is defined as the output current to output voltage.

$$G_o = \frac{I_o}{V_o} \quad \text{... (7)}$$

From the output circuit,

$$I_o = h_f I_i + h_o V_o$$

$$\Rightarrow \quad \frac{I_o}{V_o} = h_f \frac{I_i}{V_o} + h_o \quad \text{... (8)}$$

From the input circuit of diagram shown in figure (1).

$$V_s = R_s I_i + h_i I_i + h_r V_o$$

For, $V_S = 0$

$$\Rightarrow \quad R_s I_i + h_i I_i + h_r V_o = 0$$

$$\Rightarrow \quad I_i (R_s + h_i) = -h_r V_o$$

$$\Rightarrow \quad \frac{I_i}{V_o} = \frac{-h_r}{R_s + h_i} \quad \text{... (9)}$$

Substituting equation (9) in equation (8),

$$G_o = \frac{I_i}{V_o} = h_f \left(\frac{-h_r}{R_s + h_i}\right) + h_o$$

$$= h_o - \frac{h_r h_f}{R_s + h_i}$$

$$\boxed{\therefore \text{Output Conductance}(G_o) = h_o - \frac{h_r h_f}{h_i + R_s}} \quad \text{... (10)}$$

5. **Overall Voltage Gain:** It is defined as the ratio of output voltage to source voltage and it is given as,

$$A_{VS} = \frac{V_o}{V_S} \quad \text{... (11)}$$

Equation (11) can be written as,

$$A_{VS} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_S}$$

$$A_{VS} = A_V \cdot \frac{V_i}{V_S} \quad \text{... (12)}$$

The Thevenin's equivalent circuit for input circuit shown in figure (1), is as shown in figure (2).

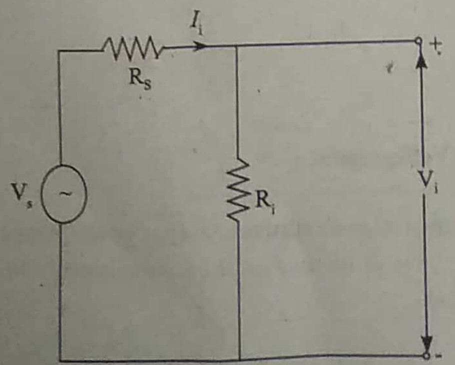


Figure (2): Thevenin's Equivalent Circuit

Using voltage division rule,

$$V_i = V_S \frac{R_i}{R_i + R_S}$$

$$\frac{V_i}{V_S} = \frac{R_i}{R_i + R_S} \quad \text{... (13)}$$

Substituting equation (13) in equation (12),

$$\Rightarrow \quad A_{VS} = A_V \cdot \frac{R_i}{R_i + R_S}$$

$\therefore$ The voltage gain with source resistance,

$$A_{VS} = A_V \cdot \frac{R_i}{R_i + R_S}$$

6. **Overall Current Gain:** It is defined as the ratio of output current to source current and is given as,

$$A_{IS} = \frac{I_o}{I_s} \quad \text{... (14)}$$

Equation (4) can be written as,

$$A_{IS} = \frac{I_o}{I_i} \cdot \frac{I_i}{I_s} = A_i \frac{I_i}{I_s} \quad \text{... (15)}$$

The Norton's equivalent circuit of input circuit shown in figure (2) is a shown in figure (3).

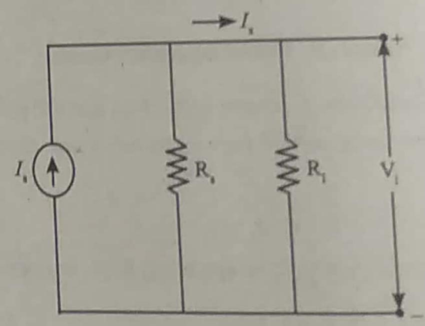


Figure (3) : Norton's Equivalent Circuit

Using current divison rule,

$$I_i = \frac{R_s}{R_s + R_i} I_s$$

$$\frac{I_i}{I_s} = \frac{R_S}{R_i + R_s} \quad \text{... (16)}$$

Substituting equation (16) in equation (15),

$$A_{IS} = A_i \frac{R_S}{R_i + R_s}$$

$$\boxed{\therefore \text{Currentgain with source resistance, } A_{IS} = \frac{R_s}{R_i + R_s}}$$

Q14. Determine h-parameters from transistor characteristics.

Ans:

Determination of h-parameters from Transistor Characteristics

The *V-I* equations of common emitter configuration are given as,

$$V_B = h_{ie} I_B + h_{re} V_C$$

$$I_C = h_{fe} I_B + h_{oe} V_C$$

Where,

h_{ie}, h_{re}, h_{fe} and h_{oe} are *h*-parameters.

The input and output characteristics common emitter configuration is as shown figure. The output characteristics gives the relationship between the output current and voltage with the input current as a parameter. The input characteristics gives the relationship between the input current and voltage with the output voltage as parameter.

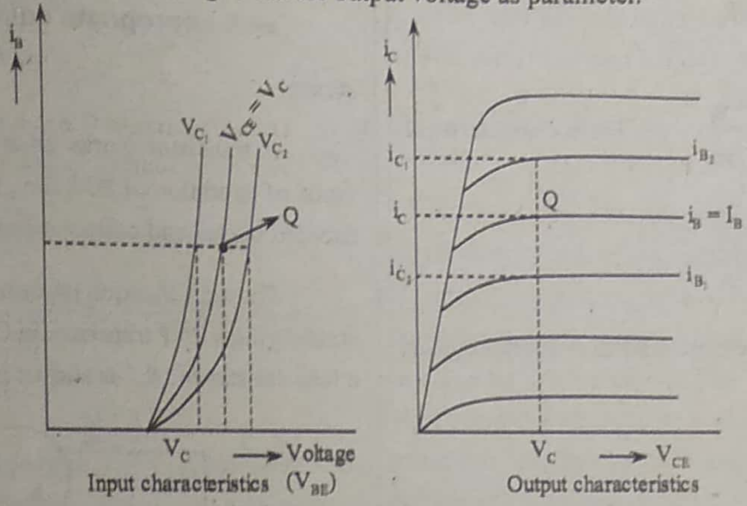


Figure: CE Input/Output Characteristics

Parameter h_{fe}

The parameter h_{fe} is defined as ratio of change in collector current to change in base current keep 'V_C' as constant.

$$h_{fe} = \frac{\partial i_C}{\partial i_B} = \left.\frac{\partial i_C}{\partial i_B}\right|_{V_C}$$

$$= \frac{i_{C_2} - i_{C_1}}{i_{B_2} - i_{B_1}} \quad (\because \text{ From characteristics})$$

$$\therefore \quad h_{fe} = \frac{i_{C_2} - i_{C_1}}{i_{B_2} - i_{B_1}}$$

The current increments are taken around the operating point Q, which corresponds to the base current $i_B = I_B$ and to the collector voltage $V_{CE} = V_C$.

Parameter h_{oe}

'h_{oe}' is defined as ratio of change in collector current to change in collector voltage by keeping base current as constant.

$$h_{oe} = \frac{\partial i_C}{\partial V_C}$$

$$= \left.\frac{\Delta i_C}{\Delta V_C}\right|_{I_B}$$

$$h_{oe} = \frac{i_{C_2} - i_{C_1}}{V_{C_2} - V_{C_1}} \quad (\because \text{ From characteristics})$$

The slope of the output characteristics at the operating point gives the value of h_{oe}.

Parameter h_{ie}

'h_{ie}' is defined as the ratio of change in base voltage to the change in base current by keeping 'V_C' as constant.

$$h_{ie} = \frac{\partial V_B}{\partial i_B}$$

$$= \left.\frac{\Delta V_B}{\Delta i_B}\right|_{V_C}$$

$$= \frac{V_{B_2} - V_{B_1}}{i_{B_2} - i_{B_1}} \quad (\because \text{ From characteristics})$$

$$\therefore \quad h_{ie} = \frac{V_{B_2} - V_{B_1}}{i_{B_2} - i_{B_1}}$$

The slope of the input characteristics at operating point gives the value of 'h_{ie}'

Parameter h_{re}

'h_{re}' is defined as the ratio of change in base voltage to the change in collector voltage by keeping base current as constant.

$$h_{re} = \frac{\partial V_B}{\partial V_C}$$

$$= \left.\frac{\partial V_B}{\partial V_C}\right|_{I_B}$$

$$= \frac{V_{B_2} - V_{B_1}}{V_{C_2} - V_{C_1}} \quad (\because \text{ From characteristics})$$

The vertical line on the current axis represents constant base current at Q point.

Q15. List out the typical values of h-paramaters in the three BJT configurations (CE, CB and CC).

Ans:

The comparison table of transistor configurations is shown below:

Parameter	Configuration CE	CB	CC
h_i	1 kΩ	20 Ω	1 kΩ
h_r	2.5×10^{-4}	3.0×10^{-4}	1
h_f	50	−0.98	− 50
h_o	25 μA/V	0.5 μA/V	25 μA/V
$\frac{1}{h_o}$	40 kΩ	2 kΩ	40 kΩ

Table: Transistor Configurations in terms of A_i, A_v, R_i, R_o

Q16. Analyze the functionality of BJT as an amplifier with appropriate equivalent circuit model.

Ans:

A transistor works as an amplifier only in the active mode of operation of BJT (i.e., when emitter-base junction is forward biased and collector-base junction is reverse biased).

The amplification process of a BJT can be illustrated by considering a PNP transistor in CB configuration connected to a load resistance 'R_L' as shown in figure (1).

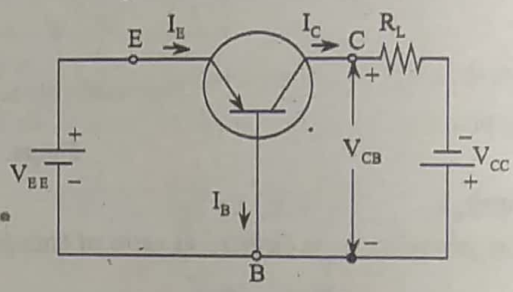


Figure (1): Transistor as an Amplifier

The load resistor 'R_L' is connected in series with the collector supply voltage 'V_{CC}'. A small variation in the value of input voltage (ΔV_i) (applied between the emitter and base) produces a large variation in the emitter current (ΔI_E).

The variation in output voltage (ΔV_o) across a load resistor R_L can be given as,

$$\Delta V_o = \Delta I_C R_L$$

$$\Delta V_o = \alpha' R_L \Delta I_E \quad \left[\because \alpha' = \frac{\Delta I_C}{\Delta I_E}\right] \quad \dots(1)$$

Where,

ΔI_C – Change in collector current.

ΔI_E – Change in emitter current.

α' – Small-single forward short circuit current gain.

The change in input voltage (ΔV_i) across the dynamic resistance r_e' at the emitter junction is given as,

$$\Delta V_i = r_e' \Delta I_E \quad \text{... (2)}$$

For amplification to occur, ΔV_i should be multiplied by some factor to give ΔV_o. This factor is known as voltage amplification factor (A) and is given as,

$$A = \frac{\Delta V_o}{\Delta V_i} \quad \text{... (3)}$$

On substituting equations (1) and (2) in equation (3),

$$A = \frac{\alpha' R_L \Delta I_E}{r_e' \Delta I_E}$$

$$\therefore \quad A = \frac{\alpha' R_L}{r_e'} > 1 \quad \text{... (4)}$$

From equation (4), it can be observed that ΔV_o is amplified by a factor $\frac{\alpha' R_L}{r_e'}$. Hence, transistor acts as an amplifier.

Here, the voltage amplification $A_v = \frac{\Delta V_o}{\Delta V_i}$ is around 150 without any phase shift and thus transistor acts as an amplifier.

4.2 ANALYSIS OF CE, CC, CB AMPLIFIERS AND CE AMPLIFIER WITH EMITTER RESISTANCE

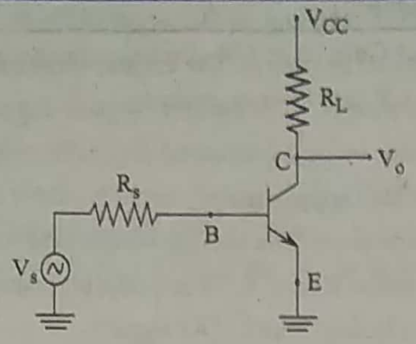


Figure (1): Common-Emitter Amplifier

Hybrid Model Analysis: Figure (2) shows the h-parameter equivalent circuit of the transistor in the common emitter configuration using exact model.

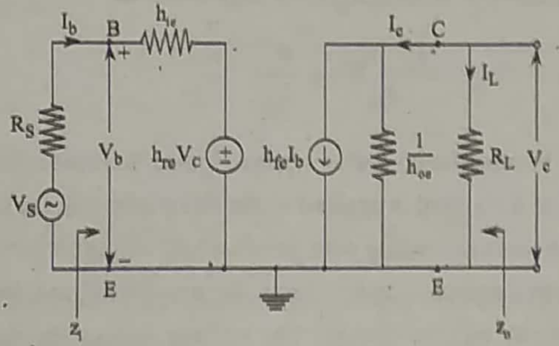


Figure (2): Hybrid Model for CE Amplifier

1. **Current Gain (A_I):** The current gain, A_I of a transistor amplifier is defined as the ratio of output current to the input current, i.e.,

$$A_I = \frac{I_L}{I_b} = -\frac{I_c}{I_b} \quad \text{... (1)}$$

Applying KCL to output loop,

$$I_c = h_{fe} I_b + h_{oe} V_c \quad \text{... (2)}$$

Since $V_c = I_L R_L = -I_c R_L$, equation (2) becomes,

$$I_c = h_{fe} I_b - I_c h_{oe} R_L$$

$$\Rightarrow \quad h_{fe} I_b = [1 + h_{oe} R_L] I_c$$

$$\Rightarrow \quad I_c = \frac{h_{fe} I_b}{1 + h_{oe} R_L}$$

Thus, $$A_I = \frac{-I_c}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R_L}$$

$$\boxed{\therefore A_I = \frac{-h_{fe}}{1 + h_{oe} R_L}} \quad \text{... (3)}$$

2. **Input Impedance (Z_i):** The resistance, R_s in the figure (2) is referred as the signal source resistance. The input impedance of the CE amplifier is the impedance seen through the terminals (B, E) as shown in figure (2).

$$Z_i = \frac{V_b}{I_b} \quad \text{... (4)}$$

The input loop equation is obtained as,

$$V_b = h_{ie} I_b + h_{re} V_c$$

$$\Rightarrow \quad Z_i = \frac{h_{ie} I_b + h_{re} V_c}{I_b}$$

$$Z_i = h_{ie} + h_{re} \frac{V_c}{I_b}$$

Here, $V_c = I_L R_L = -I_c R_L = A_I I_b R_L$ [∵ From equation (1)]

$$\Rightarrow \quad Z_i = h_{ie} + h_{re} \frac{A_I I_b R_L}{I_b}$$

$$Z_i = h_{ie} + h_{re} A_I R_L$$

$$\boxed{\therefore Z_i = h_{ie} + h_{re} A_I R_L} \quad \text{... (5)}$$

3. **Voltage Gain (A_V):** The voltage gain, A_V of a transistor amplifier circuit is defined as the ratio of output voltage to the input voltage, i.e.,

$$A_V = \frac{V_c}{V_b} \quad \text{... (6)}$$

Since, $V_c = I_L R_L = -I_c R_L = A_I I_b R_L$, equation (6) implies,

$$A_V = \frac{A_I I_b R_L}{V_b} = \frac{A_I R_L}{V_b / I_b} = \frac{A_I R_L}{Z_i}$$

$$A_V = \frac{A_I R_L}{Z_i} \quad \text{... (7)}$$

$$\therefore \quad A_V = \frac{h_{fe} R_L}{h_{re} h_f R_L - h_{ie}(1 + h_{oe} R_L)}$$

4. **Output Impedance (Z_o):** The output impedance, Z_o of a transistor amplifier circuit is defined as the ratio of output voltage to the output current, i.e.,

$$Z_o = \frac{V_c}{I_c} \quad \text{... (8)}$$

$$\Rightarrow \quad Y_o = \frac{I_c}{V_c} = \frac{1}{Z_o}$$

Where,

Y_o – Output admittance

Since, $I_c = h_{fe} I_b + h_{oe} V_c$, '$Y_o$' becomes,

$$\frac{I_c}{V_c} = h_{fe}\frac{I_b}{V_c} + h_{oe} \quad \text{... (9)}$$

Applying KVL to the input circuit with $V_S = 0$,

$$R_S I_b + h_{ie} I_b + h_{re} V_c = 0$$

$$\Rightarrow I_b (R_S + h_{ie}) + h_{re} V_c = 0$$

$$\Rightarrow I_b (R_S + h_{ie}) = -h_{re} V_C$$

$$\Rightarrow \frac{I_b}{V_c} = \frac{-h_{re}}{R_s + h_{ie}} \quad \text{... (10)}$$

Substituting equation (10) in equation (9),

$$\frac{I_c}{V_c} = h_{fe} \times \frac{-h_{re}}{R_s + h_{ie}} + h_{oe}$$

$$\Rightarrow Y_o = \frac{I_c}{V_c} = h_{oe} - \frac{h_{re} h_{fe}}{R_s + h_{ie}}$$

$$\boxed{\therefore Z_o = \frac{1}{h_{oe} - \left[\frac{h_{fe} h_{re}}{R_s + h_{ie}}\right]}} \quad \text{... (11)}$$

Q19. Derive the expressions for voltage gain, current gain, input impedance of CE amplifier using approximate model.

Ans:

Approximate Model Analysis

Figure shows the h-parameter equivalent circuit of the transistor in the common emitter configuration.

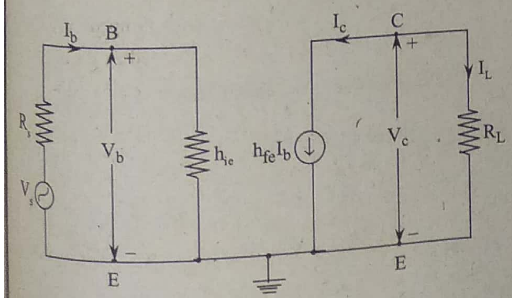


Figure: Approximate Model of CE Amplifier

1. **Current Gain (A_I):** The general expression for current gain of CE amplifier is given by,

$$A_I = \frac{-h_{fe}}{1 + h_{oe} R_L}$$

Here, $h_{oe} R_L << 1$

$$\boxed{\therefore A_I \simeq -h_{fe}} \quad \text{... (1)}$$

2. **Input Impedance (Z_i):** The general expression for input impedance of CE amplifier is given by,

$$Z_i = h_{ie} + h_{re} A_I R_L$$

The above equation can also be written as,

$$Z_i = h_{ie}\left[1 + \frac{h_{re} h_{fe} A_I h_{oe} R_L}{h_{ie} h_{oe} h_{fe}}\right]$$

By using the typical values for h-parameters,

$$\frac{h_{re} h_{fe}}{h_{ie} h_{oe}} \simeq 0.5$$

Thus, the equation approximates to,

$$Z_i = h_{ie}\left[1 - \frac{0.5\, h_{fe} h_{oe} R_L}{h_{fe}}\right] \quad [\because A_I = -h_{fe}]$$

Since, $h_{oe} R_L << 0.1$

$$\therefore Z_i = \frac{V_b}{I_b} \simeq h_{ie} \quad \text{... (2)}$$

3. **Voltage Gain (A_V):** The general expression for voltage gain of CE configuration is given by the equation (7) as,

$$A_V = \frac{A_I R_L}{Z_i}$$

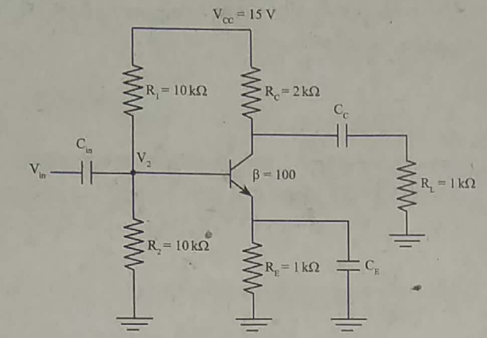
From equations (1) and (2), A_v is obtained as,

$$\boxed{A_V \simeq \frac{-h_{fe} R_L}{h_{ie}}} \quad \text{... (3)}$$

4. **Output Impedance (Z_o):** The approximated circuit has infinite output impedance because with $V_S = 0$ and external voltage source applied at the output, it is found that $I_b = 0$ and hence, $I_C = 0$.

$$\boxed{\therefore Z_o = \infty} \quad \text{... (4)}$$

Q20. For the circuit shown below, find (i) dc bias levels (ii) dc voltages across the capacitors (iii) ac emitter resistance (iv) voltage gain and (v) state of the transistor.



Figure

Ans:

Given that,

For a common emitter amplifier,

Emitter resistance, $R_E = 1\text{ k}\Omega$

Collector resistance, $R_C = 2\text{ k}\Omega$

Load resistance, $R_L = 1\text{ k}\Omega$

Collector input volage, $V_{CC} = 15\text{ V}$

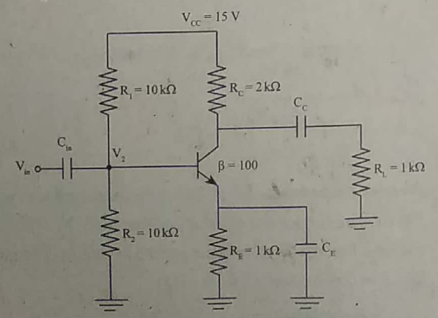
Amplification factor, $\beta = 100$

Input resistance, $R_1 = 40\text{ k}\Omega$ and $R_2 = 10\text{ k}\Omega$

Voltage gain, $A_v = ?$

AC emitter resistance, $r_e = ?$

The given common emitter amplifier circuit is as shown in the figure below.



Figure

(i) **dc Bias Levels:** DC bias levels of CE amplifier determined by calculating various dc voltages and dc currents.

DC voltage, V_2 across resistaor, R_2 is,

$$\Rightarrow \quad V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

Substituting the corresponding values, V_2 is obtained as,

$$\Rightarrow \quad V_2 = \frac{15}{40+10} \times 10$$

$$\Rightarrow \quad V_2 = 3\text{ V}$$

$\therefore$ DC base voltage, $V_2 = 3\text{ V}$

DC emitter voltage, V_E across emitter resistor, R_E is,

$$\Rightarrow \quad V_E = V_2 - 2V_{BE}$$

$$= 3\text{ V} - 0.7\text{ V} \qquad [\because V_{BE} = 0.7\text{ V}]$$

$$= 2.3\text{ V}$$

$\therefore$ DC emitter voltage, $V_E = 2.3\text{ V}$

DC emitter current, I_E is given by,

$$\Rightarrow \quad I_E = \frac{V_E}{R_E}$$

$$I_E = \frac{2.3\text{ V}}{1\text{ k}\Omega}$$

$$\therefore I_E = 2.3\text{ mA}$$

DC collector voltage, V_C is determined as,

$$\Rightarrow \quad V_C = V_{CC} - I_C R_C$$

$$\Rightarrow \quad V_C = 15\text{ V} - 2.3 \times 2\text{ k}\Omega \qquad [\because I_E \simeq I_C]$$

$$= 10.4\text{ V}$$

$$\therefore V_C = 10.4\text{ V}$$

DC base current, I_B is obtained as,

Using the relation $I_C = \beta I_B$

$$\Rightarrow \quad I_B = \frac{I_C}{\beta}$$

$$\Rightarrow \quad I_B = \frac{2.3\text{ mA}}{100}$$

$$\therefore I_B = 0.023\text{ mA}$$

(ii) **DC Voltages across the Capacitors:** From the above calculations, DC voltages across capacitors in the circuit is obtained as,

DC voltage across capacitor, C_{in} is,

$$V_2 = 3 \text{ V}$$

DC voltage across emitter capacitor, C_E is,

$$V_E = 2.3 \text{ V}$$

DC voltage across collector capacitor, C_C is,

$$V_C = 1.4 \text{ V}$$

(iii) **AC Emitter Resistance:** The ac emitter resistance, r_e' is given by,

$$r_e' = \frac{25 \text{ mV}}{I_E}$$

$$= \frac{25 \text{ mV}}{2.3 \text{ mA}} \qquad [\because I_E = 2.3 \text{ mA}]$$

$$\therefore \ r_e' = 10.9\ \Omega$$

(iv) **Voltage Gain (A_V):** The voltage gain, A_V of CE amplifier is defined as,

$$A_V = \frac{r_c}{r_e'}$$

Here, total ac collector resistance, r_c is determined by,

$$r_c = R_C \parallel R_L$$

$$\Rightarrow \quad r_c = \frac{R_C R_L}{R_C + R_L}$$

$$= \frac{2 \times 1}{2 + 1}$$

$$\therefore r_c = 0.667 \text{ k}\Omega$$

Substituting r_c value in A_V, implies,

$$A_V = \frac{0.667 \text{ k}\Omega}{10.9\ \Omega}$$

$$= 61.2$$

$\therefore$ Voltage gain, $A_V = 61.2$

(v) **State of the Transistor:** From the above calculations it can be determined that the transistor is in active state. Since $V_C > V_E$.

Q21. A CE amplifier is drawn by a voltage source of internal resistance R_s = 800 ohms and load impedance is a resistance R_L = 1000 ohms. The h-parameters are h_{ie} = 1.0 k ohms, $h_{re} = 2 \times 10^{-4}$, h_{fe} = 50 and h_{oe} = 25 μ A/V, compute A_I, R_I, A_V, R_o using exact analysis.

Ans:

Given that,

For a transistor in CE amplifier,

Internal resistance, $R_s = 800\ \Omega$

Load resistance, $R_L = 1000\ \Omega$

Input impedance, $h_{ie} = 1.0 \text{ k}\Omega$

Reverse voltage gain, $h_{re} = 2 \times 10^{-4}$

Forward current gain, $h_{fe} = 50$

Output admittance, $h_{oe} = 25\ \mu$ A/V

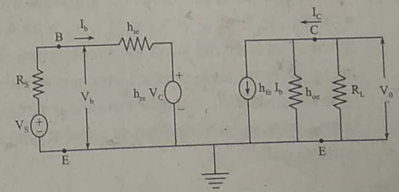
Current gain , A_I = ?

Input resistance, R_i = ?

Voltage gain, A_v = ?

Output resistance, R_0 = ?

The h-parametere model of CE amplifier is as shown in figure.



Figure

Current Gain A_I: The expression for current gain A_I of a C_E amplifier is given by,

$$A_I = \frac{-h_{fe}}{1 + h_{oe} R_L}$$

$$= \frac{-50}{1 + 25 \times 10^{-6} \times 1000} = \frac{-50}{1.025} = -48.78$$

$$\boxed{\therefore A_I = -48.78}$$

Input Resistance R_i: The expression for input impedance R_i of a C_E amplifier is given by,

$$R_I = h_{ie} + h_{re} A_I R_L$$

$$= 1.0 \times 10^3 + 2 \times 10^{-4} \times (-48.78) \times 1000$$

$$= 1000 - 9.756 = 990.244 = 0.99 \text{ k}\Omega$$

$$\boxed{\therefore R_I = 0.99 \text{ k}\Omega}$$

Voltage Gain A_v: The expression for voltage gain A_V of a C_E amplifier is given by,

$$A_V = \frac{A_I R_L}{R_I} = \frac{-48.78 \times 1000}{0.99 \times 10^3} = -49.26$$

$$\boxed{\therefore A_V = -49.26}$$

Output Resistance R_o: The expression for output resistance R_o of a C_E amplifier is given by,

$$R_o = \frac{1}{Y_0}$$

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s}$$

$$= 25 \times 10^{-6} - \frac{50 \times 2 \times 10^{-4}}{1 \times 10^3 + 800} = 1.94 \times 10^{-5} \mho$$

$$R_o = \frac{1}{Y_0} = \frac{1}{1.94 \times 10^{-5}} = 51428.57 = 51.4 \times 10^3 \Omega$$

$$\boxed{\therefore R_0 = 51.4 \text{ k}\Omega}$$

Q22. The hybrid parameters for CE amplifier are h_{ie} = 1000Ω, h_{fe} 150, h_{re} = 1.2 × 10^{-4}, h_{oe} = 25 × 10^{-6} mhos. The transistor has load resistance of 10 kΩ in collector and supplied from signal source of resistance 5 kΩ. Calculate the values of input impedance, output impedance, current gain and voltage gain.

Ans:

Given that,

For a CE amplifier h-parameters are,

Input impedance, $h_{fe} = 1000\ \Omega$

Forward current gain, $h_{fe} = 150$

Reverse current gain, $h_{re} = 1.2 \times 10^{-4}$

Output admittance, $h_{oe} = 25 \times 10^{-6} \mho$

Load resistance, $R_L = 10 \times 10^3\ \Omega$

Source resistance, $R_S = 5 \times 10^{-3}\ \Omega$

Input Impedance (z_i)

Input impedance of CE amplifier is defined as,

$$Z_{in} = h_{ie} - \frac{h_{re} . h_{fe}}{h_{oe} + \frac{1}{R_L}}$$

$$= 1000 - \frac{1.2 \times 10^{-4} \times 150}{25 \times 10^{-6} + 100}$$

$$= 1000 - 1.79 \times 10^{-4}$$

$$Z_{in} = 999.9\ \Omega$$

$\therefore$ Input impedance $Z_{in} = 999.9\ \Omega$

Output Impedance (Z_o)

Expression for output impedance of CE amplifier is,

$$Z_0 = \frac{h_{ie} + R_S}{1 + h_{fe}} = \frac{1000 - 5 \times 10^3}{1 + 150}$$

$$Z_0 = -26.49\ \Omega$$

$\therefore$ Output impedance Z_0 is $-26.49\ \Omega$

Current Gain (A_i)

Current gain of CE amplifier is given by,

$$A_i = \frac{h_{fe}}{1 + h_{oe} \times R_L}$$

$$= \frac{150}{1 + (25 \times 10^{-6} \times 10 \times 10^3)}$$

$$A_i = 120$$

$\therefore$ Current gain of CE amplifier is 120

Voltage Gain (A_V)

Voltage gain of CE amplifier is defined as,

$$A_V = \frac{-h_{fe}}{\left(h_{oe} + \frac{1}{R_L}\right) Z_{in}}$$

Substituting Z_{in} value in above equation,

$$A_V = \frac{-150}{(25 \times 10^{-6} + 100) \times 992.8}$$

$$A_V = -604.351$$

$\therefore$ Voltage gain, A_V of CE amplifier is -604.351.

Q23. Draw the h-parameter model for common base configuration and derive the equations for voltage gain, current gain, input and output impedance.

Ans:

Analysis of CB Configuration Using h-parameters

The circuit diagram for transistor common base configuration is as shown in figure (1).

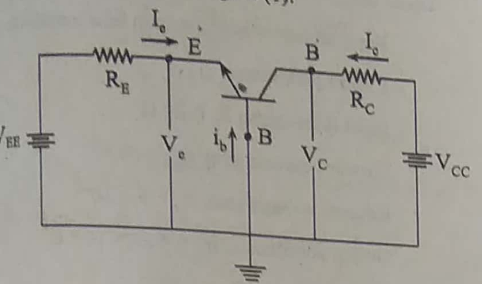


Figure (1): CB Configuration

The hybrid equivalent circuit for transistor CB configuration is as shown in figure (2).

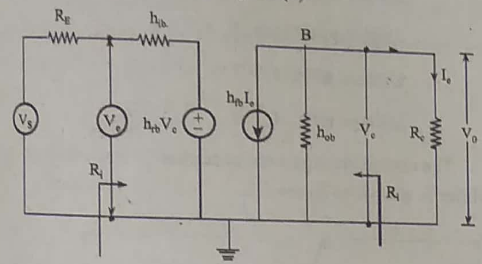


Figure (2): Hybrid Equivalent Circuit

On applying Kirchoff's voltage law to input and output loops of circuit shown in figure (2),

$$V_e = h_{ib} I_e + h_{rb} . V_c \quad \text{... (1)}$$

$$I_c = h_{fb} I_e + h_{ob} . V_c \quad \text{... (2)}$$

1. **Current Gain**

The ratio of collector current to the emitter current is known as current gain of CB amplifier and is given as,

$$A_i = \frac{I_c}{I_e} \quad \text{... (3)}$$

On applying KCL at node 'B',

$$h_{fb} I_e + h_{ob} . V_c = - I_c \quad \text{... (4)}$$

And collector 'V_c' is given as,

$$V_c = I_c R_c$$

Then equation (4) becomes,

$$h_{fb} I_e + h_{ob} . I_c R_c + I_c = 0$$

$$\Rightarrow \quad I_e h_{fb} + I_c (1 + h_{ob} . R_c) = 0$$

$$\Rightarrow \quad I_e h_{fb} = - I_c (1 + R_c . h_{ob})$$

$$\Rightarrow \quad A_i = - \frac{h_{fb}}{1 + h_{ob} . R_c}$$

$$\boxed{\therefore \text{Current Gain}(A_{ib}) = \frac{h_{fb}}{1 + h_{ob} . R_c}} \quad \text{... (5)}$$

2. **Input Resistance**

Input resistance of common base transistor amplifier is given as,

$$R_{ib} = \frac{V_e}{I_e} \quad \text{... (6)}$$

On substituting equation (1) in above expression,

$$R_{ib} = \frac{h_{ib} . I_e + h_{rb} . V_c}{I_e}$$

$$= h_{ib} + h_{rb} . \frac{V_e}{I_e}$$

$$= h_{ib} + h_{rb} . \frac{V_c}{I_c} . \frac{I_c}{I_e}$$

$$= h_{ib} + h_{rb} . R_c . A_{ib}$$

$$\therefore \quad R_{ib} = h_{ib} + A_{ib} R_c h_{rb} \quad \text{... (7)}$$

On substituting value of A_{ib} in above expression,

$$R_{ib} = h_{ib} + R_c h_{rb} \left(\frac{- h_{fb}}{1 + h_{ob} . R_c} \right)$$

$$= h_{ib} - \frac{h_{rb} . h_{fb}}{1 + h_{ob} . R_c} . R_c$$

$$\boxed{\therefore R_{ib} = h_{ib} - \frac{h_{rb} . h_{fb}}{1 + h_{ob} . R_c} . R_c} \quad \text{... (8)}$$

3. **Voltage Gain**

The voltage gain of common base amplifier is defined as the ratio of collector to emitter voltage i.e.,

$$A_{vb} = \frac{V_c}{V_e} \quad \text{... (9)}$$

Since, $V_e = I_e R_e$

$$A_{vb} = \frac{I_c R_c}{V_e}$$

$$= \frac{I_c R_c}{I_e R_{ib}} \quad (\because V_e = R_{ib} \cdot I_e)$$

$$= \left(\frac{I_c}{I_e}\right) \frac{R_c}{R_{ib}}$$

$$= A_{ib} \cdot \frac{R_c}{R_{ib}}$$

$$\boxed{\therefore \text{Voltage gain}, (A_{vb}) = A_{ib} \cdot \frac{R_c}{R_{ib}}} \quad \text{... (10)}$$

4. Output Conductance

The output conductance of CB amplifier is defined as,

$$G_{ob} = \frac{I_c}{V_c} \quad \text{... (11)}$$

From equation (2),

$$\Rightarrow \quad I_c = h_{fb} I_e + h_{ob} V_c$$

Then,

$$\frac{I_c}{V_c} = h_{fb} \frac{I_e}{V_c} + h_{ob}$$

$$\Rightarrow \quad G_{ob} = h_{ob} + h_{fb} \frac{I_e}{V_c} \quad \text{... (12)}$$

From the input circuit shown in figure (2),

$$V_s = I_e R_E + I_e h_{ib} + h_{rb} V_c$$

For $V_s = 0$,

$$I_e R_E + I_e h_{ib} + h_{rb} V_c = 0$$

$$\Rightarrow \quad I_e (R_E + h_{ib}) = -h_{rb} V_c$$

$$\Rightarrow \quad \frac{I_e}{V_c} = -\frac{h_{rb}}{R_E + h_{ib}} \quad \text{... (13)}$$

On substituting equation (13) in equation (12), we get,

$$G_{ob} = h_{ob} + h_{fb}\left(\frac{-h_{rb}}{R_E + h_{ib}}\right)$$

$$\boxed{\therefore G_{ob} = h_{ob} - \frac{h_{rb} \cdot h_{fb}}{R_E + h_{ib}}}$$

Q24. A transistor used in a CB amplifier has the following values of h-parameters $h_{ib} = 28\ \Omega$, $h_{fb} = -0.98$, $h_{rb} = 5 \times 10^{-4}$ and $h_{ob} = 0.34 \times 10^{-6}$ ℧. Calculate the values of R_i, R_o, A_i and A_v, if the load resistance is 1.2 kΩ. Assume source resistance as zero.

Ans:

Given that,

For a transistor in a common base amplifier,

Circuit parameters,

Input impedance, $h_{ib} = 28\ \Omega$

Forward current gain, $h_{fb} = -0.98$

Reverse voltage gain, $h_{rb} = 5 \times 10^{-4}$

Output admittance, $h_{ob} = 0.34 \times 10^{-6}$ ℧

Load resistance, $R_L = 1.2\ \text{k}\Omega$

Source resistance, $R_S = 0\ \Omega$

Input resistance, $R_i = ?$

Output resistance, $R_o = ?$

Current gain, $A_I = ?$

Voltage gain, $A_V = ?$

The circuit arrangement of transistor in a common base amplifier is shown in figure (1).

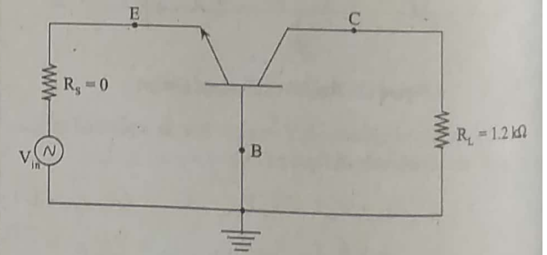


Figure (1)

The h-parameter equivalent circuit of the transistor in the CB configuration is shown in figure (2).

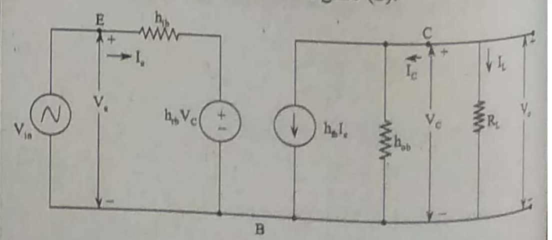


Figure (2)

Exact Analysis

Current Gain (A_I): The expression for current gain in common base configuration is obtained as,

$$A_I = \frac{I_L}{I_e} = \frac{-I_c}{I_e} \quad \text{... (1)}$$

From figure (2), $I_e = h_{fb} I_e + h_{ob} V_c$

But, $V_c = I_L R_L = -I_c R_L$

$\Rightarrow \quad I_c = h_{fb} I_e - I_c h_{ob} R_L$

$\Rightarrow \quad I_c (1 + h_{ob} R_L) = h_{fb} I_e$

$$\Rightarrow \quad \frac{I_c}{I_e} = \frac{h_{fb}}{1+h_{ob}R_L}$$

$$\therefore \quad A_I = \frac{-h_{fb}}{1+h_{ob}R_L} \quad \text{... (2)}$$

$$= \frac{-(-0.98)}{1+0.34\times10^{-6}\times1.2\times10^{3}} \simeq 0.98$$

$$\boxed{\therefore A_I \simeq 0.98}$$

Input Resistance (R_i): The expression for input resistance of a common base amplifier is obtained as,

$$R_i = \frac{V_e}{I_e} \quad \text{... (3)}$$

From figure (2),

$$V_e = h_{ib} I_e + h_{rb} V_c$$

$$\Rightarrow \quad R_i = \frac{h_{ib} I_e + h_{rb} V_c}{I_e}$$

$$= h_{ib} + h_{rb} \frac{V_c}{I_e}$$

But, $V_c = -I_c R_L = A_I I_e R_L$ (From equation (1))

Then,

$$R_i = h_{ib} + h_{rb} \frac{A_I I_e R_L}{I_e}$$

$$= h_{ib} + h_{rb} A_I R_L \quad \text{... (4)}$$

Thus,

$$R_i = 28 + 5 \times 10^{-4} \times 0.98 \times 1.2 \times 10^3$$

$$= 28 + 0.588$$

$$= 28.59\ \Omega$$

$$\boxed{\therefore R_i = 28.59\ \Omega}$$

Voltage Gain (A_v): The expression for voltage gain of a common base amplifier is obtained as,

$$A_V = \frac{V_c}{V_e} \quad \text{... (5)}$$

But, $V_c = -I_c R_L = A_I I_e R_L$ (From equation (1))

$$\text{Then, } A_V = \frac{A_I I_e R_L}{V_e}$$

$$= \frac{A_I R_L}{(V_e / I_e)} = \frac{A_I R_L}{R_i} \quad \text{... (6)}$$

Thus,

$$A_V = \frac{0.98\times1.2\times10^3}{28.59} = 41.13$$

$$\boxed{\therefore A_V = 41.13}$$

Output Resistance (R_o): The expression for output admittance of a common base amplifier is obtained as,

$$Y_o = \frac{I_c}{V_c} \quad \text{... (7)}$$

From figure (2), $I_c = h_{fb} I_e + h_{ob} V_c$

Dividing above equation with 'V_c'

$$\Rightarrow \quad \frac{I_c}{V_c} = h_{fb} \frac{I_e}{V_c} + h_{ob} \quad \text{... (8)}$$

With $V_{in} = 0$, by KVL in input circuit,

$$h_{rb} V_c + h_{ib} I_e = 0 \qquad (\because R_S = 0)$$

$$\Rightarrow \quad \frac{I_e}{V_c} = \frac{-h_{rb}}{h_{ib}}$$

Substituting above value in equation (8),

$$\frac{I_c}{V_c} = h_{fb}\left(\frac{-h_{rb}}{h_{ib}}\right) + h_{ob}$$

$$\therefore \quad Y_o = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib}}$$

Thus,

$$Y_o = 0.34 \times 10^{-6} + \frac{0.98\times5\times10^{-4}}{28}$$

$$= 0.34 \times 10^{-6} + 0.175 \times 10^{-4}$$

$$= 17.84 \times 10^{-6}\ \mho$$

Then, output resistance is given as,

$$R_o = \frac{1}{Y_o} = \frac{1}{17.84\times10^{-6}} = 56.05\ \text{k}\Omega$$

$$\boxed{\therefore R_o = 56.05\ \text{k}\Omega}$$

Q25. Draw the CC amplifier and derive the expression for A_i, R_i, A_v, Y_o.

Ans:

Common collector amplifier is also called as emitter follower. It has a voltage gain close to unity. Hence, any change in the base voltage appears as an equal change across the load at the emitter i.e., the emitter follows the input signal.

The circuit diagram of CC amplifier is as shown in figure (1).

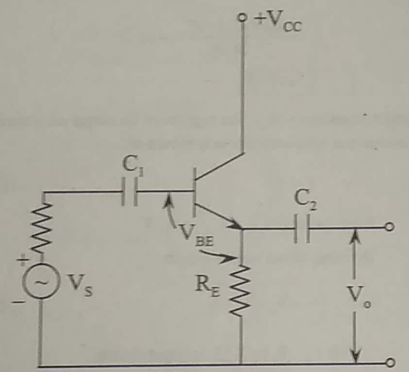


Figure (1): CC Amplifier Circuit

The hybrid equivalent circuit for CC amplifier is as shown in figure (2).

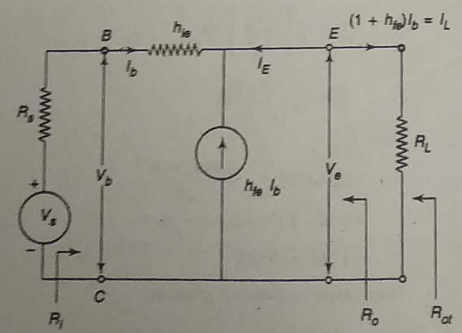


Figure (2): Low Frequency Equivalent Circuit of an Emitter Follower

The simplified hybrid model of an emitter follower using the approximate analysis with collector grounded, input signal applied between the base and the ground and load impedance is connected between emitter and ground.

The circuit parameters in terms of h-parameters can be obtained as follows.

1. **Current Gain**

The current through the load R_L is given by,

Load current, $I_L = (1 + h_{fe}) I_b$ ... (1)

Current gain, $A_I = \frac{I_L}{I_b} = (1+h_{fe})$

$$\boxed{\therefore A_I = 1 + h_{fe}} \quad ...(2)$$

2. **Input Resistance**

Applying KVL to the circuit,

$$V_b = I_b h_{ie} + (1 + h_{fe}) I_b . R_L \quad ...(3)$$

Hence, approximate input resistance is,

$$R_i = \frac{V_b}{I_b} = h_{ie} + (1 + h_{fe}) R_L$$

$$\boxed{\therefore R_i = h_{ie} + (1 + h_{fe} R_L)} \quad ...(4)$$

3. **Voltage Gain**

From figure (2), the voltage gain of the amplifier is given as,

Here, $V_e = (1 + h_{fe}) I_b R_L$ ... (5)

From equations (3) and (5), A_V is obtained as,

$$A_V = \frac{V_e}{V_b} = \frac{(1+h_{fe})R_L}{h_{ie} + (1+h_{fe})R_L} = 1 - \frac{h_{ie}}{h_{ie} + (1+h_{fe})R_L}$$

$$= 1 - \frac{h_{ie}}{R_i}$$

$$\boxed{\therefore A_V = 1 - \frac{h_{ie}}{R_i}}$$

4. **Output Resistance (R_o)**

The output admittance is defined as,

$$\text{Output admittance } (Y_o) = \frac{\text{Short circuit current in output terminal}, I_L}{\text{Open circuit voltage between output terminals}, V_s}$$

$$I_L = 1 + (h_{fe})\, I_b$$

$$= \frac{(1+h_{fe})V_s}{h_{ie}+R_s} \qquad \left(\because I_b = \frac{V_S}{h_{ie}+R_1}\right)$$

Where,

V_S – open circuit voltage between output terminals.

$$\therefore Y_o = \frac{1+h_{fe}}{h_{ie}+R_1}$$

Hence, the output impedance resistance,

$$R_o = \frac{1}{Y_o}$$

$$\text{i.e., } R_o = \frac{1}{\dfrac{1+h_{fe}}{h_{ie}+R_s}} = \frac{h_{ie}+R_s}{1+h_{fe}} \qquad \boxed{\therefore R_o = \frac{h_{ie}+R_s}{1+h_{fe}}}$$

Q26. A CC amplifier shown in below figure has Vcc = 15 V, R_B = 75kΩ and RE = 910 Ω. The β of the silicon transistor is 100Ω and the load resistor is 600 Ω find r_{in} and A_V.

Model Paper-III, Q8

Ans:

Given that,

For a common collector amplifier,

Base resistance, $R_B = 75\ \text{k}\Omega$

Collector input voltage, $V_{CC} = 15$ V

Emitter resistance, $R_E = 910\ \Omega$

Amplification factor, $\beta = 100$

Load resistance, $R_L = 600\ \Omega$

Voltage gain, $A_V = ?$

The given CC configured BJT amplifier circuit is shown in figure.

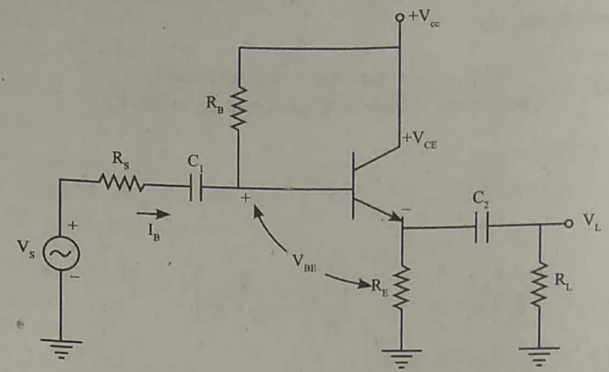


Figure: Common-Collector Amplifier

The input impedance/resistance of a CC amplifier circuit is given by,

$$r_{in} = R_B \| (1+\beta)(r_e + r_L) \quad \text{... (1)}$$

Where,

r_e – Dynamic resistance

$$r_e = \frac{0.026}{I_E}$$

r_L – Load resistance of emitter

$$r_L = R_E \| R_L$$

$$= 910 \| 600$$

$$= \frac{910 \times 600}{910 + 600}$$

$$r_L = 361.59\ \Omega$$

From figure,

$$V_{CC} = V_{BE} + I_B R_B + I_E R_E$$

$$= V_{BE} + I_B R_B + (1+\beta) I_B R_E$$

$$\Rightarrow \quad I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

From the given specifications,

$$I_B = \frac{15 - 0.7}{75 + (101)(0.91)} \times 10^{-3}$$

$$= 0.0857 \times 10^{-3}\ \text{A}$$

$$\therefore \quad I_B = 85.7\ \mu\text{A}$$

Since, $I_E = I_C + I_B$

$= (\beta + 1)I_B$

$I_E = (101)(85.7)\times10^{-6}$

$I_E = 8.65$ mA

From equation 'r_e',

$$r_e = \frac{0.026}{8.65\times10^{-3}}$$

$$= 361.59\Omega$$

Substituting corresponding values in equation (1),

$$r_{in} = 75||(101)(361.59+3)$$

$$= \frac{75\times36.82}{75+36.82}$$

$$= 24.696 \text{ k}\Omega$$

$\therefore$ $\boxed{\text{Input impedance, } r_{in} = 24.696 \text{ k}\Omega}$

The overall gain, A_V in a CC amplifier is given by,

$$A_V = \frac{V_L}{V_S}$$

$$= \left(\frac{r_L}{r_e + r_L}\right)\left(\frac{Z_i}{R_S + Z_i}\right)$$

For $R_S = 0$,

$$A_V = \frac{361.59}{361.59+3}$$

$$= 0.992$$

$\therefore$ $\boxed{\text{Voltage gain, } A_V = 0.992}$

Q27. Compare the characteristics of CB, CE and CC amplifiers.

Ans:

Comparison between characteristics of CE, CB and CC amplifiers is given in table below.

	CE		CB		CC
1.	It has high current gain	1.	Current gain is less than one	1.	Current gain is large
2.	It has high voltage gain	2.	Voltage gain is very large	2.	Voltage gain is approximately one
3.	Since A_V and A_I are large, power gain is also high.	3.	Power gain is nearly equal to voltage gain	3.	Power gain is approximately equal to current gain
4.	The phase shift in output is 180°	4.	No phase shift in output	4.	No phase shift in output
5.	Input impedance is moderate	5.	Input impedance is less	5.	Input impedance is high
6.	Output impedance is moderate	6.	Output impedance is high	6.	Output impedance is very small.

Q28. Draw the CE amplifier with unbypassed emitter resistance and derive the expression for R_i and A_V.

Model Paper-I, Q8

Ans:

The CE amplifier circuit with an unbypassed emitter resistance is as shown in figure (1).

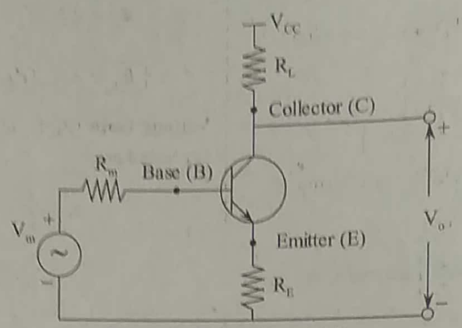


Figure (1): CE Amplifier with R_E

From figure (1), it can be observed that, resistance R_E is connected between emitter and ground. By using dual of Miller's theorem, R_E can be splitted into two seperate resistances, one connected between base and source and the other connected between collector and load.

The two resistances become $R_E(1-A_I)$ and $R_E\left(1-\frac{1}{A_I}\right)$

Where, A_I - Current gain.

The h-parameter model incorporating the two resistances at the respective positions is as shown in figure (2).

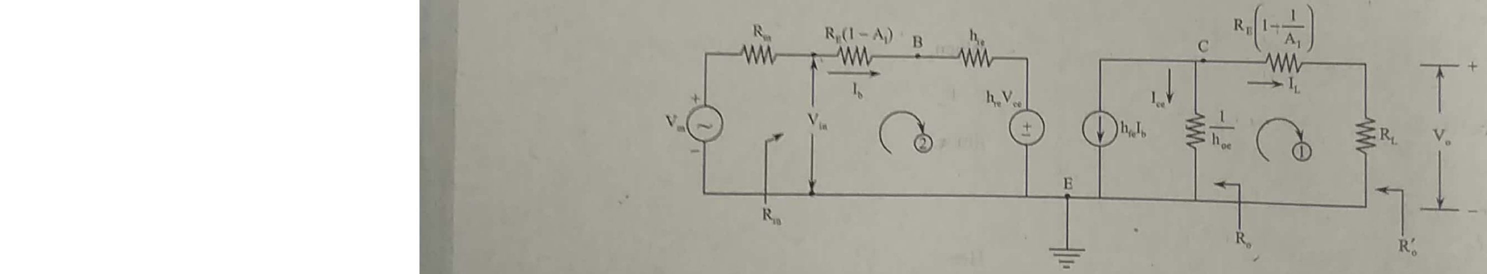


Figure (2): h-Parameter Model For CE Amplifier with R_E

Using h-parameter model, the circuit parameters can be obtained as,

Current Gain A_I: The current gain of an amplifier is expressed as,

$$A_I = \frac{I_L}{I_b}$$

Applying KVL for loop (1),

$$-\left[(-I_{ce})\times\frac{1}{h_{oe}}\right]-I_L\left[R_E\left(1-\frac{1}{A_I}\right)\right]-I_L R_L=0$$

$$\Rightarrow \quad I_{ce} = I_L h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right] \quad \text{... (1)}$$

$$h_{fe}I_b + I_L h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]+I_L = 0$$

[$\because$ From equation (1)]

$$\Rightarrow \quad I_L\left[h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]+1\right] = -h_{fe}I_b$$

Rearranging the above equation for current gain, A_I,

$$A_I = \frac{I_L}{I_b} = \frac{-h_{fe}}{h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]+1}$$

$$\Rightarrow \quad A_I = \frac{-h_{fe}}{h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]+1}$$

$$\Rightarrow \quad A_I h_{oe} R_E\left(1-\frac{1}{A_I}\right) + h_{oe} A_I R_L + A_I = -h_{fe}$$

$$A_I h_{oe} R_E - h_{oe} R_E + h_{oe} A_I R_L + A_I = -h_{fe}$$

$$A_I [h_{oe} R_E + h_{oe} R_L + 1] = -h_{fe} + h_{oe} R_E$$

$$\boxed{\therefore A_I = \frac{-h_{fe}+h_{oe}R_E}{1+h_{oe}(R_E+R_L)}} \quad \text{... (2)}$$

Input Resistance (R_{in}): The input resistance, R_{in} of an amplifier is expressed as,

$$R_{in} = \frac{V_{in}}{I_b}$$

On applying KVL to loop (2),

$$\frac{V_{in} - V_{ce}h_{re}}{I_b} = R_E(1-A_I) + h_{ie} \quad \text{... (3)}$$

Where,

$$V_{ce} = \frac{1}{h_{oe}} \times I_{ce} = \frac{1}{h_{oe}} \times I_L h_{oe}\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]$$

$$\Rightarrow \quad V_{ce} = I_L\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]$$

Substituting the value of 'V_{ce}' in equation (3),

$$\frac{V_{in}}{I_b} - \left(\frac{I_L}{I_b}\right)\left[R_E\left(1-\frac{1}{A_I}\right)+R_L\right]h_{re} = R_E(1-A_I) + h_{ie}$$

Since,

$$A_I = \frac{I_L}{I_b}$$

$$R_{in} = A_I R_E h_{re} - R_E h_{re} + R_L A_I h_{re} + R_E(1-A_I) + h_{ie}$$

$$\boxed{R_{in} = A_I h_{re}(R_E+R_L) + R_E(1-A_I-h_{re}) + h_{ie}}$$

Voltage Gain (A_V): The voltage gain, A_V of an amplifier is expressed as,

$$A_V = \frac{V_o}{V_{in}}$$

$$= \frac{A_I I_b \times R_L}{V_{in}} \quad [\because V_o = I_L R_L \text{ and } I_L = A_I I_b]$$

$$\therefore \quad \frac{V_{in}}{I_b} = R_i$$

$$\boxed{A_V = \frac{A_I R_L}{R_i}} \quad \text{... (4)}$$

Output Resistance (R_o): The output resistance, R_o of an amplifier is expressed as,

$$R_o = \frac{V_{out}}{I_{out}} = \left.\frac{V_o}{I_L}\right|_{\text{with } V_{in}=0}$$

When, $V_{in} = 0$, applying KVL to input loop (2),

$$V_{in} - I_b R_m - I_b R_E(1-A_I) - I_b h_{ie} - h_{re}V_{ce} = 0 \quad \text{... (5)}$$

Since,

$$V_{ce} = I_{ce} \times \frac{1}{h_{oe}} = \frac{-h_{fe}I_b}{h_{oe}} \quad [\because I_{ce} = -h_{fe}I_b]$$

Hence, equation (5) becomes,

$$0 - I_b R_m - I_b R_E(1-A_I) - I_b h_{ie} + \frac{h_{re}h_{fe}I_b}{h_{oe}} = 0$$

$$\therefore \quad I_b = 0$$

$$\Rightarrow \quad I_{ce} = -h_{fe}I_b = 0$$

$$\Rightarrow \quad I_L = 0$$

Hence, $R_o = \frac{V_o}{I_L} = \infty$

Thus, the output resistance considering load is,

$$R_o' = R_o \parallel R_L = R_L$$

$$\boxed{R_o' = R_L}$$

4.3 LOW FREQUENCY RESPONSE OF BJT AMPLIFIERS EFFECT OF COUPLING AND BYPASS CAPACITORS ON CE AMPLIFIER

Q29. Explain the concept of low frequency response of BJT.

Ans:

Low Frequency Response: The low frequency response of BJT amplifier is explained by considering self biased common emitter amplifier i.e., as shown in figure (1).

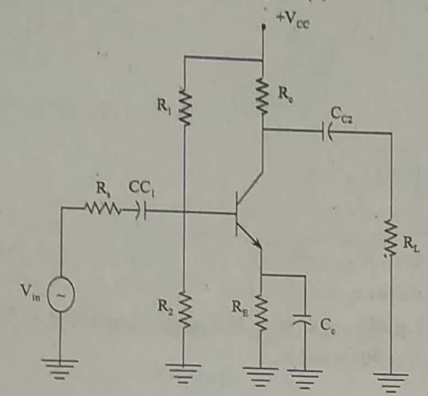


Figure (1): Self Biased CE Amplifier

The base circuit of common emitter amplifier is as shown in figure (2).

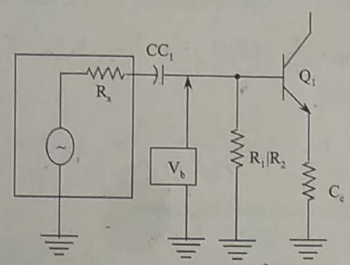


Figure (2): Base Circuit

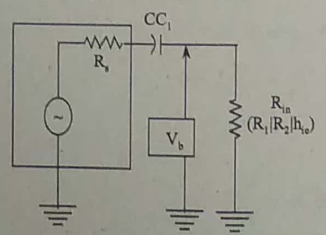


Figure (3): Equivalent Circuit

In the above equivalent circuit figure (2), the resistance R_1 and R_2 are in parallel and the resultant of R_1 and R_2 is in parallel with h_{ie}. If source resistance R_s is equal to zero then total input resistance is $R_1 \| R_2 \| h_{ie}$.

The base voltage (V_b) can be determined by considering input base circuit shown in figure (3).

$$V_b = V_{in} \frac{R_{in}}{\sqrt{X_c^2 + R_{in}^2}}$$

$$\left(\because |R_{in} - jX_c| = \sqrt{R_{in}^2 + X_c^2} \text{ voltage divider rule}\right)$$

If $X_c = R_{in}$ then,

$$V_b = V_{in} \frac{R_{in}}{\sqrt{2R_{in}^2}} = \frac{1}{\sqrt{2}} V_{in}$$

$$\boxed{V_b = 0.707\, V_{in}}$$

When $X_c = R_{in}$, the base voltage $V_n = 0.707\, V_{in}$. Therefore voltage gain of the circuit is effectively diminished to 0.707 $A_{v(mid)}$. The basic capacitive reactance is given by the expression,

$$X_c = \frac{1}{2\pi f C}$$

$$\Rightarrow \quad f = \frac{1}{2\pi X_c . C}$$

The above frequency expression can be written as,

$$f = \frac{1}{2\pi RC}$$

Because, the X_c (Capacitive reactance) is equal to the total A.C resistance at lower cutoff frequencies,

$$\Rightarrow \quad f_{IB} = \frac{1}{2\pi RC}$$

Where,

f_{IB} – Output lower cutoff frequency of base circuit

R – Total A.C resistance

C – Value of coupling capacitor.

But in practical circuits $R_s \neq 0$, therefore R_s in the circuit is in series with input resistance R_{in}. Hence, total A.C resistance R' is given as,

$$R' = R_s + R_{in}$$

Then,

$$f_{IB} = \frac{1}{2\pi R' C}$$

$$f_{IB} = \frac{1}{2\pi(R_{in} + R_s)C}$$

$$\boxed{\therefore f_{IB} = \frac{1}{2\pi(R_{in} + R_s)C}}$$

The reactance of coupling capacitor is same as the value of the effective resistance of R_C and R_L. Then the output voltage falls to 0.707 times midband value i.e., 0.707 A_v. The collector circuit cutoff frequency is given by the expression.

$$f_c = \frac{1}{2\pi(R_C + R_L)C}$$

Where,

f_{1C} – Lowest cutoff frequency of collector circuit

C – Value of output coupling capacitance.

Q30. Show that for low frequency response of CE amplifier the gain in dB is given by, $A_{v(dB)} = -20\log_{10}(f/f_1)$ where f_1 is the lower cut-off frequency.

Ans:

The gain of a CE amplifier at low frequencies is given by the expression,

$$A_u = \frac{A_{mid}}{\sqrt{1+\left(\frac{f}{f_1}\right)^2}} \quad \text{... (1)}$$

Where,

A_{mid} - Gain at mid frequency range

f - Operating frequency

f_1 - Lower cutoff frequency.

At low frequencies, the gain of an amplifier at mid frequency range is approximately equal to unity i.e.,

$$\Rightarrow A_{mid} \approx 1$$

Then, equation (1) becomes,

$$\Rightarrow A_v = \frac{1}{\sqrt{1+\left(\frac{f}{f_1}\right)^2}}$$

$$\Rightarrow A_v = \frac{1}{\sqrt{(f_1^2+f^2)/f_1^2}} = \sqrt{\frac{f_1^2}{f_1^2+f^2}}$$

$$= \sqrt{\frac{f_1^2}{f^2}} \quad (\because f >> f_1 \text{ (Low frequencies)})$$

$$= \frac{f_1}{f}$$

$$\boxed{\therefore A_v = \frac{f_1}{f}} \quad \text{... (2)}$$

The gain of an amplifier in terms of dB is expressed by the following equation,

$$\Rightarrow A_{v(dB)} = 20 \log A_v$$

Then, from equation (2),

$$\Rightarrow A_{v(dB)} = 20 \log\left(\frac{f_1}{f}\right) = 20 \log\left(\frac{f}{f_1}\right)^{-1}$$

$$= -20 \log\left(\frac{f}{f_1}\right)$$

$$\boxed{\therefore A_{v(dB)} = -20 \log\left(\frac{f}{f_1}\right)}$$

Q31. What are the circuit components which determine the low frequency cut-off of a small signal BJT amplifier in common emitter configuration? Discuss.

Ans:

The circuit components which determine the low frequency cut-off of a small signal BJT amplifier in common emitter configuration are emitter by pass capacitor (C_e) coupling capacitor (C_c) and source capacitance (C_s).

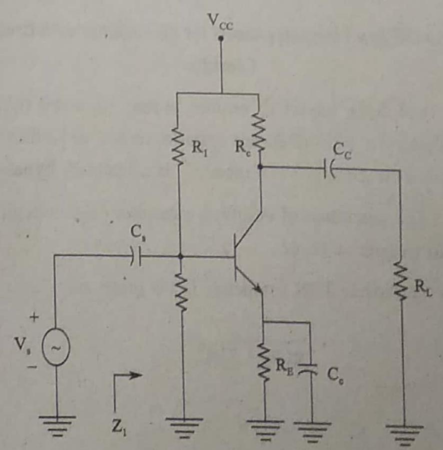


Figure (1): BJT Amplifier Loaded with Capacitors that affect the Low-frequency Response

The low frequency response of the BJT amplifier shown in figure (1) is determined by the capacitors C_C, C_s and C_E.

An approximate small signal hybrid equivalent circuit at low frequencies is as shown in figure (2).

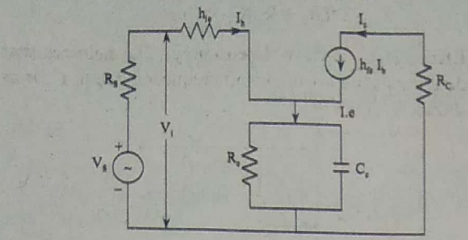


Figure (2): Small Signal Hybrid Equivalent Circuit of CE Amplifier

Effect of Coupling Capacitor 'C_C' on Low Frequency Response of CE Amplifier: At low frequencies the reactive capacitance will not affect the circuit behaviour because capacitors experiences larger values. Coupling capacitor affect is negligible at low frequency range.

The low frequency model for CE amplifier with coupling capacitor C_C is as shown in figure (3).

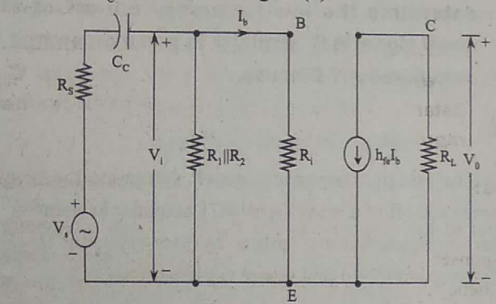


Figure (3): Low Frequency Model for CE Amplifier with Coupling Capacitor

For large values of emitter bypass capacitor (C_E), the low frequency gain does not experience any reduction in its value and the emitter resistance 'R_E' is effectively bypassed.

The reactance of coupling capacitor (C_C) is negligible for mid frequency range.

The lower 3 dB frequency (f_l) is given as,

$$f_l = \frac{1}{2\pi(R_s + R_i')C_C}$$

Where,

$R_i' = R_1 \,||\, R_2 \,||\, R_i$

$R_i = h_{ie}$ (for ideal C_E)

And $R_i \cong h_{ie} + (1 + h_{fe}) R_{CE}$ (When capacitors series resistance is considered)

Therefore, in order to achieve good low frequency response, the capacitors C_C and C_E must be maintained large.

Q32. With the help of a neat circuit diagram source capacitance of a common emitter amplifier explain,

(i) The effect of C_s on low frequency response

(ii) The effect of C_C on low frequency response

(iii) The effec f C_E on low frequency response.

Ans:

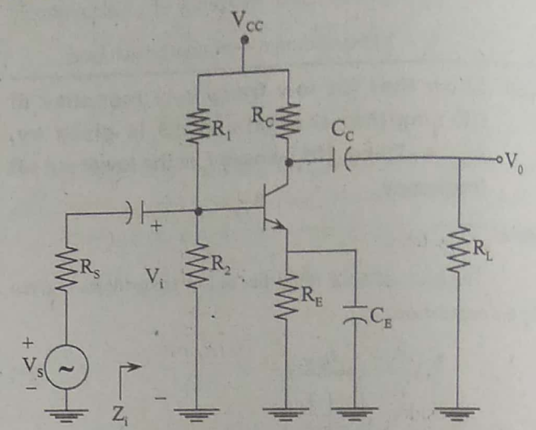


Figure (1): BJT Amplifier Loaded with Capacitors that Affect the Low-frequency Response

The low frequency response of the BJT amplifier shown in figure (1) is determined by the capacitors C_C, C_S and C_E.

(i) Effect of C_S on the Low Frequency Response

Effect of C_S on the low frequency response is illustrated by explaining the affect of C_S on lower cut off frequency.

In order to determine the effect of C_S, the circuit in figure (1) is modified as shown in figure (2).

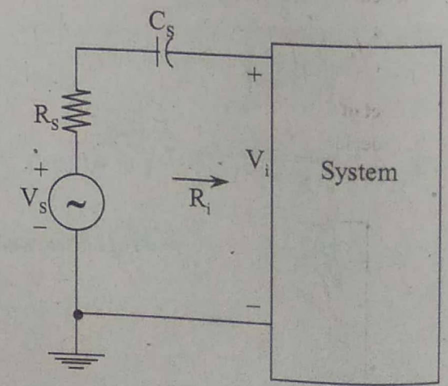


Figure (2): Network to Determine Effect of C_S

From figure (2).

$$V_i = \frac{R_i V_s}{R_s + R_i - jX_{C_s}} \quad \text{... (1)}$$

$$\Rightarrow \frac{V_i}{V_s} = \frac{R_i}{R_s + R_i - jX_{C_s}} = \frac{1}{1 + \frac{R_s}{R_i} - \frac{jX_{C_s}}{R_i}}$$

$$= \frac{1}{\left(1+\frac{R_s}{R_i}\right)\left(1-\frac{jX_{C_s}}{R_i}\left(\frac{R_i}{R_i+R_s}\right)\right)} \quad \text{... (2)}$$

$$\Rightarrow \frac{V_i}{V_s} = \frac{1}{\left(1+\frac{R_s}{R_i}\right)\left(1-\frac{jX_{C_s}}{R_i+R_s}\right)}$$

The factor $\frac{X_{C_s}}{R_i+R_s} = \left(\frac{1}{2\pi f C_s}\right)\left(\frac{1}{R_i+R_s}\right)$

$$= \frac{1}{2\pi f(R_i+R_s)C_s}$$

Considering, $\frac{1}{2\pi f(R_i+R_s)C_s} = f_i$

The equation (2) can be written as,

$$\frac{V_i}{V_s} = \frac{1}{\left(1+\frac{R_s}{R_i}\right)\left(1-\frac{1}{(1-jf_i/f)}\right)}$$

And $A_v = \frac{V_i}{V_s} = \frac{1}{\left(1+\frac{R_s}{R_i}\right)\left(1-\frac{1}{(1-jf_i/f)}\right)}$

The cut-off frequency offered by C_S is,

$$f_{Ls} = \frac{1}{2\pi(R_s+R_i)C_s}$$

(ii) **Effect of C_C on Low Frequency:** The R_C configuration that decides the lower cut-off frequency due to C_C is as shown in figure (3).

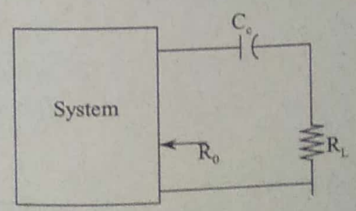


Figure (3)

From figure (3), the lower cut-off frequency due to C_c is,

$$f_{LC} = \frac{1}{2\pi(R_0+R_L)C_C}$$

(iii) **Effect of C_E on low Frequency:** The network that determines the lower cut-off frequency due to C_E is as shown in figure (4).

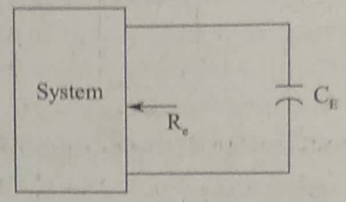


Figure (4)

The lower cut-off frequency due to C_E is,

$$f_{LE} = \frac{1}{2\pi R_e C_E}.$$

If the lower cutoff frequencies due to C, C and C_E are relative far apart then among the three f_{Ls}, f_{Lc}, and f_{LE} the one having the highest frequency determine the lower cut-off frequency of the entire systems.

Q33. How does the emitter by-pass capacitor C_E determines a lower 3 dB frequency? Derive the required results.

Ans: Model Paper-II, Q9

Effect of Emitter Bypass Capacitor on Low Frequency Response: C_E is the emitter bypass capacitor which causes frequency response of an amplifier to break at a cut-off frequency, f_c and prevents the reduction of A.C gain by passing A.C signal current through it.

The gain falls at low frequency region because of coupling capacitors C_1, C_2, C_3... and emitter bypass capacitor C_{E1}, C_{E2}, C_{E3}, C_E.

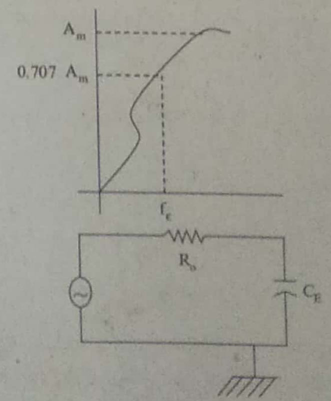


Figure (1): Frequency Response

The bypass capacitor C_E also effects the circuit performance at low frequency. The effect of C_E is voltage drop across C_C reduces V_i with a drop in V_o.

The C_E avoids the loss in A.C signal gain of the stages.

The A.C voltage drop across R_E reduces the gain. So, C_E capacitor is connected across R_E so that, all the A.C current is passed through C_E and decrease A.C voltage drop across R_E, thus increasing overall gain.

The frequency at which the gain drops by a factor of $\frac{1}{\sqrt{2}}$ is lower 3-dB frequency, $f_1 = \frac{1}{2\pi(R_s + R_i)C}$.

Derivation

A single stage CE amplifier is as shown in figure (2).

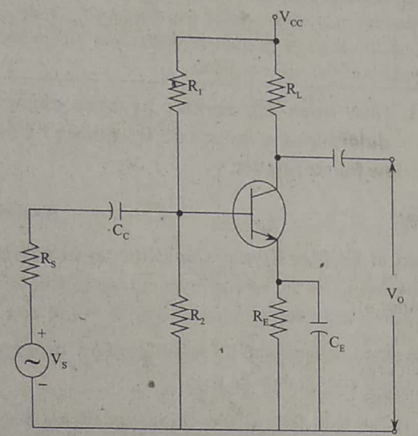


Figure (2): Single Stage CE Amplifier

The expression for low voltage gain in low frequency region '$A_{V(LF)}$' is given as,

$$A_{V(LF)} = \frac{V_O}{V_S}$$

Where,

V_O – Output voltage

V_S – Source voltage

Assuming coupling capacitor C_C to be large in low frequency region such that X_C is small. Also, $R_1 \| R_2$ to be greater than R_i such that both X_C and $R_1 \| R_2$ can be neglected in the h-parameter equivalent circuit as shown in figure (3).

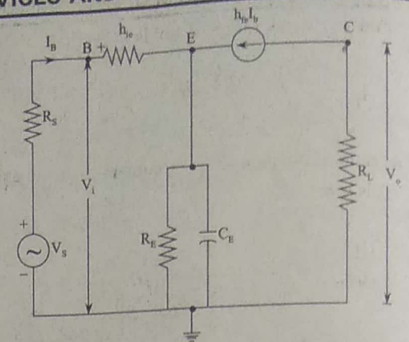


Figure (3): Simplified h-parameter Equivalent Circuit for CE Amplifier

From figure (3),

$$V_o = -h_{fe}I_BR_L \quad \text{... (1)}$$

Where,

$$I_b = \frac{V_s}{R_s + R_i} \quad \text{... (2)}$$

Since, for a CE amplifier,

$$R_i = h_{ief} + (1 + h_{fe})Z_E \quad \text{... (3)}$$

Where,

$$Z_E = R_E \| X_{CE}$$

$$Z_E = \frac{R_E}{1 + j\omega C_E R_E} \quad \text{... (4)}$$

On substituting equation (4) in equation (3),

$$R_i = h_{ie} + \frac{(1+h_{fe})R_E}{1 + j\omega C_E R_E} \quad \text{... (5)}$$

On substituting equation (5) in equation (2),

$$I_b = \frac{V_s}{R_s + h_{ie} + \frac{(1+h_{fe})R_E}{1 + j\omega C_E R_E}} \quad \text{... (6)}$$

On substituting equation (6) in equation (1),

$$V_o = -h_{fe}R_L \frac{V_S}{R_s + h_{ie} + \frac{(1+h_{fe})R_E}{1 + j\omega C_E R_E}} \quad \text{... (7)}$$

$$\Rightarrow A_{V(LF)} = \frac{V_o}{V_s} = \frac{-h_{fe}R_L}{R_s + h_{ie} + \frac{(1+h_{fe})R_E}{1 + j\omega C_E R_E}} \quad \text{... (8)}$$

In mid-frequency range, if 'ω' is large then,

$$A_{V(MF)} = \frac{V_o}{V_s} = \frac{-h_{fe}R_L}{R_s + h_{ie}} \quad \text{... (9)}$$

The ratio of the gain at low frequencies to the gain mid frequencies is given as,

$$\frac{A_{V(LF)}}{A_{V(MF)}} = \frac{R_s + h_{ie}}{R_s + h_{ie} + \frac{(1+h_{fe})R_E}{1+j\omega C_E R_E}} \quad \text{... (10)}$$

$$= \frac{1}{1+\frac{(1+h_{fe})R_E}{R_s+h_{ie}}} \times \frac{1+j\frac{f}{f_o}}{1+j\frac{f}{f_p}} \quad \text{... (11)}$$

Where,

$$f_o = \frac{1}{2\pi C_E R_E} \text{ and } f_p = \frac{1+\frac{(1+h_{fe})R_E}{R_s+h_{ie}}}{2\pi C_E R_E}$$

If $\frac{(1+h_{fe})R_E}{R_S+h_{ie}} >> 1$ then,

$$f_p \approx \frac{\frac{(1+h_{fe})R_E}{R_s+h_{ie}}}{2\pi C_E R_E} \quad \text{... (12)}$$

From equation (11) and equation (12), $f_p >> f_o$.

At $f = f_p$ $\frac{A_{V(LF)}}{A_{V(MF)}}$ becomes,

$$\frac{A_{V(LF)}}{A_{V(MF)}} = \frac{R_s+h_{ie}}{(1+h_{fe})R_E} \times \frac{1+j\frac{f_p}{f_o}}{1+j1}$$

$$\simeq \frac{R_s+h_{ie}}{(1+h_{fe})R_E} \times \frac{j\frac{f_p}{f_o}}{1+j1}$$

The magnitude of this ratio is,

$$\left|\frac{A_{V(LF)}}{A_{V(MF)}}\right| = \frac{R_s+h_{ie}}{(1+h_{fe})R_E} \times \frac{\frac{f_p}{f_o}}{\sqrt{2}}$$

Since,

$$\frac{f_p}{f_o} \approx \frac{(1+h_{fe})R_E}{R_s+h_{ie}}$$

$$\left|\frac{A_{V(LF)}}{A_{V(MF)}}\right| = \frac{1}{\sqrt{2}} \quad \text{... (13)}$$

The ratio of voltage gain is dropped by $\frac{1}{\sqrt{2}}$, hence the power gain at low frequency drops by $\frac{1}{2}$ or 3 dB forming gain at mid frequency.

$$\therefore f_1 \approx f_p = \frac{1+\frac{(1+h_{fe})R_E}{R_s+h_{ie}}}{2\pi C_E R_E} = \frac{(1+h_{fe})R_E}{(R_s+h_{ie})2\pi C_E R_E}$$

$$= \frac{(1+h_{fe})}{(R_s+h_{ie})2\pi C_E} \quad \text{... (14)}$$

Consider, $f_p = f_o$, when this condition is not satisfied, $f_1 \neq f_p$ and no 3-dB point exists.

From equation (14), the expression for C_E at lower 3 dB frequency f_1 is obtained as,

$$C_E = \frac{1+h_{fe}}{2\pi f_1 (R_s + h_{ie})} \quad \text{... (15)}$$

Q34. Explain the effect of coupling capacitor C_c on low frequency range.

Ans:

Effect of Coupling Capacitor 'C_C' on Low Frequency Response of CE Amplifier: At low frequencies the reactive capacitance will not affect the circuit behavior because capacitors experiences larger values. Coupling capacitor affect is negligible at low frequency range.

The low frequency model for CE amplifier with coupling capacitor C_C is as shown in figure.

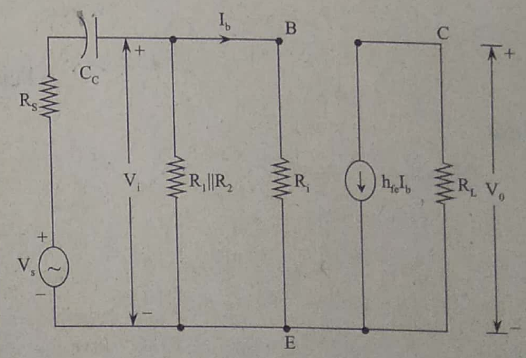


Figure: Low Frequency Model for CE Amplifier with Coupling Capacitor

For large values of emitter bypass capacitor (C_E), the low frequency gain does not experience any reduction in its value and the emitter resistance 'R_E' is effectively bypassed.

The reactance of coupling capacitor (C_C) is negligible for mid frequency range.

The lower 3 dB frequency (f_1) is given as,

$$f_1 = \frac{1}{2\pi(R_s + R_i')C_C}$$

Where,

$R'_i = R_1 \| R_2 \| R_i$

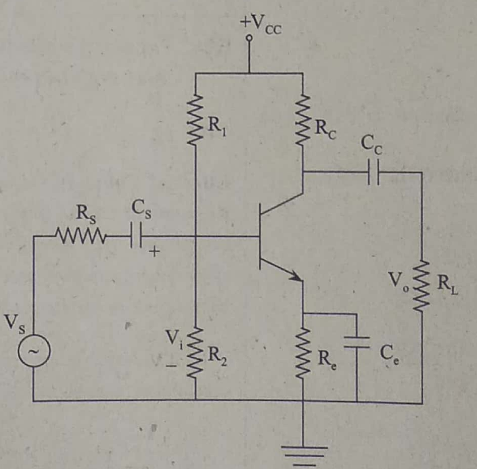
$R_i = h_{ie}$ (for ideal C_E)

When capacitors series resistance is considered

$R_i \cong h_{ie} + (1 + h_{fe})\, R_{CE}$

Therefore, in order to achieve good low frequency response, the capacitors C_C and C_E must be maintained large.

Q35. Determine the lower cut-off frequency for the circuit given below in figure using the following parameters, C_s = 10 μF, C_e = 20 μF, C_C = 1 μF, R_s = 1 kΩ, R_1 = 40 kΩ, R_2 = 10 kΩ, R_e = 2 kΩ, R_C = 4 kΩ, R_L = 2.2 kΩ, b = 100, V_{CC} = 20 V. Assume any parameter values required.



Figure

Ans: **Model Paper-III, Q9**

Given that,

For a network,

C_S = 10 μF, C_E = 20 μF, C_C = 1 μF

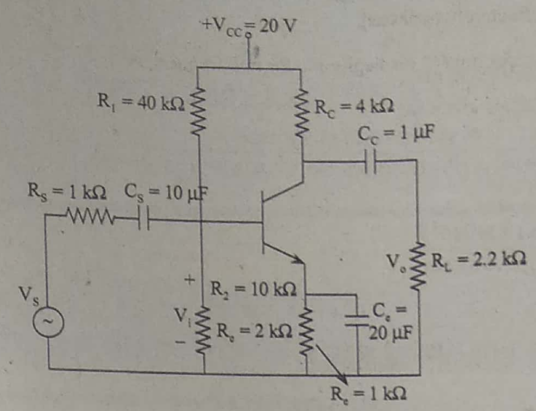
R_S = 1 kΩ, R_1 = 40 kΩ, R_2 = 10 kΩ

R_E = 2 kΩ, R_C = 4 kΩ, R_2 = 10 kΩ

β = 100, V_{CC} = 20 V

Lower cut-off frequency, f_{LS} = ?

The given circuit arrangement is shown in figure.



Figure

The expression for lower cut-off frequency of a common emitter amplifier circuit is,

$$\boxed{F_{LS} = \frac{1}{2\pi(R_s + R_i)C}}$$

- Where, $R_i = R_1 \| R_2 \| \beta_{re}$

The value of resistance r_e is obtained as,

$$\beta R_E = (100)\ (2 \times 10^3) = 200\ k\Omega >> 10\ R_2$$

Where, R_E is the unbypassed resistor.

Thus,

$$V_B \cong \frac{R_2 V_{CC}}{R_2 + R_1} = \frac{10 \times 10^3 \times 20}{10 \times 10^3 + 40 \times 10^3} = \frac{10^3 (10 \times 20)}{10^3 (10 + 40)} = 4\ V$$

$$I_E = \frac{V_E}{R_E} = \frac{V_B - 0.7}{R_E} \qquad (\because V_{BE} = V_B - V_E \text{ and } V_{BE} = 0.7 \text{ for silicon})$$

$$\Rightarrow \quad I_E = \frac{4 - 0.7}{2 \times 10^3} = \frac{3.3}{2 \times 10^3} = 1.65 \times 10^{-3} = 1.65\ mA$$

$$r_e = \frac{26}{I_{E(mA)}} = \frac{26}{1.65} = 15.76\ \Omega$$

$$\therefore \quad \beta r_e = 100(15.76) = 1576 \text{ or } 1.576\ k\Omega$$

$$\boxed{\therefore \beta r_e = 1.576\ k\Omega}$$

Then,

$$R_i = R_1 \parallel R_2 \parallel \beta r_e$$

$$= 40\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 1.576\text{ k}\Omega$$

$$= \frac{(40\times10^3)(10\times10^3)(1.576\times10^3)}{(40\times10^3)(10\times10^3)+(10\times10^3)(1.576\times10^3)+(40\times10^3)(1.5765\times10^3)} \qquad \left(\because R_1 \parallel R_2 \parallel R_3, R_{eq} = \frac{R_1R_2R_3}{R_1R_2+R_2R_3+R_1R_3}\right)$$

$$= \frac{10^6(40\times10\times1.576\times10^3)}{10^6(400+15.76+63.04)}$$

$$= \frac{630.4\times10^3}{478.8} = 1.316\times10^3 = 1.32\text{ k}\Omega$$

$$\boxed{\therefore R_i = 1.32\text{ k}\Omega}$$

$$F_{LS} = \frac{1}{2\pi(R_S+R_i)C_S} = \frac{1}{2\pi(1\times10^3+1.32\times10^3)[10\times10^{-6}]}$$

$$= \frac{1}{2\pi(2.32)10^3\times10\times10^{-6}}$$

$$= \frac{1}{14.56\times10^{-2}} = 6.86\text{ Hz}$$

$$\boxed{\therefore F_{LS} = 6.86\text{ Hz}}$$