ELECTRONIC DEVICES AND CIRCUITS

UNIT III
Transistor Biasing and Stabilization: Bias Stability, Fixed Bias, Collector to Base bias, Self Bias, Bias compensation using Diodes and Transistors.
Analysis and Design of Small Signal Low Frequency BJT Amplifiers: Analysis of CE, CC,CB Amplifiers and CE Amplifier with emitter resistance, low frequency response of BJT Amplifiers, effect of coupling and bypass capacitors on CE Amplifier.

3.1 Introduction to Bias Stability

- The biasing circuit should be designed to fix the operating point or Q point at the center of the active region.
- While designing the biasing circuit, care should be taken so that the operating point will not shift into an undesirable region (i.e. into cut-off or saturation region).
- Designing the biasing circuit to stabilize the Q point is known as **bias stability**.
- Two important factors are to be considered while designing the biasing circuit which is responsible for shifting the operating point
    - Temperature dependent factors (I_{co}, V_{BE})
    - Transistor current gain β / h_{fe}
- To maintain the operating point stable by keeping I_C and V_{BE} constant so that the transistor will always work in active region, the following techniques are normally used
    - Stabilization techniques
    - Compensation techniques.

3.1.1 Stabilization techniques

- Stabilization techniques refer to the use of resistive biasing circuits which allow I_B to vary so as to keep I_C relatively constant with variations in I_{CO}, β and V_{BE}.

3.1.2 Compensation techniques

- Compensation techniques refer to the use of temperature sensitive devices such as diode, transistors, thermistors, etc., which provide compensating voltages and currents to maintain the operating point stable.

3.2 Stability Factor

The stability factor may be defined as the rate of change of collector current with respect to the reverse saturation current keeping the common-emitter current gain (β) and base emitter voltage (V_{BE}) as constant.

$$S = \left.\frac{\partial I_C}{\partial I_{CO}}\right|_{V_{BE},\ \beta \text{ constant}} \quad \text{or} \quad S = \left.\frac{\Delta I_C}{\Delta I_{CO}}\right|_{V_{BE},\ \beta \text{ constant}}$$

- The stability factor is a measure of bias stability of a transistor circuit.
- Stability factor indicates the degree of change in operating point due to variation in temperature.
- Ideally stability factor should be perfectly zero to keep the operating point stable.

- Practically stability factor have the value as minimum as possible.
- Other stability factors are

$$S' = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_{I_{CO},\ \beta \text{ constant}} \quad \text{or} \quad S' = \left.\frac{\Delta I_C}{\Delta V_{BE}}\right|_{I_{CO},\ \beta \text{ constant}}$$

$$S'' = \left.\frac{\partial I_C}{\partial \beta}\right|_{I_{CO},\ V_{BE} \text{ constant}} \quad \text{or} \quad S'' = \left.\frac{\Delta I_C}{\Delta \beta}\right|_{I_{CO},\ V_{BE} \text{ constant}}$$

3.2.1 Derivation of stability factor

For a common emitter configuration collector current is given as,

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

When I_{CBO} changes by ΔI_{CO}, I_B changes by ∂I_B and I_C changes by ∂I_C. So this equation becomes,

$$\partial I_C = \beta\, \partial I_B + (1+\beta)\, \partial I_{CO}$$

$$1 = \beta \frac{\partial I_B}{\partial I_C} + (1+\beta) \frac{\partial I_{CO}}{\partial I_C}$$

$$1 - \beta \frac{\partial I_B}{\partial I_C} = (1+\beta) \frac{\partial I_{CO}}{\partial I_C}$$

$$\frac{\partial I_{CO}}{\partial I_C} = \frac{1-\beta(\partial I_B / \partial I_C)}{1+\beta} \qquad \because\ S = \frac{\partial I_C}{\partial I_{CBO}}$$

$$S = \frac{(1+\beta)}{1-\beta(\partial I_B / \partial I_C)}$$

- The above equation can be considered as a standard equation for derivation of stability factors of other biasing circuits.

3.3 Methods of Transistor Biasing

Following are the most commonly used methods for biasing the transistors.

- Fixed bias (Base bias)
- Emitter feedback bias (Base bias with emitter feedback)
- Collector feedback bias (Base bias with collector feedback)
- Collector - Emitter Feedback Bias (Base bias with Collector - Emitter Feedback)
- Voltage divider bias (self bias)

3.4 Fixed bias (Base bias)

- The Fig. 3.1 shows the common emitter amplifier using fixed bias circuit.
- It is the simplest d.c bias configuration.

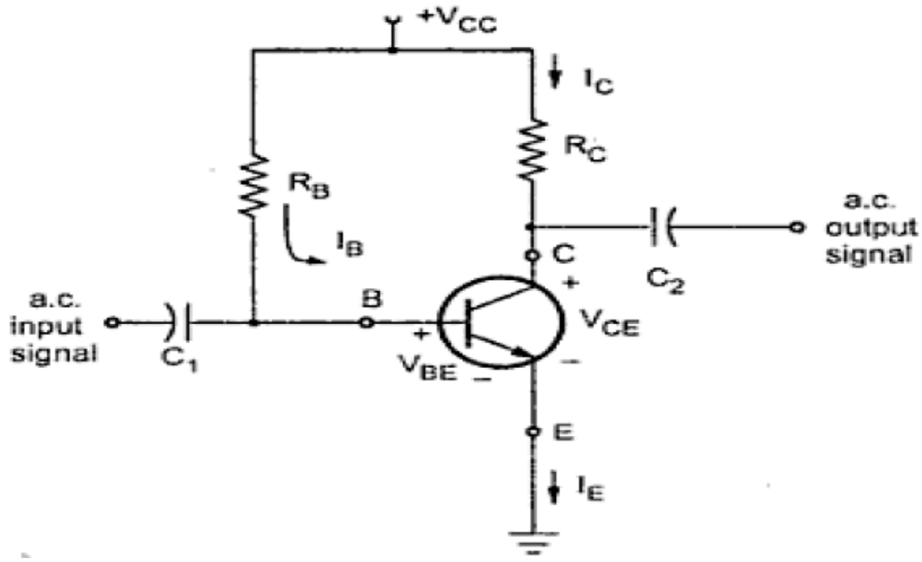


Fig. 3.1 Common emitter amplifier using fixed bias

- For the d.c analysis we can replace capacitor with an open circuit.
- The d.c equivalent circuit of fixed bias is shown in Fig. 3.2.

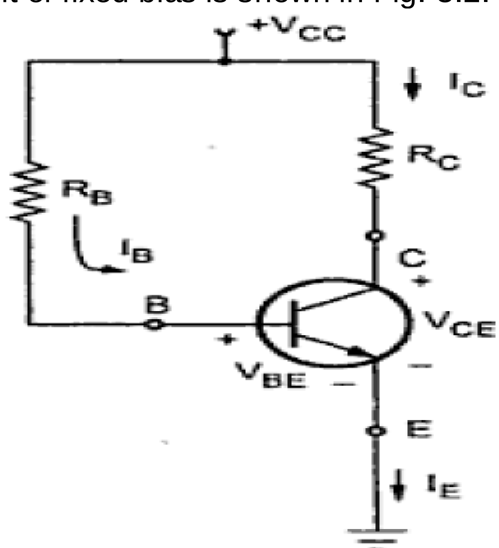


Fig. 3.2 DC equivalent circuit of fixed bias

3.4.1 Base-Emitter Circuit Analysis

- Applying Kirchhoff's voltage law to the base-emitter circuit of figure 4.12, we get

$$V_{CC} - I_B R_B - V_{BE} = 0$$

Solving for the current I_B,

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}} \qquad \ldots (1)$$

3.4.2 Collector-Emitter Circuit Analysis

- Applying Kirchhoff's voltage law to the collector-emitter circuit of figure 3.2, we get

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\therefore \quad \boxed{V_{CE} = V_{CC} - I_C R_C} \quad \ldots (2)$$

The magnitude of collector current is given by,

$$\therefore \quad \boxed{I_C = \beta I_B} \quad \ldots (3)$$

and from equation (2) we have,

$$\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}} \quad \ldots (4)$$

- However, the change in R_C will change the value of V_{CE}.

$$\boxed{V_{CE} = V_C - V_E} \quad \ldots (5)$$

Where, V_C : Collector voltage

V_E : Emitter voltage

Similarly,

$$\boxed{V_{BE} = V_B - V_E} \quad \ldots (6)$$

Where, V_B : Base voltage

In this circuit, $V_E = 0$,

$$\therefore \quad \boxed{V_{BE} = V_B} \quad \ldots (7)$$

and $$\boxed{V_{CE} = V_C} \quad \ldots (8)$$

3.4.3 Stability factor for fixed bias

- From the base-emitter circuit analysis of figure 3.2, we have base current

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

- Differentiate the above equation with respect to Collector current I_C

$$\frac{\partial I_B}{\partial I_C} = 0 \quad \text{--- (i)}$$

- We have general formula for stability factor

$$S = \frac{1+\beta}{1-\beta(\partial I_B / \partial I_C)} \quad \text{--- (ii)}$$

- Substitute the value of equation (i) in equation (ii), we get

$$S = \frac{1+\beta}{1-0}$$

$$\boxed{S = 1 + \beta}$$

3.4.4 Advantages and Disadvantages of Fixed bias circuit

Advantages

- Simple circuit which uses very few components.
- It provides maximum flexibility in the design.

Disadvantages

- Operating point is not maintained.
- Stabilization of operating point is very poor.

Example: *For the circuit shown in the Fig. calculate $I_B, I_C, V_{CE}, V_B, V_C$ and V_{BC}. Assume $V_{BE} = 0.7\ V$ and $\beta = 50$.*

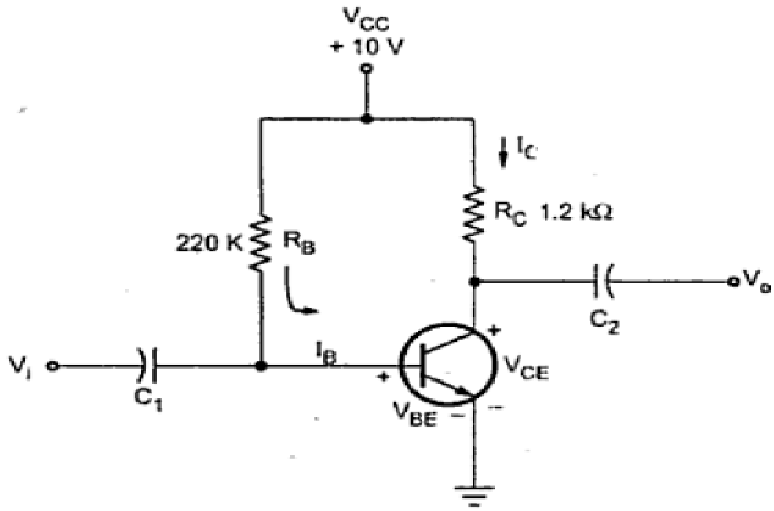


Fig.

Solution :

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{220 \times 10^3} = \mathbf{42.27\ \mu A}$$

$$I_C = \beta I_B = 50 \times 42.27 \times 10^{-6} = \mathbf{2.1135\ mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 10 - 2.1135 \times 10^{-3} \times 1.2 \times 10^3$$

$$= \mathbf{7.4638\ V}$$

$$V_B = V_{BE} = \mathbf{0.7\ V}$$

$$V_C = V_{CE} = \mathbf{7.4638\ V}$$

$$V_{BC} = V_B - V_C = 0.7 - 7.4638 = -\ \mathbf{6.7638}$$

The negative voltage V_{BC} indicates that base-collector junction is reverse biased.

3.5 Collector feedback bias (Base bias with collector feedback)

- The Fig. 3.3 shows the d.c bias with voltage feedback.
- It is also called the collector to base bias circuit.

- It is an improvement over the fixed-bias method.
- In this the biasing resistor is connected between the collector and the base of the transistor to provide a feedback path.
- Thus I_B flow through R_B and $(I_C + I_B)$ flows through the R_C.

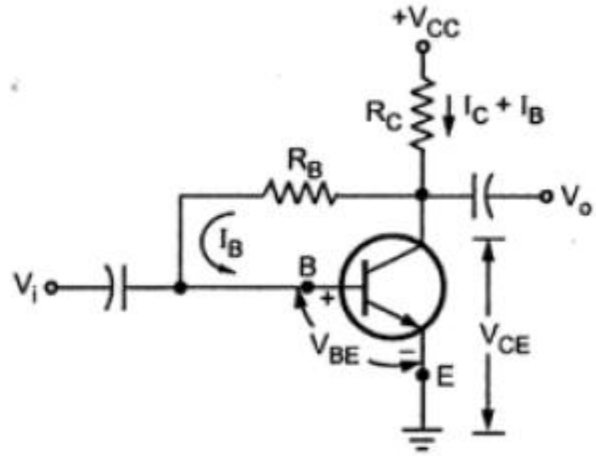


Fig. 3.3 Common emitter amplifier using Collector feedback bias

- The d.c equivalent circuit of Collector feedback bias is shown in Fig. 3.4.

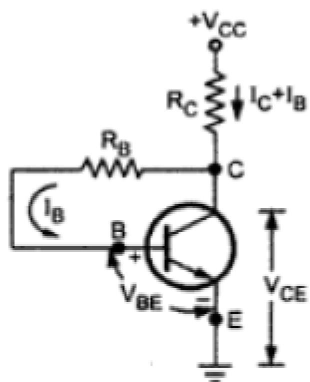


Fig. 3.4 DC Equivalent circuit of Fig. 3.3

3.5.1 Base-Emitter circuit analysis

- Applying Kirchoff's Voltage Law to the base-emitter circuit loop of figure 3.4, we get

$$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$$

$$\therefore \quad V_{CC} = (R_B + R_C)I_B + I_C R_C + V_{BE}$$

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

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

$$\therefore \quad \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_C}} \qquad \because \beta >> 1$$

3.5.2 Collector-Emitter circuit analysis

- Now Applying Kirchoff's Voltage Law to collector-emitter circuit loop of figure 3.4, we get

$$V_{CC} - (I_C + I_B)R_C - V_{CE} = 0$$

$$\therefore \quad \boxed{V_{CE} = V_{CC} - (I_C + I_B)R_C}$$

$$\boxed{I_C = \beta I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta \cdot R_C}}$$

3.5.3 Stability factor for collector feedback bias

- From the base-emitter circuit analysis of figure 3.4, we have base current

$$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$$

$$\boxed{I_B = \frac{V_{CC} - V_{BE} - I_C \cdot R_C}{R_C + R_B}}$$

- Differentiate the above equation with respect to Collector current I_C

$$\boxed{\frac{\partial I_B}{\partial I_C} = \frac{0 - 0 - 1 \cdot R_C}{R_C + R_B} = -\frac{R_C}{R_C + R_B}} \quad \text{--- (i)}$$

- We have general formula for stability factor

$$S = \frac{1+\beta}{1-\beta(\partial I_B / \partial I_C)} \quad \text{--- (ii)}$$

- Substitute the value of equation (i) in equation (ii), we get

$$S = \frac{1+\beta}{1-\beta\left(-\frac{R_C}{R_C + R_B}\right)} = \boxed{\frac{1+\beta}{1+\beta \cdot \frac{R_C}{R_C + R_B}}}$$

Example : *Calculate the Q point values (I_C and V_{CE}) for the circuit in Fig.*

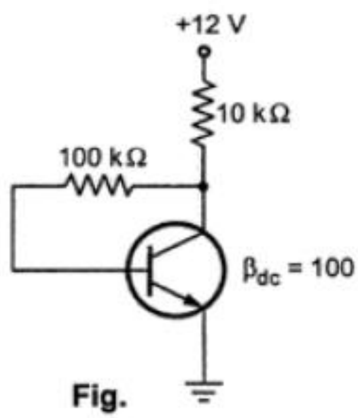


Fig.

Solution :

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_C} = \frac{12-0.7}{100\times10^3 + (1+100)\times10\times10^3}$$

$$= \mathbf{10.18\ \mu A}$$

$$\therefore \quad I_C = \beta I_B = 100 \times 10.18\ \mu A = \mathbf{1.018\ mA}$$

$$V_{CE} = V_{CC} - (I_B + I_C)\ R_C$$

$$= 12 - (10.18 \times 10^{-6} + 1.018 \times 10^{-3}) \times 10 \times 10^3 = \mathbf{1.7182\ V}$$

3.6 Voltage Divider Bias (or) Self bias

- In all the d.c biasing methods discussed earlier, we have found that the values of d.c bias current and voltage of the collector depends upon the current gain (β) of the transistor.
- The value of current gain (β) is temperature sensitive especially for silicon transistors.
- It would be desirable to provide a d.c bias circuit which is independent of the transistor current gain (β)
- Fig. 3.5 Common Emitter amplifier using Voltage divider bias circuit.
- In this circuit, the biasing is provided by three resistors: R_1, R_2 and R_C.
- The emitter resistor (R_E) providers the d.c stability.
- The resistors R_1 and R_2 act as a potential divider giving a fixed voltage to the base terminal.

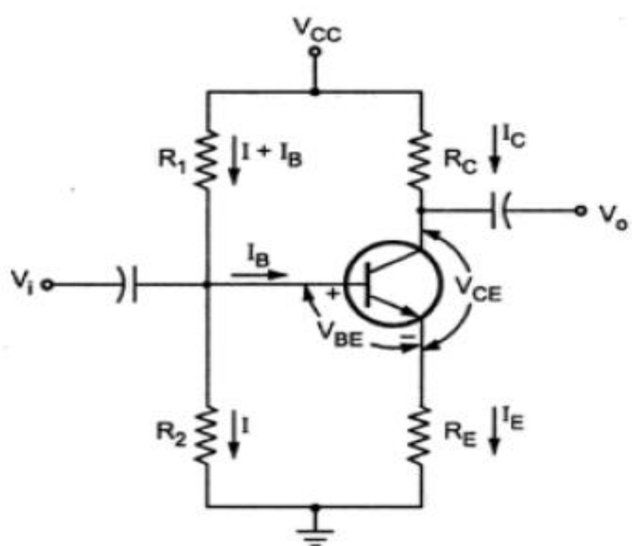


Fig. 3.5 Common Emitter amplifier using Voltage divider bias circuit

- The d.c equivalent circuit of Collector - Emitter Feedback Bias is shown in Fig. 3.6.

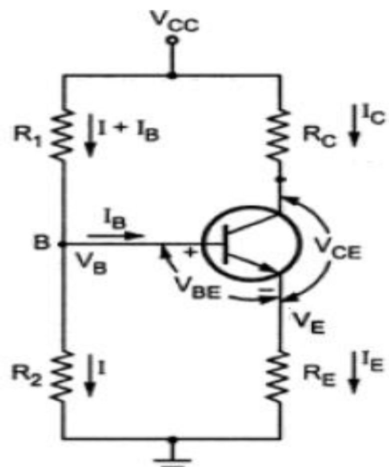


Fig. 3.6 DC Equivalent circuit of Voltage divider bias circuit

3.6.1 Base-Emitter circuit analysis

- From the figure 3.6, Voltage across R_2 is the base voltage V_B.
- Applying the voltage divider theorem to find V_B, we get,

$$\boxed{V_B = \frac{R_2}{R_1 + R_2} \times V_{CC}}$$

3.6.2 Collector-Emitter circuit analysis

- Now Applying Kirchoff's Voltage Law to collector-emitter circuit loop of figure 3.6, we get

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

Substituting $I_E \approx I_C$ in the above equation

$$\boxed{V_{CE} = V_{CC} - I_C (R_C + R_E)}$$

Voltage across R_E (V_E) can be obtained as,

$$V_E = I_E R_E = V_B - V_{BE}$$

$$\therefore \boxed{I_E = \frac{V_B - V_{BE}}{R_E}}$$

3.6.3 Simplified Circuit of Voltage Divider Bias

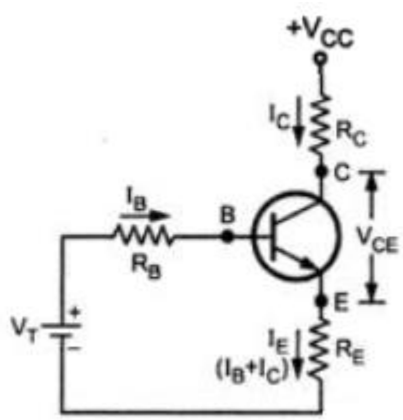


Fig. 3.7 Thevenin's equivalent circuit for voltage divider bias

- Fig. 3.7 shows simplified circuit of voltage divider bias.
- Here, R_1 and R_2 are replaced by R_B and V_B is replaced by Thevenin's voltage V_T
- R_B and V_T can be calculated as

$$\boxed{V_T = \frac{R_2 \times V_{CC}}{R_1 + R_2}}$$

$$\boxed{R_B = \frac{R_1 R_2}{R_1 + R_2}}$$

3.6.4 Stability factor for Voltage Divider Bias

- From the base-emitter circuit analysis of figure 3.7, we have base current

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

Differentiating w.r.t. I_C

$$0 = \frac{\partial I_B}{\partial I_C} \times R_B + \frac{\partial I_B}{\partial I_C} \times R_E + R_E$$

$$\therefore \quad \frac{\partial I_B}{\partial I_C}(R_E + R_B) = -R_E$$

$$\therefore \quad \frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_E + R_B}$$

We have already seen the generalized expression for stability factor S given by

$$S = \frac{1+\beta}{1-\beta\,(\partial I_B/\partial I_C)}$$

Substituting value of $\frac{\partial I_B}{\partial I_C}$ in the above equation we get,

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E + R_B}\right)}}$$

- Let R_E **>>** R_B

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E}\right)}$$

$$S = \frac{(1+\beta)}{(1+\beta)}$$

$$\boxed{S = 1}$$

3.6.5 Advantages of Self Bias or Voltage Divider Bias Circuit

- Stability factor S for voltage divider bias or self bias is less as compare to other biasing circuits.
- So this circuit is more stable and hence it is most commonly used.

Example *Determine the value of collector current and collector-to-emitter voltage for the voltage divider bias circuit shown in Fig.*

Assume $V_{BE} = 0.7$ *V and* $\beta = 100$.

Solution. Given: $V_{CC} = 10$ volts; $R_C = 1\ k\Omega = 1 \times 10^3\ \Omega$; $R_1 = 10\ k\Omega$; $R_2 = 5\ k\Omega$; $R_E = 500\ \Omega$; $V_{BE} = 0.7$ volt and $\beta = 100$.

Collector current

We know that voltage at the base,

$$V_B = V_{CC}\left(\frac{R_2}{R_1 + R_2}\right) = 10\left(\frac{5}{10+4}\right) \text{ V}$$
$$= 3.33 \text{ V}$$

and voltage at the emitter,

$$V_E = V_B - V_{BE} = 3.33 - 0.7 = 2.63 \text{ V}$$

$\therefore$ Emitter current,

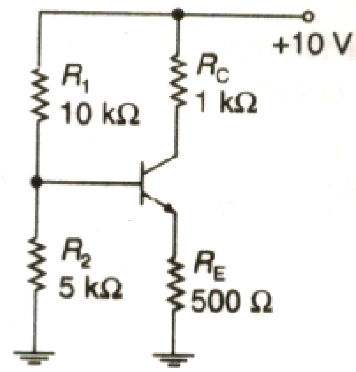


Fig.

$$I_E = \frac{V_E}{R_E} = \frac{2.63}{500} = 5.26 \times 10^{-3} \text{ A} = 5.26 \text{ mA}$$

and collector current,

$$I_C = I_E = 5.26 \text{ mA } \textbf{Ans.}$$

Collector-to-emitter voltage

We also know that the collector-to-voltage,

$$V_{CE} = V_{CC} - (R_C + R_E) = 10 - 5.26 \times 10^{-3}(1 \times 10^3 + 500) \text{ V}$$
$$= 10 - 7.89 = 2.11 \text{ V } \textbf{Ans.}$$

Example : *For a circuit shown in Fig.* $V_{CC} = 20$ *V,* $R_C = 2\ k\Omega$, $\beta = 50$, $V_{BEact} = 0.2$ *V,*
$R_1 = 100\ k\Omega$, $R_2 = 5\ k\Omega$ *and* $R_E = 100\ \Omega$ *Calculate* I_B, V_{CE}, I_C *and stability factor S.*

Solution : $$V_{CC} = R_1[I + I_B] + I R_2$$

$$\therefore \quad I = \frac{V_{CC} - I_B R_1}{R_1 + R_2}$$

$$V_{CC} = R_1[I + I_B] + V_{BE} + I_E R_E$$

We know that, $I_E = I_B + I_C = I_B + \beta I_B$

$$\therefore \quad V_{CC} = R_1[I + I_B] + V_{BE} + (1+\beta) I_B R_E$$

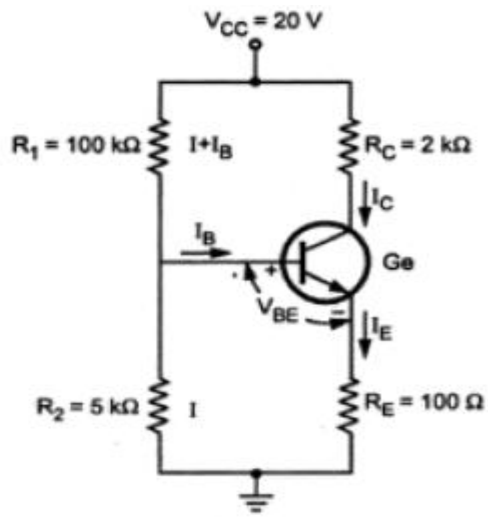


Fig.

Substituting value of I we get,

$$V_{CC} = R_1\left[\frac{V_{CC} - I_B R_1}{R_1 + R_2} + I_B\right] + V_{BE} + (1+\beta) I_B R_E$$

$$= R_1\left[\frac{V_{CC} - I_B R_1 + I_B R_1 + I_B R_2}{R_1 + R_2}\right] + V_{BE} + (1+\beta) I_B R_E$$

$$= R_1\left[\frac{V_{CC} + I_B R_2}{R_1 + R_2}\right] + V_{BE} + (1+\beta) I_B R_E$$

Substituting values of V_{CC}, R_1, R_2, V_{BE}, β and R_E

We get, $$20 = 100\times10^3\left[\frac{20 + I_B\times5\times10^3}{100\times10^3 + 5\times10^3}\right] + 0.2 + (51) I_B \times 100$$

$$20 = 19.047619 + 4761.9\, I_B + 0.2 + 5100\, I_B$$

$$0.752381 = 9861.9\, I_B$$

$\therefore$ $$I_B = 76.29\ \mu A$$

As $$I_C = \beta I_B = 50 \times 76.29\ \mu A = 3.814\ mA$$

Applying KVL to collector circuit we get,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

$$= I_C R_C + V_{CE} + (1+\beta) I_B R_E$$

$\therefore$ $$V_{CE} = V_{CC} - I_C R_C - (1+\beta) I_B R_E$$

$\therefore$ $$V_{CE} = 20 - 3.814\times10^{-3}\times2\times10^3 - (51)\times76.29\times10^{-6}\times100$$

$$= 11.983\ V$$

Stability factor for voltage divider bias is given as

$$S = \frac{\beta + 1}{1 + \beta \frac{R_E}{R_E + R_B}}$$

Before substituting the values in the equation it is necessary to calculate R_B.

We know that $R_B = R_1 || R_2$

$$= \frac{R_1 R_2}{R_1 + R_2} = \frac{100 \times 10^3 \times 5 \times 10^3}{100 \times 10^3 + 5 \times 10^3} = 4761.9\ \Omega$$

Now substituting values of , R_E and β in the equation of stability factor we get,

$$S = \frac{50 + 1}{1 + 50 \times \frac{100}{100 + 4761.9}} = 25.143$$

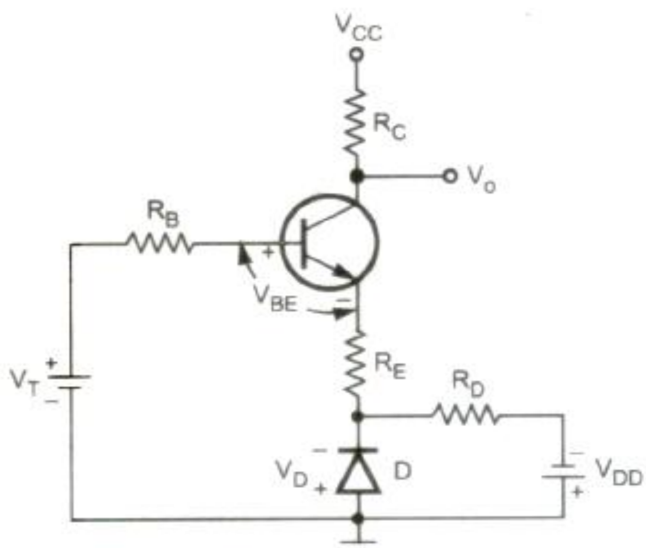
3.7 Bias Compensation using Diodes and Transistors

- The collector to base bias and the voltage follower bias use the negative feedback to do the stabilization action.
- This negative feedback reduces the amplification of the signal.
- If this loss in signal amplification is intolerable and extremely stable biasing conditions are required, then it is necessary to use compensation techniques.
  - Compensation for V_{BE}
  - Compensation for I_{CO}

3.7.1 Compensation for V_{BE}

3.7.1.1 Diode in Emitter Circuit

- Fig. 3.8 shows the voltage divider bias with bias compensation technique.



- **Fig. 3.8 Stabilization by means of voltage divider bias and diode compensation technique**

- Here, separate supply V_{DD} is used to keep diode in forward biased condition.
- If the diode used in the circuit is of same material and type as the transistor, the voltage across the diode will have the same temperature coefficient (-2.5 mV/^{0}C) as the base to emitter voltage V_{BE}.
- So when V_{BE} changes by a əV_{BE} with change in temperature, V_D changes by a əV_D and əV_D'= ə V_{BE}, the changes tend to cancel each other.
- Applying KVL to the base circuit of Fig. 3.8 we have

$$\begin{aligned} V_T &= I_B R_B + V_{BE} + (I_B + I_C) R_E - V_D \\ &= I_B(R_B + R_E) + I_C R_E + V_{BE} - V_D \qquad \dots (5.6.1) \end{aligned}$$

Considering leakage current we have,

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

$$\therefore \quad I_B = \frac{I_C}{\beta} + \frac{(1+\beta)I_{CO}}{\beta}$$

Substituting the value of I_B in equation 5.6.1 we have

$$\begin{aligned} V_T &= \left[\frac{I_C}{\beta} + \frac{(1+\beta)I_{CO}}{\beta}\right](R_B + R_E) + I_C R_E + V_{BE} - V_D \\ &= \frac{I_C}{\beta}(R_B + R_E) + \frac{\beta I_C R_E}{\beta} + \frac{(1+\beta)I_{CO}(R_B + R_E)}{\beta} + V_{BE} - V_D \\ &= \frac{I_C}{\beta}[R_B + (1+\beta) R_E] + \frac{(R_B + R_E)(1+\beta)I_{CO}}{\beta} + V_{BE} - V_D \end{aligned}$$

$$\therefore \quad \frac{I_C}{\beta}[R_B + (1+\beta)R_E] = V_T - V_{BE} + V_D + \frac{(R_B + R_E)(1+\beta)I_{CO}}{\beta}$$

$$\therefore \quad \boxed{I_C = \frac{\beta[V_T - (V_{BE} - V_D)] + (R_B + R_E)(1+\beta)I_{CO}}{R_B + (1+\beta)R_E}} \qquad \dots (5.6.2)$$

- Since V_D tracks V_{BE} with respect to temperature, it is clear from equation (5.6.2) that I_C will be insensitive to variations in V_{BE}.

3.7.1.2 Diode in voltage divider circuit

- Fig. 3.9 shows diode compensation technique used in voltage divider bias.
- Here, diode is connected in series with resistance R_2 in the voltage divider circuit and it is forward biased condition.

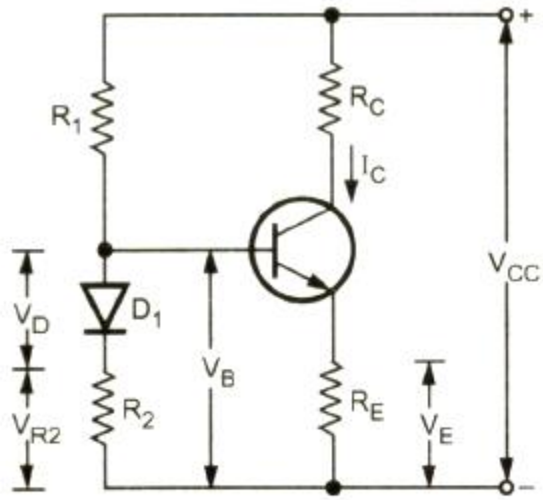


Fig. 3.9 Diode compensation in voltage divider bias circuit

- From the voltage divider bias circuit, we get

$$I_E = \frac{V_B - V_{BE}}{R_E} = \frac{V_E}{R_E}$$

$$\therefore \quad \boxed{I_C \approx \frac{V_B - V_{BE}}{R_E}} \qquad \because\ I_C \approx I_E \qquad \dots (5.6.3)$$

- When V_{BE} changes with temperature, I_C also changes.
- To cancel the change in I_C, one diode is used in this circuit for compensation as shown in Fig. 3.9. The voltage at the base V_B is now,

$$V_B = V_{R2} + V_D$$

Substituting in equation (5.6.3), we get,

$$I_C \approx \frac{V_{R2} + V_D - V_{BE}}{R_E} \qquad \dots (5.6.4)$$

- If the diode used in the circuit is of same material and type as the transistor, the voltage across the diode will have the same temperature coefficient (-2.5 mV/^{0}C) as the base to emitter voltage V_{BE}.
- So when V_{BE} changes by a əV_{BE} with change in temperature, V_D changes by a əV_D and əV_D'= ə V_{BE}, the changes tend to cancel each other.

$$\boxed{I_C \approx \frac{V_{R2}}{R_E}}$$

- From the above equation, we can see collector current I_C is unaffected by change in V_{BE}.

3.7.2 Compensation for I_{CO}

- In case of germanium transistors, changes in I_{CO} with temperature are comparatively larger than silicon transistor.
- Thus, in germanium transistor changes in I_{CO} with temperature play the more important role in collector current stability than the changes in the V_{BE}.

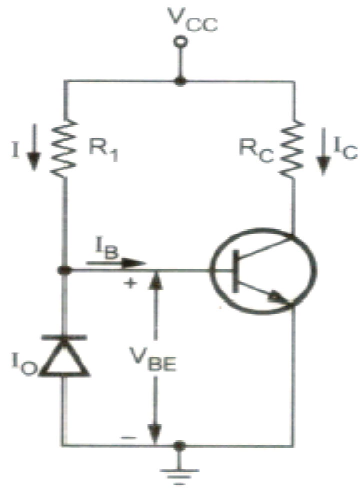


Fig. 3.10 Diode compensation for a germanium transistor

- The Fig. 3.10 shows diode compensation technique commonly used for stabilizing germanium transistors.
- It offers stabilization against variation in I_{CO}.
- In this circuit diode is kept in reverse biased condition.
- In reverse biased condition the current flowing through diode is only the leakage current.
- If the diode and the transistor are of the same type and material, the leakage current I_O of the diode will increase with temperature at the same rate as the collector leakage current I_{CO}.
- From Fig. 3.10 we have

$$I = \frac{V_{CC} - V_{BE}}{R_1}$$

and $$I = I_B + I_O \qquad \therefore \; I_B = I - I_O$$

For germanium transistor $\dot{V}_{BE} = 0.2$ V, which is very small and neglecting change in V_{BE} with temperature we can write,

$$I \cong \frac{V_{CC}}{R_1} \cong \text{constant}$$

We know, $$I_C = \beta I_B + (1+\beta) I_{CO}$$

Substituting value of I_B in above equation we get,

$$I_C = \beta I - \beta I_O + (1+\beta) I_{CO}$$

if $\beta >>1$ we get,

$$\boxed{I_C = \beta I - \beta I_O + \beta I_{CO}}$$

Now if $I_O = I_{CO}$ we get,

$$\boxed{I_C = \beta I}$$

- As I is constant, I_C remains fairly constant.
- In other words we can say that changes by I_{CO} with temperature are compensated by diode and thus collector current remains fairly constant.

3.8 Analysis of CE, CC, and CB Amplifiers

The following procedure is used to analyze various parameters of transistor in CE, CC, and CB Configuration.

- First draw the transistor amplifier in any one of the configuration.
- Find the AC analysis of the above circuit.
- Then replace the transistor with its small-signal (h Parameter Model) equivalent circuit.
- From the above equivalent circuit, find transistor parameters like A_V, A_I, R_i, R_o, A_{VS} and A_{IS} of amplifier.

3.9 Analysis of Common Emitter (CE) Amplifier

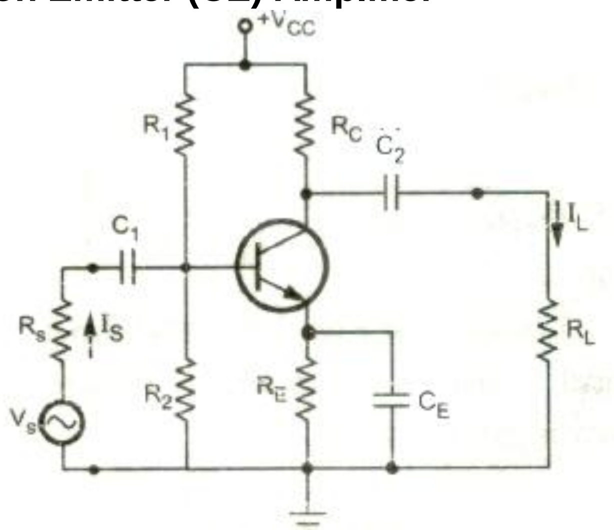


Fig. 3.11 Common Emitter Amplifier

- Fig. 3.11 shows the practical circuit of common emitter transistor amplifier.
- It consists of different circuit component.
- The functions of these components are as follows:
- The resistances R_1, R_2 and R_E used to form the voltage biasing and stabilization circuit. The biasing circuit needs to establish a proper operating Q-point
- The capacitor C_1 couples the signal to the base of the transistor. It blocks any d.c. component present in the signal and passes only a.c. signal for amplification.
- An emitter bypass capacitor C_E is connected in parallel with the emitter resistance R_E to provide a low reactance path to the amplified a.c. signal.

- If it is not inserted, the amplified a.c. signal passing through R_E will cause a voltage drop across it. This will reduce the output voltage, reducing the gain of the amplifier.
- The coupling capacitor C_2 couples the output of the amplifier to the load or to -the next stage of the amplifier. It blocks d.c. and passes only a.c. part of the amplified signal.

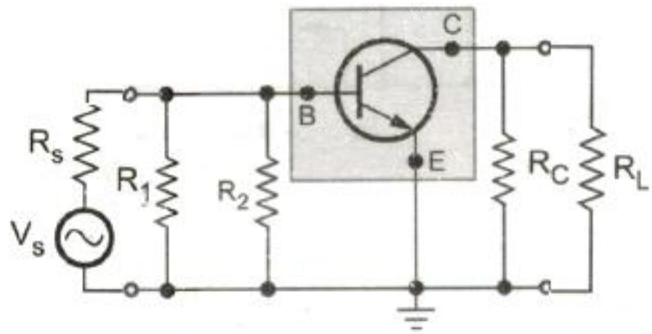


Fig. 3.12 AC Equivalent circuit of Fig. 3.11

- Figure 3.12 shows an AC Equivalent circuit of Common Emitter amplifier in Fig. 3.11.
- Replace the transistor in Figure 3.12 by h parameter model and is shown in Fig. 3.13.

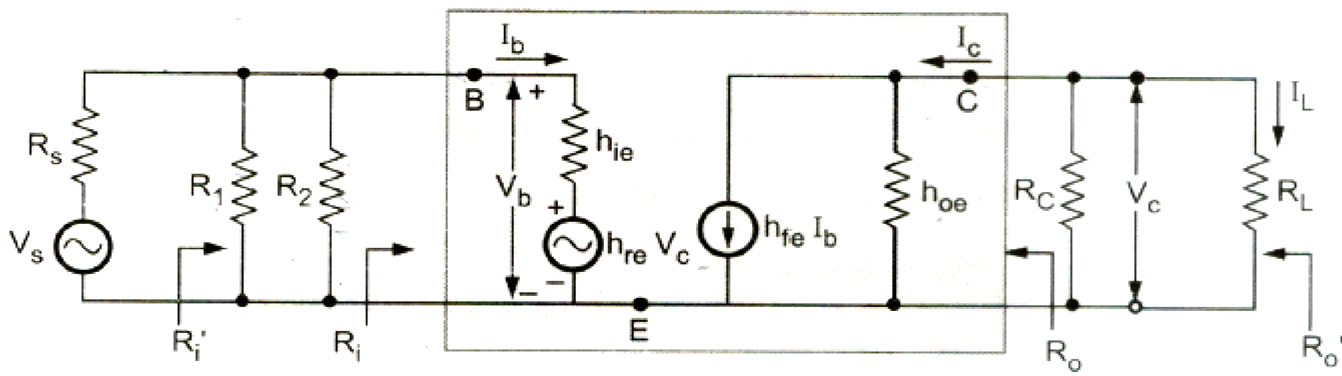


Fig. 3.13 CE Amplifier and its h-parameter equivalent circuit

- Let us analyze hybrid model to find the current gain, the input resistance, the voltage gain, and the output resistance.

3.9.1 Current Gain (A_i)

- From the figure 1.11, we can write current gain as

$$A_i = \frac{I_L}{I_b} = -\frac{I_c}{I_b} \quad \ldots (1)$$

$$I_c = h_{fe} I_b + h_{oe} V_c = h_{fe} I_b + h_{oe}(-I_c R'_L) \quad \ldots (2)$$

$$\because V_c = -I_c R'_L$$

$$\therefore \quad (1 + h_{oe} R'_L)\, I_c = h_{fe} I_b \qquad \text{where} \quad R'_L = R_C \,\|\, R_L$$

$$\therefore \quad \frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{oe} R'_L}$$

$$\therefore \quad \boxed{A_i = -\frac{I_c}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R'_L}} \quad \ldots (3)$$

3.9.2 Input Resistance (R_i)

$$\mathbf{R_i} = \frac{V_b}{I_b} \qquad \ldots (4)$$

- From the input circuit of Fig. 1.11, we have

$$V_b = h_{ie} I_b + h_{re} V_c \qquad \ldots (5)$$

and $$V_c = -I_c R'_L = A_i I_b R'_L \qquad \text{We have } \mathbf{A_i} = -\frac{I_c}{I_b}$$

$\therefore$ $$R_i = \frac{h_{ie} I_b + h_{re} A_i I_b R'_L}{I_b}$$

$$\boxed{R_i = h_{ie} + h_{re} A_i R'_L} \qquad \ldots (6)$$

Substituting $A_i = -\dfrac{h_{fe}}{1 + h_{oe} R'_L}$

We get, $$\boxed{R_i = h_{ie} - \frac{h_{re}\, h_{fe}\, R'_L}{1 + h_{oe}\, R'_L}} \qquad \ldots (7)$$

3.9.3 Voltage Gain (A_V)

$$\mathbf{A_v} = \frac{V_c}{V_b}$$

Already we have

$$V_c = -I_c R'_L = A_i I_b R'_L$$

$$\mathbf{A_v} = \frac{V_c}{V_b}$$

$$\mathbf{A_v} = \frac{A_i I_b R'_L}{V_b} \qquad \because \frac{I_b}{V_b} = \frac{1}{R_i}$$

$$\boxed{\mathbf{A_v} = \frac{A_i R'_L}{R_i}} \qquad \ldots (8)$$

3.9.4 Output Admittance (Y_O)

$$\mathbf{Y_o} = \frac{I_c}{V_c} \text{ with } V_s = 0 \qquad \ldots (9)$$

From equation (2), we have, $\quad I_c = h_{fe} I_b + h_{oe} V_c$

Dividing above equation by V_c we get,

$$Y_o = \frac{I_c}{V_c} = \frac{h_{fe} I_b}{V_c} + h_{oe}$$

- From Fig. 1.11 with $V_S = 0$, we can write

$$R'_s I_b + h_{ie} I_b + h_{re} V_c = 0 \qquad \text{Where } R'_s = R_s \| R_1 \| R_2 \qquad \dots (10)$$

$$\therefore (R'_s + h_{ie}) I_b = -h_{re} V_c$$

$$\therefore \quad \frac{I_b}{V_c} = \frac{-h_{re}}{R'_s + h_{ie}} \qquad \dots (11)$$

Substituting value of $\frac{I_b}{V_c}$ from equation (11) in equation (10), we obtain,

$$\boxed{Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R'_s}} \qquad \dots (12)$$

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

3.9.5 Overall Input Resistance

$$\boxed{R'_i = R_i \| R_1 \| R_2}$$

3.9.6 Overall Output Resistance

$$\boxed{R'_o = R_o \| R'_L}$$

3.9.7 Overall Voltage Gain (A_{VS})

- From Figure 3.13, we can write

$$A_{vs} = \frac{V_c}{V_s} = \frac{V_c}{V_b} \times \frac{V_b}{V_s}$$

- Figure 3.13 can be redrawn as

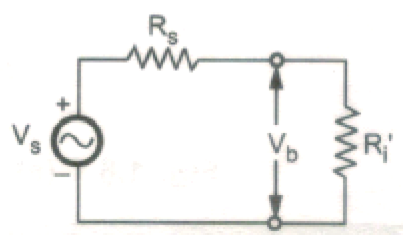


Fig. 3.14 Redrawn circuit of Fig. 3.13

- Looking at Fig. 3.14 and voltage divider equation we get,

$$V_b = \frac{V_s R'_i}{R_s + R'_i} \qquad \therefore \qquad \frac{V_b}{V_s} = \frac{R'_i}{R_s + R'_i}$$

$$\therefore\ \mathbf{A_{vs}} = \frac{V_c}{V_b} \times \frac{V_b}{V_s}$$

$$\boxed{\mathbf{A_{vs}} = A_v \times \frac{R_i'}{R_s + R_i'}}$$

3.9.8 Overall Current Gain (A_{is})

- From Figure 3.13, we can write

$$\mathbf{A}_{is} = \frac{I_L}{I_s} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$$

- Figure 3.13 can be redrawn as

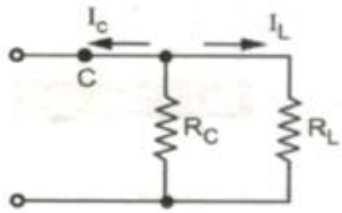


Fig. 3.15

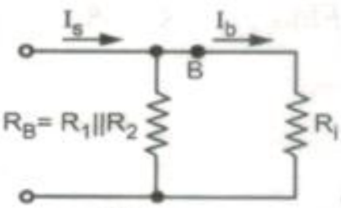


Fig. 3.16

- Looking at Fig. 3.15 and 3.16 using current divider equation we get,

$$I_L = \frac{-I_c R_C}{R_C + R_L}$$

$$\therefore \quad \frac{I_L}{I_c} = \frac{-R_C}{R_C + R_L}$$

and $$I_b = \frac{I_s R_B}{R_B + R_i} \quad \text{where} \quad R_B = R_1 \parallel R_2$$

$$\therefore \quad \frac{I_b}{I_s} = \frac{R_B}{R_B + R_i}$$

$$\therefore\ A_{is} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$$

$$\boxed{A_{is} = \frac{-R_C}{R_C + R_L} \times A_i \times \frac{R_B}{R_B + R_i}}$$

Example *Consider a single stage CE amplifier with $R_s = 1\ k\Omega$, $R_1 = 50\ K$, $R_2 = 2\ K$, $R_C = 1\ K$, $R_L = 1.2\ K$, $h_{fe} = 50$, $h_{ie} = 1.1\ K$, $h_{oe} = 25\ \mu A/V$ and $h_{re} = 2.5\times10^{-4}$, as shown in Fig.*

Find A_i, R_i, A_v, $A_i = \frac{I_L}{I_S}$, $A_{VS} = \frac{V_o}{V_s}$ and R_o.

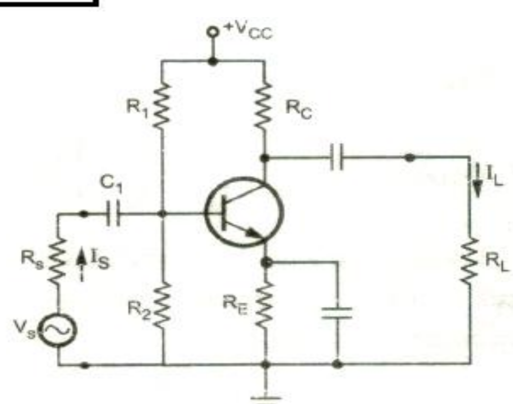


Fig.

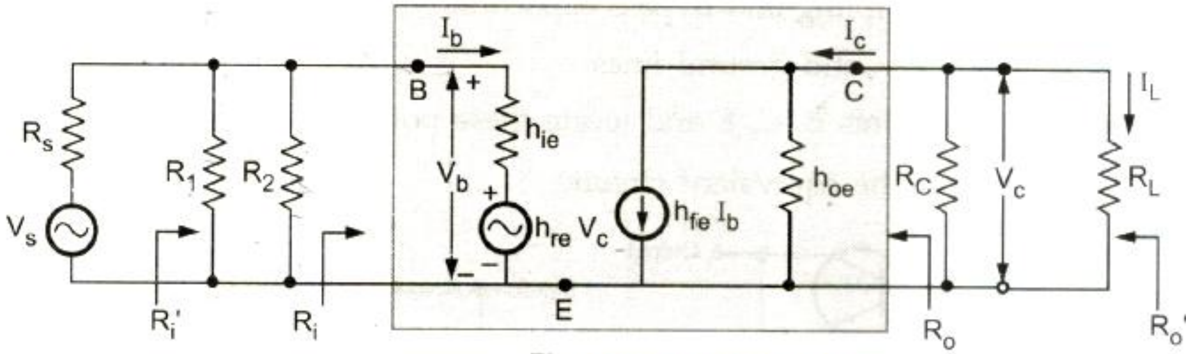


Fig. h parameter model

a) Current gain $A_i = \dfrac{-I_c}{I_b} = \dfrac{-h_{fe}}{1+h_{oe}R_L'}$

where $R_L' = R_C \parallel R_L = 1\text{ K} \parallel 1.2\text{ K} = \mathbf{545.45\ \Omega}$

$$\therefore \quad A_i = \frac{-50}{1+25\ \mu A / V\,(545.45)} = -\mathbf{49.32}$$

b) Input resistance $R_i = h_{ie} + h_{re} A_i R_L'$

$$= 1.1\text{ K} + 2.5\times10^{-4} \times(-49.32)\times 545.45 = \mathbf{1093\ \Omega}$$

c) Voltage gain $A_v = \dfrac{V_c}{V_b} = \dfrac{A_i R_L'}{R_i} = \dfrac{-49.32\times545.45}{1093} = -\mathbf{24.61}$

d) Overall input resistance $R_i' = R_i \parallel R_1 \parallel R_2 = 1093 \parallel 50\text{ K} \parallel 2\text{ K} = \mathbf{696.9\ \Omega}$

e) Overall voltage gain

$$\mathbf{A_{vs}} = A_v \times \frac{R_i'}{R_s + R_i'} = 24.61 \times \frac{696.9}{1\text{ k} + 696.9} = \mathbf{10.1}$$

f) Overall current gain

$$A_{is} = \frac{-R_C}{R_C+R_L} \times A_i \times \frac{R_B}{R_B+R_i}$$

$$= \frac{-1\text{ K}}{1\text{ K}+1.2\text{ K}} \times 49.32 \times \frac{1.923\text{ K}}{1.923\text{ K}+1.093\text{ K}} = -\mathbf{14.29}$$

g) Output Admittance

$$Y_o = h_{oe} - \frac{h_{fe}h_{re}}{h_{ie}+R_s'} \qquad \text{where } R_s' = R_s \parallel R_1 \parallel R_2 = 1\text{K} \parallel 50\text{K} \parallel 2\text{K} = \mathbf{657.9\Omega}$$

$$= 25\times10^{-6} - \frac{50\times2.5\times10^{-4}}{1.1\times10^{3} + 657.9} = 1.7889\times10^{-5}$$

h) Output Resistance

$$R_o = Z_o = \frac{1}{Y_o} = 55.899\ k\Omega$$

i) Overall Output Resistance

$$R'_o = R_o \| R'_L = 55.899\ k\Omega \| 545.45 = 540\ \Omega$$

3.10 Analysis of Common Collector (CC) Amplifier

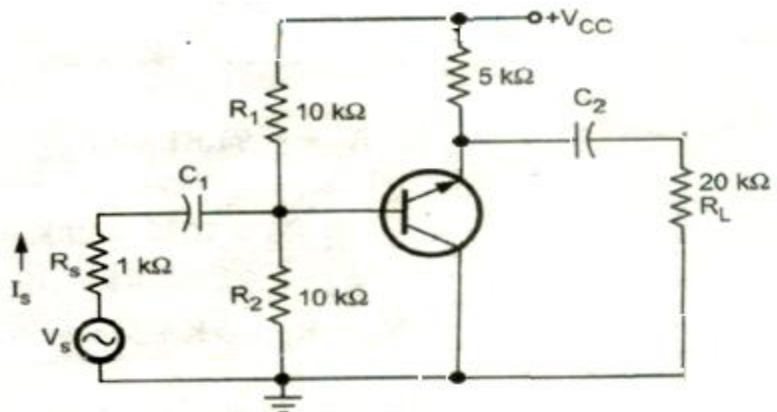


Fig. 3.17 Common Collector Amplifier

- Fig. 3.17 shows the practical circuit of common collector transistor amplifier.
- It consists of different circuit components.
- Replace the transistor in Figure 3.17 by h parameter model and is shown in Fig. 3.18.

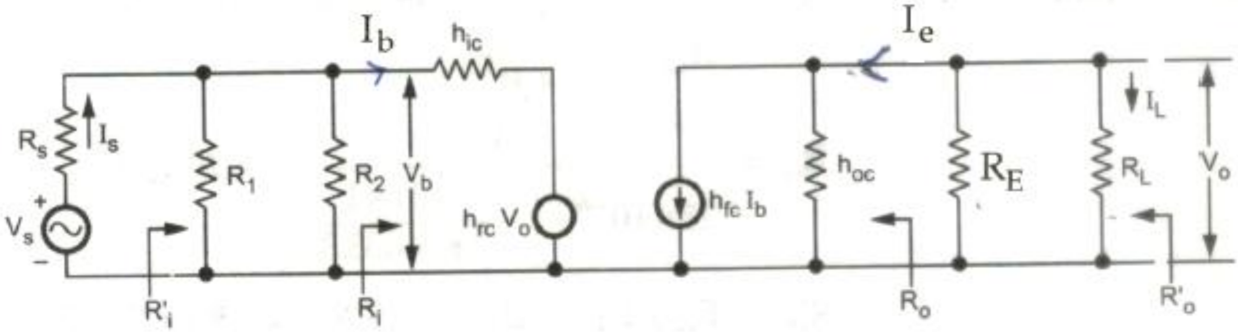


Fig. 3.18 CC Amplifier and its h-parameter equivalent circuit

- Derivation of current gain, input resistance, voltage gain and output resistance is same as CE Amplifier.

a) Current gain $(A_i) = -\frac{I_e}{I_b} = \frac{-h_{fc}}{1+h_{oc}R'_L}$ where $R'_L = R_E \| R_L$

b) Input resistance $(R_i) = h_{ic} + h_{rc}\, A_i R'_L$

c) Overall input resistance $(R'_i) = R_i \| R_1 \| R_2$

d) Voltage gain $(A_v) = \frac{A_i R'_L}{R_i}$

e) **Overall voltage gain** $(A_{vs}) = \frac{V_o}{V_s} = \frac{V_o}{V_b} \times \frac{V_b}{V_s}$

where $\frac{V_o}{V_b} = A_v$ and $\frac{V_o}{V_s} = \frac{R_i'}{R_i' + R_s}$

$$A_{vs} = A_v \cdot \frac{R_i'}{R_i' + R_s}$$

f) **Overall current gain** $(A_{is}) = \frac{I_L}{I_s} = \frac{I_L}{I_e} \times \frac{I_e}{I_b} \times \frac{I_b}{I_s}$

where $\frac{I_L}{I_e} = \frac{-R_E}{R_E + R_L}$ $\quad \frac{I_e}{I_b} =$ $\quad \frac{I_b}{I_s} = \frac{R_B}{R_B + R_i}$

$R_B = R_1 \parallel R_2$

$$(A_{is}) = \frac{I_L}{I_s} = \frac{-R_E}{R_E + R_L} \times -A_i \times \frac{R_B}{R_B + R_i}$$

g) Output Admittance

$$Y_o = h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic} + R_s'}$$

where $R_s' = R_s \parallel R_1 \parallel R_2$

h) Output Resistance

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

i) Overall Output Resistance

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

Example *In the common collector in Fig. , the transistor parameters are $h_{ic} = 1.2$ K, $h_{fc} = -101$, $h_{rc} = 1$ and $h_{oc} = 25\ \mu A/V$. Calculate the R_i, $A_i = \frac{I_L}{I_s}$, A_v, $A_{vs} = \frac{V_o}{V_s}$, R_o for the circuit.*

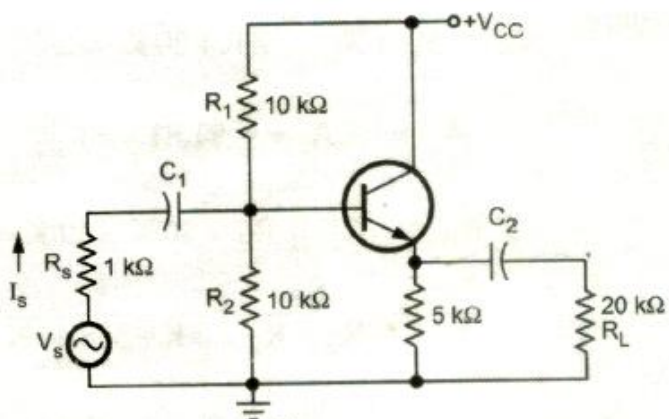


Fig.

Solution : Fig. shows the h-parameters equivalent model for the given circuit.

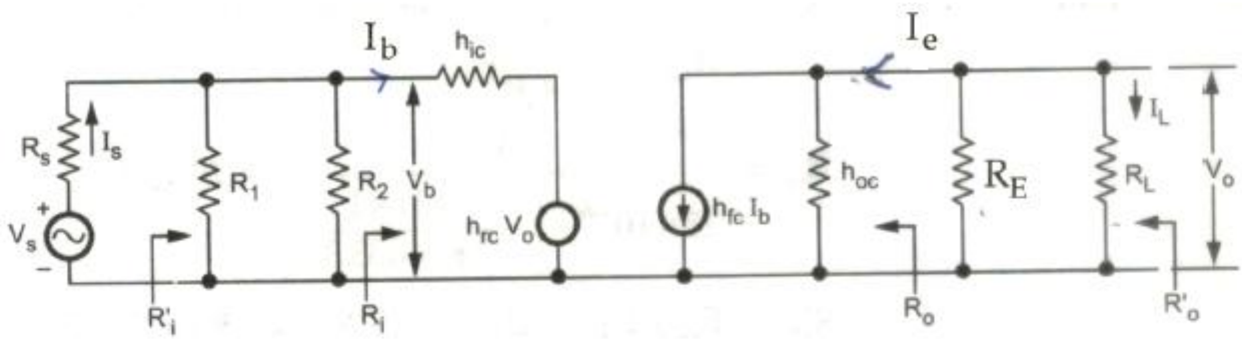


Fig. h-parameter equivalent model

a) Current gain $(A_i) = -\dfrac{I_e}{I_b} = \dfrac{-h_{fc}}{1+h_{oc}R'_L}$ where $R'_L = R_E \parallel R_L$

$$= \frac{-(-101)}{1+25\times10^{-6}(5\,K||20\,K)} = \mathbf{91.81}$$

b) Input resistance $(R_i) = h_{ic} + h_{rc}\, A_i R'_L$

$$= 1.2\ K + 1 \times 91.81 \times (5\ K \parallel 20K) = \mathbf{368.44\ K}$$

c) Overall input resistance $(R'_i) = R_i \parallel R_1 \parallel R_2 = 368.44\ K \parallel 10\ K \parallel 10\ K = \mathbf{4.933\ K}$

d) Voltage gain $(A_v) = \dfrac{A_i R'_L}{R_i} = \dfrac{91.81\times(5\,K \parallel 20\,K)}{368.44\,K} = \mathbf{0.996}$

e) Overall voltage gain $A_{vs} = A_v \cdot \dfrac{R'_i}{R'_i + R_s} = 0.996 \times \dfrac{4.933\,K}{4.933\,K+1\,K} = \mathbf{0.828}$

f) Overall current gain $(A_{is}) = \dfrac{I_L}{I_s} = \dfrac{I_L}{I_e}\times\dfrac{I_e}{I_b}\times\dfrac{I_b}{I_s}$

where $\dfrac{I_L}{I_e} = \dfrac{-R_E}{R_E+R_L} = \dfrac{-5\,K}{5\,K+20\,K} = \mathbf{-0.2}$

$$\frac{I_e}{I_b} = -A_i = \mathbf{-91.81}$$

$$R_B = R_1 \;||\; R_2 = 10\,K \;||\, 10\,K = 5\,K$$

$$\frac{I_b}{I_s} = \frac{R_B}{R_B+R_i} = \frac{5\,K}{5\,K+368.44\,K} = \mathbf{0.0134}$$

$\therefore \quad A_{i(\text{for circuit})} = \dfrac{I_L}{I_s} = (-0.2)\times(-91.81)\times(0.0134) = \mathbf{0.246}$

g) Output resistance $R_o = \dfrac{1}{h_{oc} - \dfrac{h_{fc} h_{rc}}{h_{ic} + R'_s}}$ where $R'_s = R_s \parallel R_1 \parallel R_2 = \mathbf{833.33\ \Omega}$

$$\therefore \quad R_o = \frac{1}{25\times10^{-6} - \left(\dfrac{-101\times1}{1.2\,K + 833.33}\right)} = \mathbf{20.12\ \Omega}$$

$$R'_o = R_o \parallel R'_L = 20.12 \parallel (5\ K \parallel 20\ K) = \mathbf{20\ \Omega}$$

3.11 Analysis of Common Base (CB) Amplifier

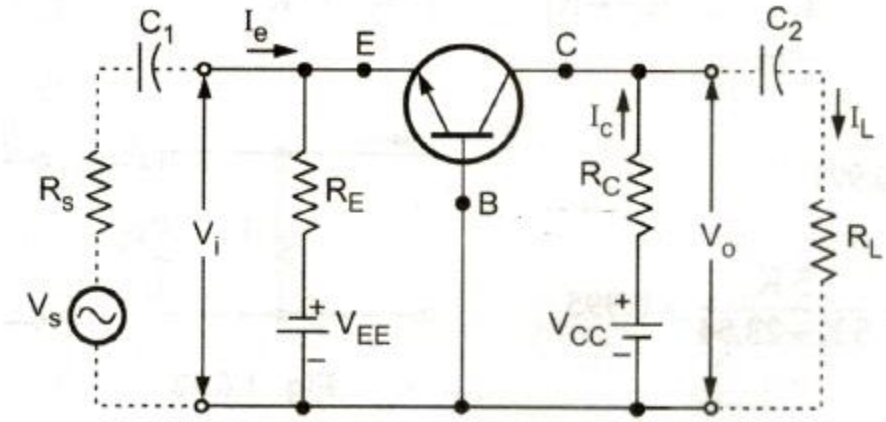


Fig. 3.19 Common Base Amplifier

- Fig. 3.19 shows the practical circuit of common base transistor amplifier.
- It consists of different circuit components.
- Replace the transistor in Figure 3.19 by h parameter model and is shown in Fig. 3.20.

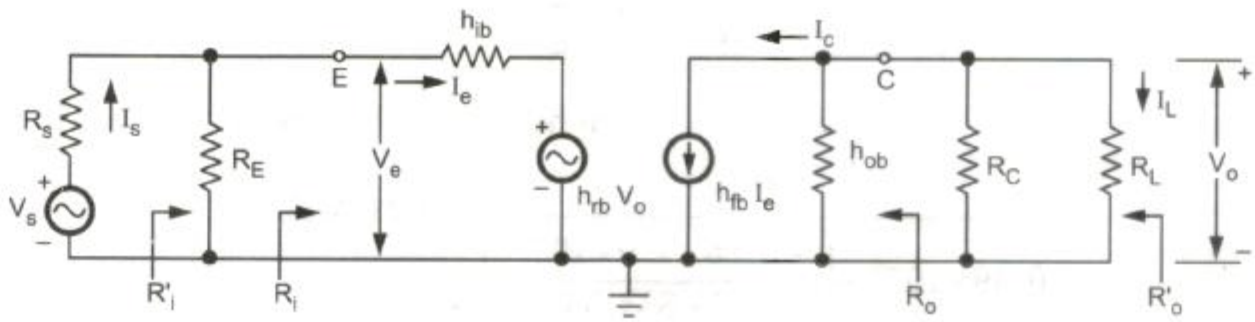


Fig. 3.20 Common Base Amplifier and its h-parameter equivalent circuit

- Derivation of current gain, input resistance, voltage gain and output resistance is same as CE Amplifier.

a) Current gain $(A_i) = -\dfrac{h_{fb}}{1 + h_{ob} R'_L}$ where $R'_L = R_C \parallel R_L$

b) Input resistance $(R_i) = h_{ib} + h_{rb}\, A_i\, R'_L$

Overall input resistance $R'_i = R_i \parallel R_E$

c) Voltage gain $(A_v) = \dfrac{A_i R'_L}{R_i}$

d) Overall voltage gain $A_{vs} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_e} \times \dfrac{V_e}{V_s}$ where $\dfrac{V_o}{V_e} = A_v$ $\dfrac{V_e}{V_s} = \dfrac{R'_i}{R'_i + R_s}$

$$\therefore \quad A_{vs} = A_v \frac{R'_i}{R'_i + R_s}$$

e) Overall current gain $A_{is} = \dfrac{I_L}{I_s} = \dfrac{I_L}{I_c} \times \dfrac{I_c}{I_e} \times \dfrac{I_e}{I_s}$

where $\dfrac{I_L}{I_c} = -\dfrac{R_C}{R_C + R_L}$ $\dfrac{I_c}{I_e} = -A_i$ $\dfrac{I_e}{I_s} = \dfrac{R_E}{R_E + R_i}$

$$A_{is} = -\frac{R_C}{R_C + R_L} \times -A_i \times \frac{R_E}{R_E + R_i}$$

f) Output resistance $(R_o) = \dfrac{1}{h_{ob} - \dfrac{h_{fb} h_{rb}}{h_{ib} + R'_s}}$

where $R'_s = R_s \parallel R_E$

$$R'_o = R_o \parallel R'_L$$

Example *For the common base circuit in Fig. , the transistor parameters are $h_{ib} = 22\ \Omega$, $h_{fb} = -0.98$, $h_{ob} = 0.49\ \mu A/V$, $h_{rb} = 2.9 \times 10^{-4}$. Calculate the values of the input resistance, output resistance, current gain and voltage gain for the given circuit.*

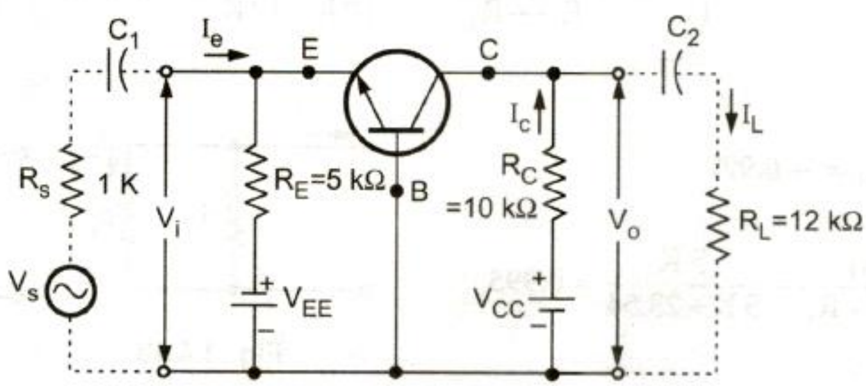


Fig.

Solution : Fig. shows the h-parameter equivalent model for the given circuit.

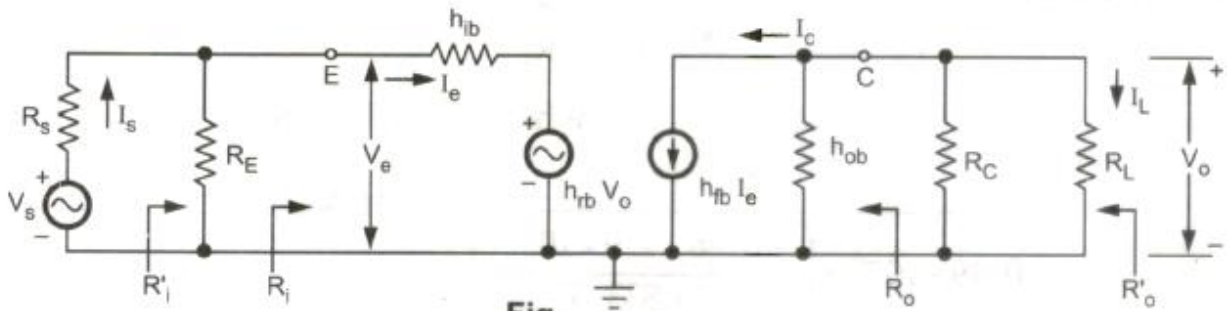


Fig.

a) Current gain $(A_i) = -\dfrac{h_{fb}}{1+h_{ob}R'_L}$ where $R'_L = R_C \parallel R_L = 10\text{ K} \parallel 12\text{ K} = 5.45\text{ K}$

$$= \frac{-(-0.98)}{1+0.49\times10^{-6}\times5.45\text{ K}} = \mathbf{0.977}$$

b) Input resistance $(R_i) = h_{ib} + h_{rb}\,A_i\,R'_L$

$$= 22\ \Omega + 2.9\times10^{-4}\times(0.977)\,(5.45\text{ K}) = \mathbf{23.54\ \Omega}$$

$$R'_i = R_i \parallel R_E = 23.54 \parallel 5\text{ K} = \mathbf{23.43\ \Omega}$$

c) Voltage gain $(A_v) = \dfrac{A_i R'_L}{R_i} = \dfrac{(0.977)\times(5.45\text{ K})}{23.54} = \mathbf{226}$

d) Overall voltage gain $A_{vs} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_e}\times\dfrac{V_e}{V_s}$ where $\dfrac{V_o}{V_e} = A_v$ $\dfrac{V_e}{V_s} = \dfrac{R'_i}{R'_i+R_s}$

$\therefore$
$$A_{vs} = A_v\frac{R'_i}{R'_i+R_s} = 226\times\frac{23.43}{20.36+1\text{ K}} = \mathbf{5.174}$$

e) Overall current gain $A_{is} = \dfrac{I_L}{I_s} = \dfrac{I_L}{I_c}\times\dfrac{I_c}{I_e}\times\dfrac{I_e}{I_s}$

where
$$\frac{I_L}{I_c} = -\frac{R_C}{R_C+R_L} = -\frac{10\text{ K}}{10\text{ K}+12\text{ K}} = \mathbf{-0.454}$$

$$\frac{I_c}{I_e} = -A_i = \mathbf{-0.977}$$

$$\frac{I_e}{I_s} = \frac{R_E}{R_E+R_i} = \frac{5\text{ K}}{5\text{ K}+23.54} = \mathbf{0.995}$$

$$\therefore A_{i(\text{for circuit})} = (-0.454)\times(-0.977)\times0.996 = \mathbf{0.441}$$

f) Output resistance $(R_o) = \dfrac{1}{h_{ob} - \dfrac{h_{fb}h_{rb}}{h_{ib} + R'_s}}$

where $R'_s = R_s \parallel R_E = 1\text{ K} \parallel 5\text{ K} = 833.33\ \Omega$

$$= \frac{1}{0.49\times10^{-6} - \left(\dfrac{-0.98\times2.9\times10^{-4}}{22+833.33}\right)} = \mathbf{1.21\ M\Omega}$$

$$R'_o = R_o \parallel R'_L = 1.21\text{ M} \parallel 5.45\text{ K} = \mathbf{5.425\ K}$$

3.12 CE Amplifier with emitter resistance

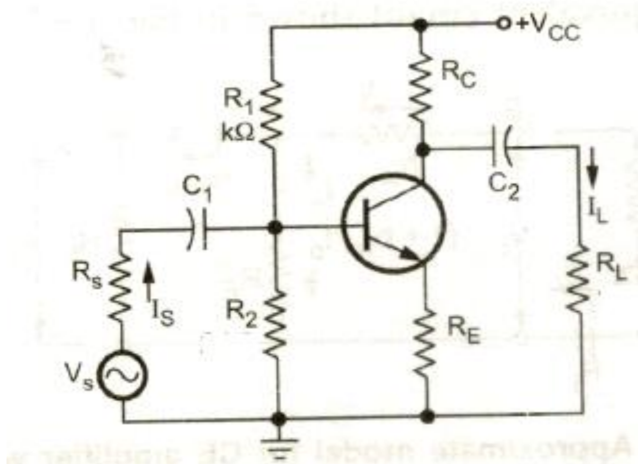


Fig. 3.21 CE Amplifier with emitter resistance

- It is important to stabilize the voltage amplification in each stage of amplifier circuits.
- The simple and effective way to obtain voltage gain stabilization is to add an emitter resistance R_E to a CE stage as shown in Fig. 3.21.
- The presence of emitter resistance has number of better effects on the amplifier performance.
- These effects can be analyzed with the help of approximate h-parameter equivalent circuit.

3.12.1 Approximate h parameter Analysis

- In approximate h parameter equivalent circuit, assume h_{re}=0 and h_{oe}=0.

a) Current Gain (A_i)

- The current gain can be given as

$$A_i = \frac{-I_c}{I_b} = \frac{-h_{fe}I_b}{I_b} = -h_{fe}$$

b) Input Resistance (R_i)

- Look at Fig. 3.22, we can write input resistance as

$$R_i = \frac{V_i}{I_b} = h_{ie} + (1 + h_{fe})\, R_E$$

- The input resistance due to factor $(1 + h_{fe})\, R_E$ may be very much larger than h_{ie}.
- Hence an emitter resistance greatly increases the input resistance.

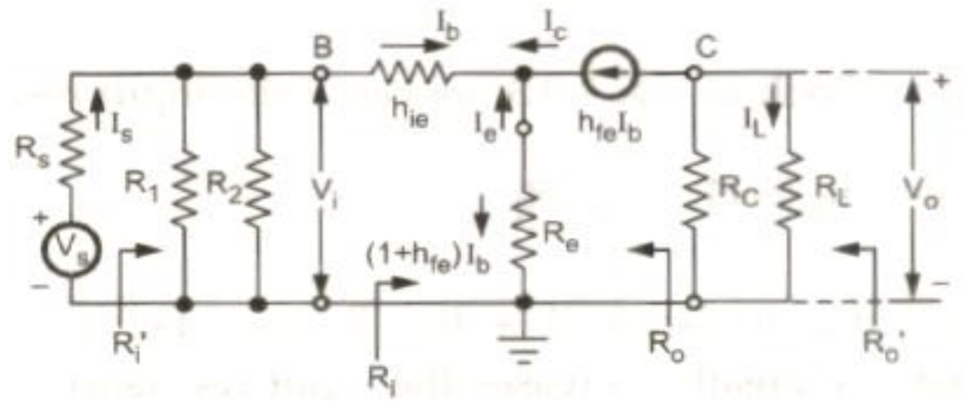


Fig. 3.22 Approximate h parameter equivalent circuit

c) Overall Input Resistance

$$R_i' = R_i \parallel R_1 \parallel R_2$$

d) Voltage Gain (A_V)

- It is given as

$$A_v = \frac{A_i R_L}{R_i} = \frac{-h_{fe} R_L}{h_{ie} + (1 + h_{fe}) R_E}$$

e) Output Resistance

- It is the resistance of an amplifier without considering the source and load (i.e. Vs = 0 and RL = ∞).
- It is defined as a ratio of output voltage V_o to output current with $V_s = 0$.

$$R_o = \left.\frac{V_o}{I_o}\right|_{V_s = 0} = \infty$$

- When $V_s = 0$, the current through the input loop $I_b = 0$, hence I_c and I_o both are zero.
- Therefore, Ro = ∞

f) Overall Output Resistance

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

g) Overall Voltage Gain

$$A_{vs} = \frac{A_v R_i'}{R_i' + R_s}$$

h) Overall current Gain

$$A_{is} = \frac{I_L}{I_s} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$$

where $\frac{I_L}{I_c} = \frac{-R_C}{R_C + R_L}$ $\quad \frac{I_b}{I_s} = \frac{R_B}{R_B + R_i}$

$$A_{is} = \frac{-R_C}{R_C + R_L} \times A_i \times \frac{R_B}{R_B + R_i}$$

Example *Fig. shows a single stage CE amplifier with unbypassed emitter resistance find current gain, input resistance, voltage gain and output resistance. Use typical values of h-parameter.*

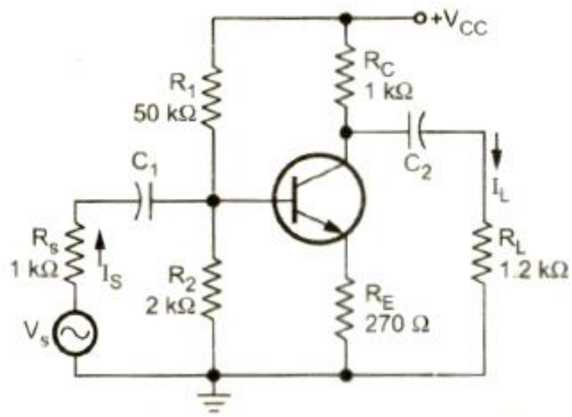


Fig.

Solution : Typical values for h-parameters are $h_{fe} = 50$, $h_{ie} = 1.1$ K, $h_{oe} = 25\ \mu A/V$, $h_{re} = 2.5 \times 10^{-4}$. Since $h_{oe}\ R_L = 25 \times 10^{-6} \times (1\ K \parallel 1.2\ K) = 0.0136$, which is less than 0.1, we use approximate analysis.

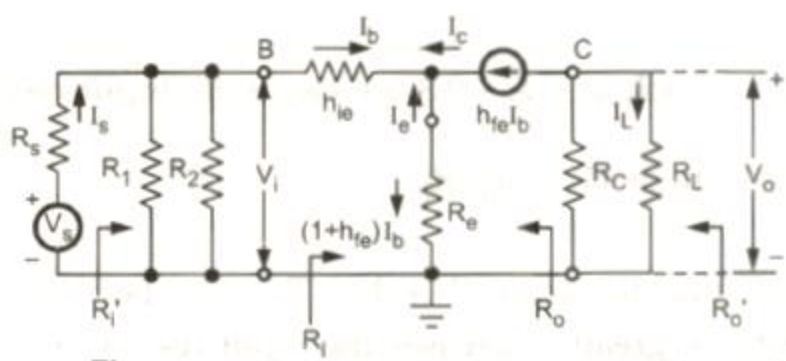


Fig. Approximate h-parameter equivalent circuit

a) Current gain $\quad (A_i) = \frac{-I_c}{I_b} = -h_{fe} = -50$

b) Input resistance $(R_i) = \frac{V_i}{I_b} = h_{ie} + (1 + h_{fe})\, R_E$

$= 1.1\text{ K} + (1 + 50) \times 270 = \mathbf{14.87\ K}$

c) Overall voltage gain $(A_v) = \frac{A_i R_L}{R_i} = \frac{-50 \times (1.2\text{K} \,||\, 1\text{K})}{14.87\text{ K}} = \mathbf{-1.834}$

d) Overall input resistance $(R'_i) = R_i \,||\, R_1 \,||\, R_2 = 14.87\text{ K} \,||\, 50\text{ K} \,||\, 2\text{ K} = \mathbf{1.7\ K}$

e) Output resistance $(R'_o) = R_o \,||\, R_c \,||\, R_L = \infty \,||\, 1\text{ K} \,||\, 1.2\text{ K} = \mathbf{545.45\ \Omega}$

f) Overall voltage gain $(A_{vs}) = \frac{A_v R'_i}{R'_i + R_s} = \frac{-1.834 \times 1.7\text{ K}}{1.7\text{K} + 1\text{K}} = \mathbf{-1.15}$

g) Overall current gain $A_i = \frac{I_L}{I_s} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$

where $\frac{I_L}{I_c} = \frac{-R_C}{R_C + R_L} = \frac{-1\text{ K}}{1\text{K} + 1.2\text{ K}} = \mathbf{-0.454}$

Looking at Fig. 1.9.4 (b) we can write

$$\frac{I_b}{I_s} = \frac{R_B}{R_B + R_i} = \frac{(50 \,||\, 2)}{(50 \,||\, 2) + 14.87} = \mathbf{0.1145}$$

$$A_{i(\text{for circuit})} = \frac{I_L}{I_s} = -0.454 \times 50 \times 0.1145 = \mathbf{-2.6}$$

3.13 Low Frequency analysis of BJT

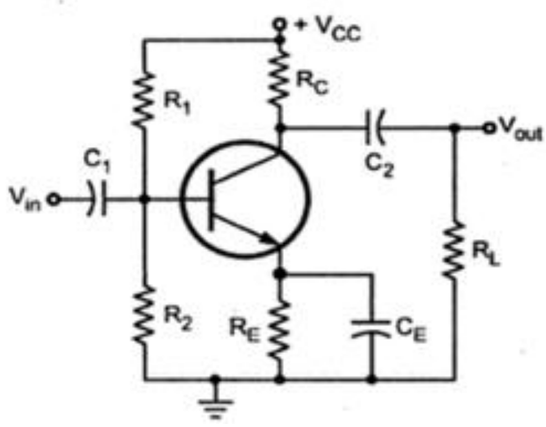


Fig. 3.23 RC coupled common Emitter amplifier

- Let us consider a typical common emitter amplifier as shown in Fig. 3.23.
- The amplifier shown in Fig. 3.23 has three RC networks that affect its gain as the frequency is reduced below midrange. These are:
  - RC network formed by the input coupling capacitor C_1 and the input impedance of the amplifier.

- ➢ RC network formed by the output coupling capacitor C_2, the resistance looking in at the collector, and the load resistance.
- ➢ RC network formed by the emitter bypass capacitor C_E and the resistance looking in at the emitter.

3.13.1 Input RC Network

- Fig. 3.24 shows input RC network formed by C_1 and the input impedance of the amplifier.

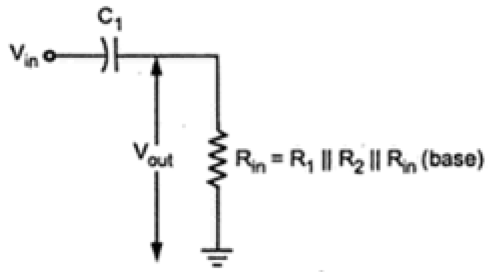


Fig. 3.24 Input RC network

- Applying voltage divider theorem to the above circuit, we can write the output voltage as

$$= \left(\frac{R_{in}}{\sqrt{R_{in}^2 + X_{C1}^2}}\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{R_{in}}{\sqrt{R_{in}^2 + X_{C1}^2}} = 0.707 = \frac{1}{\sqrt{2}}$$

- At this condition ($R_{in}=X_{C1}$), the reduction in overall gain due to the attenuation provided by the input RC network is given by

$$A_v = 20 \log \left(\frac{V_{out}}{V_{in}}\right) = 20 \log (0.707) = -3\text{dB}$$

- Lower critical frequency for input RC network is given by

$$f_c = \frac{1}{2\pi R_{in} C_1}$$

where $$R_{in} = R_1 \,||\, R_2 \,||\, h_{ie}$$

$$\therefore \quad f_c = \frac{1}{2\pi (R_1 \,||\, R_2 \,||\, h_{ie}) C_1}$$

- If the resistance of input source is taken into account the above equation becomes

$$f_c = \frac{1}{2\pi (R_s + R_{in}) C_1}$$

- The phase angle in an input RC circuit is expressed as

$$\theta = \tan^{-1}\left(\frac{X_{C1}}{R_{in}}\right)$$

3.13.2 Output RC Network

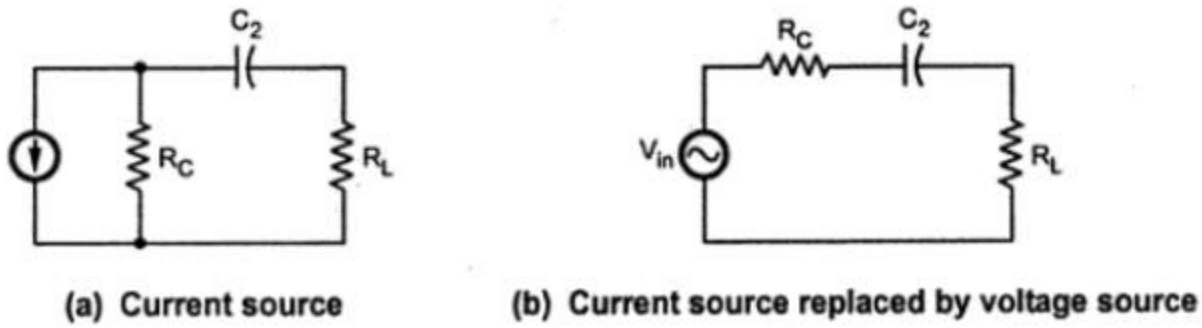


Fig. 3.25 Output RC Network

- Fig. 3.25 shows output RC network formed by C_2, resistance looking in at the collector and the load resistance.
- The critical frequency for this RC network is given by,

$$f_c = \frac{1}{2\pi(R_C + R_L)C_2}$$

- The phase angle in the output RC circuit is expressed as

$$\theta = \tan^{-1}\left(\frac{X_{C2}}{R_C + R_L}\right)$$

3.13.3 Bypass RC Network

- Fig. 3.26 shows RC network formed by the emitter bypass capacitor C_E and the resistance looking in at the emitter.

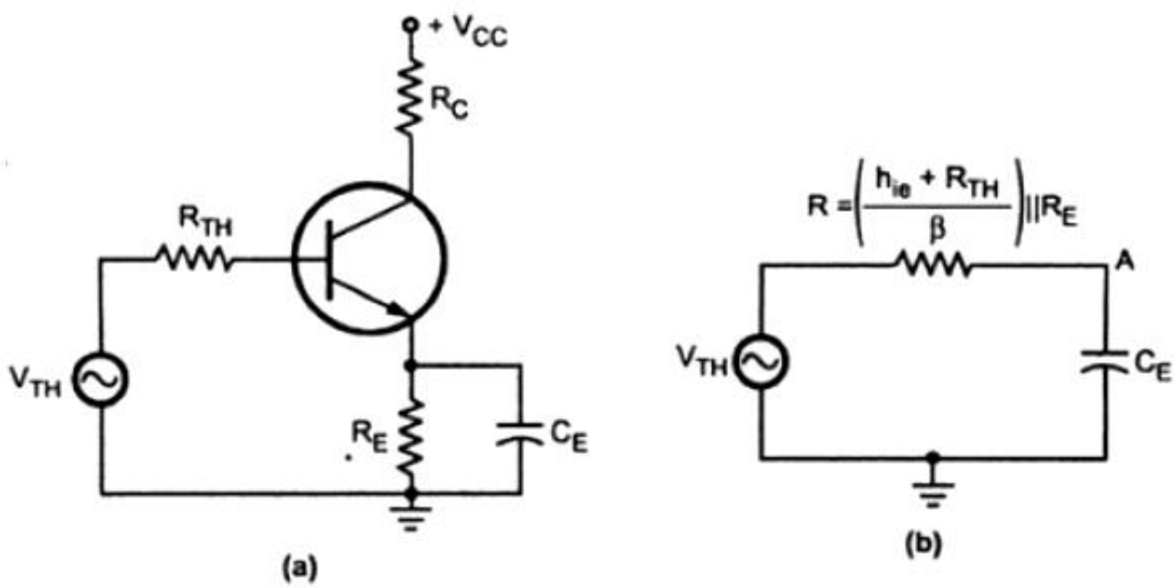


Fig. 3.26 Bypass RC Network

- The resistance looking in at the emitter is given by

$$\frac{h_{ie} + R_{TH}}{\beta}$$

- It is derived as follows

$$R = \frac{V_e}{I_e} + \frac{h_{ie}}{\beta} \cong \frac{V_b}{\beta I_b} + \frac{h_{ie}}{\beta} = \frac{I_b R_{TH}}{\beta I_b} + \frac{h_{ie}}{\beta} = \frac{R_{TH} + h_{ie}}{\beta}$$

- The thevenin's equivalent resistance looking from the base of the transistor towards the input as

$$R_{TH} = R_1 \,||\, R_2 \,||\, R_s$$

- The critical frequency for the bypass RC network is

$$f_c = \frac{1}{2\pi R C_E}$$

$$f_c = \frac{1}{2\pi\left[\left(\frac{h_{ie} + R_{TH}}{\beta}\right) || \, R_E\right] C_E}$$

Example : *Determine the low frequency response of the amplifier circuit shown in Fig.*

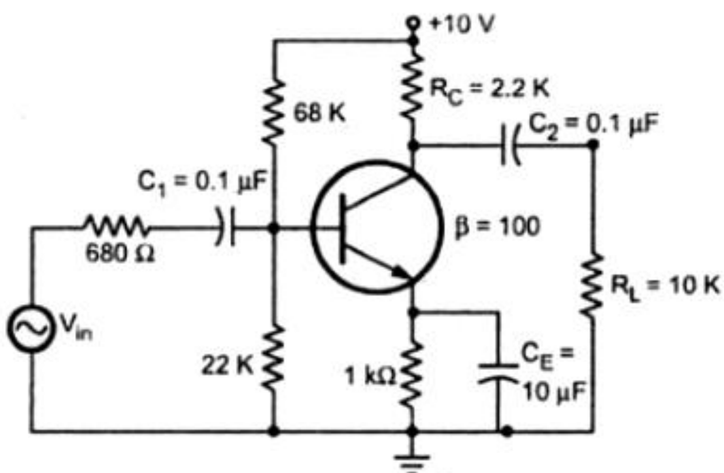


Fig.

Solution : It is necessary to analyze each network to determine the critical frequency of the amplifier

a) Input RC network

$$f_c\,(\text{input}) = \frac{1}{2\pi[R_s + (R_1 \,||\, R_2 \,||\, h_{ie})]C_1}$$

$$= \frac{1}{2\pi[680 + (68\text{ K} \,||\, 22\text{ K} \,||\, 1.1\text{ K})] \times 0.1 \times 10^{-6}}$$

$$f_c\,(\text{input}) = \frac{1}{2\pi[680 + 1031.7] \times 0.1 \times 10^{-6}} = 929.8\text{ Hz}$$

b) Output RC network

$$f_{c\,(output)} = \frac{1}{2\pi(R_C + R_L)C_2} = \frac{1}{2\pi(2.2\,K + 10\,K) \times 0.1 \times 10^{-6}} = 130.45 \text{ Hz}$$

c) Bypass RC network

$$f_{c\,(bypass)} = \frac{1}{2\pi\left[\left(\frac{R_{TH} + h_{ie}}{\beta}\right) || R_E\right] C_E}$$

$$R_{TH} = R_1 \,||\, R_2 \,||\, R_s = 68\,K \,||\, 22\,K \,||\, 680 = 653.28\,\Omega$$

$$f_{c\,(bypass)} = \frac{1}{2\pi\left[\left(\frac{653.28 + 1100}{100}\right) || 1\,K\right] \times 10 \times 10^{-6}} = \frac{1}{2\pi(17.23) \times 10 \times 10^{-6}} = 923.7$$

We have calculated all the three critical frequencies :

a) f_c (input) = 929.8 Hz b) f_c (output) = 130.45 Hz c) f_c (bypass) = 923.7 Hz

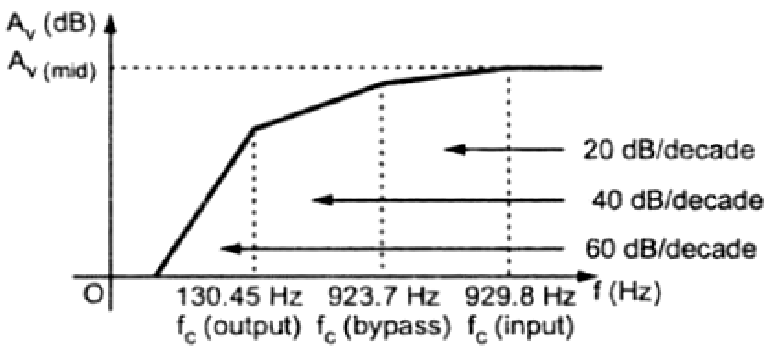


Fig. Low frequency response of the amplifier

The above analysis shows that the input network produces the dominant lower critical frequency. Fig. shows low frequency response of the given amplifier.

3.14 Effect of coupling and bypass capacitors

3.14.1 Effect of coupling capacitors

- Recall that the reactance of a capacitor is $X_C = 1/2\pi fc$.
- At medium and high frequencies, the factor f makes Xc very small, so that all coupling capacitors behave as short circuits.
- At low frequencies, X_C increases. This increase in X_C drops the signal voltage across the capacitor and reduces the circuit gain.
- As signal frequencies decreases, the capacitor reactances increase and circuit gain continues to fall, reducing the output voltage.

3.14.2 Effect of bypass capacitors

- At lower frequencies, the bypass capacitor C_E is not a short. So, the emitter is not at ac ground.
- X_C in parallel with R_E creates an impedance. The signal voltage drops across this impedance reducing the circuit gain.

3.14.3 Effect of internal transistor capacitances

- At high frequencies, the coupling and bypass capacitors act as a short circuit and do not affect the amplifier frequency response.
- However, at high frequencies, the internal capacitances, commonly known as junction capacitances do come into play, reducing the circuit gain.

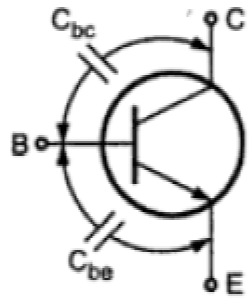


Fig. 3.27 Internal transistor capacitance

- At higher frequencies, the reactances of the junction capacitances are low.
- As frequency increases, the reactances of junction capacitances fall.
- When these reactances become small enough, then it reduces the circuit gain and hence the output voltage.