1.5 BJT CONFIGURATIONS

Depending upon common terminal, there are three possible configurations :

(i) Common Base (CB) configuration

(ii) Common Emitter (CE) configuration

(iii) Common Collector (CC) configuration

1.5.1 Common Base Configuration

In this configuration, the input is applied between emitter and base and output is taken from collector and base. Thus base is common to both input and output circuit.

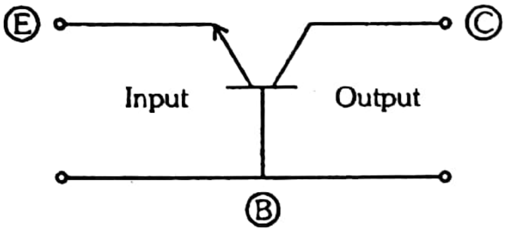


Fig. 1.3

Current amplification factor (α) : It is defined as the ratio of change in collector current to the change in emitter current at constant collector base voltage V_{CB}.

$$\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{constant}}$$

If only dc values are considered,

$$\alpha_{dc} = \frac{I_C}{I_E}$$

1.5.2 Common Emitter Configuration

In this configuration, emitter is common to input and output circuit.

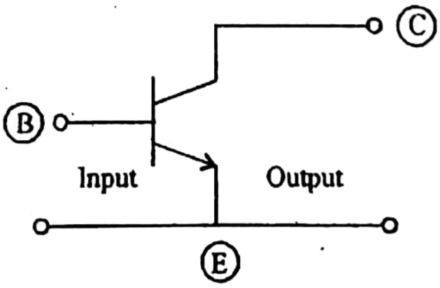


Fig. 1.4

Current amplification factor (β) : It is defined as the change in collector current to the change in base current at constant collector emitter voltage V_{CE}.

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE} = \text{constant}}$$

If only dc values are considered,

$$\beta_{dc} = \frac{I_C}{I_B}$$

1.5.3 Common Collector Configuration

In this configuration, collector is common to input and output circuit.

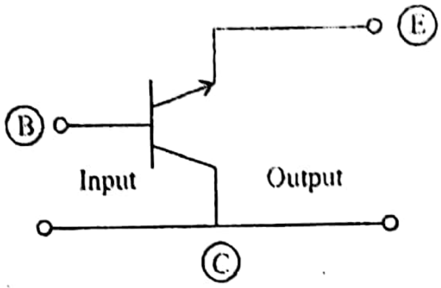


Fig. 1.5

Current amplification factor (γ) : It is defined as the ratio of change in emitter current to the change in base current at constant collector emitter voltage V_{CE}.

$$\gamma_{ac} = \left.\frac{\Delta I_E}{\Delta I_B}\right|_{V_{CE} = \text{constant}}$$

If only dc values are considered,

$$\gamma_{dc} = \frac{I_E}{I_B}$$

1.6 RELATION BETWEEN α AND β

$$I_E = I_B + I_C$$

Also,

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

$$= \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

$$= \frac{\Delta I_C/\Delta I_E}{1 - \Delta I_C/\Delta I_E}$$

$$\beta = \frac{\alpha}{1-\alpha} \qquad \left(\alpha = \frac{\Delta I_C}{\Delta I_E}\right)$$

1.7 EXPRESSION FOR COLLECTOR CURRENT (I_C)

We know that,

$$I_E = I_B + I_C \qquad \dots (1.1)$$

Also

$$I_C = \alpha I_E + I_{CBO} \qquad \dots (1.2)$$

Substituting I_E in equation (1.2),

$$I_C = \alpha (I_B + I_C) + I_{CBO}$$

$$I_C = \alpha I_B + \alpha I_C + I_{CBO}$$

$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

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

1.8 TRANSISTOR CHARACTERISTICS

1.8.1 Common Base Configuration Characteristics

Fig. 1.6 shows the experimental set up to draw input and output characteristics in CB configuration.

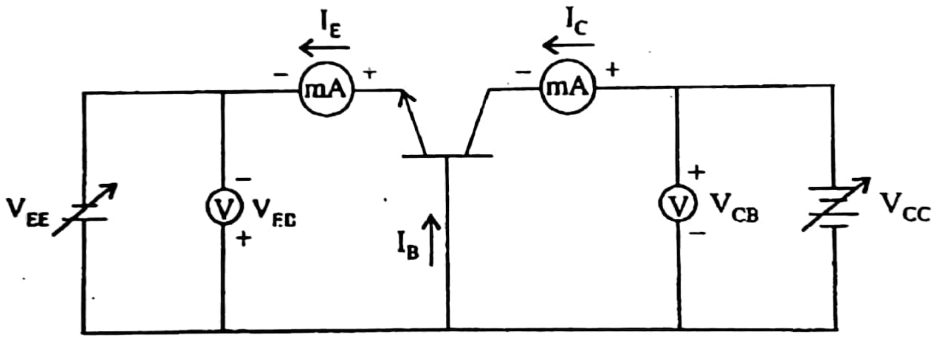


Fig. 1.6

Input characteristics

It is the graph of input current I_E versus input voltage V_{BE} when output voltage V_{CB} is kept constant.

For a given V_{CB}, the input characteristic resembles the characteristic of forward biased diode. Input current I_E increases as input voltage V_{BE} increases for fixed value of V_{CB}. For a given value of V_{BE}, I_E increases with increase in V_{CB} due to early effect.

As V_{CB} increases, width of the depletion layer in the base increases. Hence the width of the base available for conduction decreases. The reduction in the width of the base due to increase in reverse bias is known as **early effect.** Due to early effect, the chances of recombination of electrons with the holes in the base decreases. Therefore, base current decreases but more electrons can travel from emitter to collector terminal. Therefore, collector current increases with increase in emitter current I_E.

As reverse bias voltage V_{CB} further increases, at one stage the depletion region completely occupies the base at which collector base junction breaks down. This phenomenon is known as punch-through.

Dynamic input resistance $\quad r_i = \left.\frac{\Delta V_{BE}}{\Delta I_E}\right|_{V_{CB} = \text{constant}}$

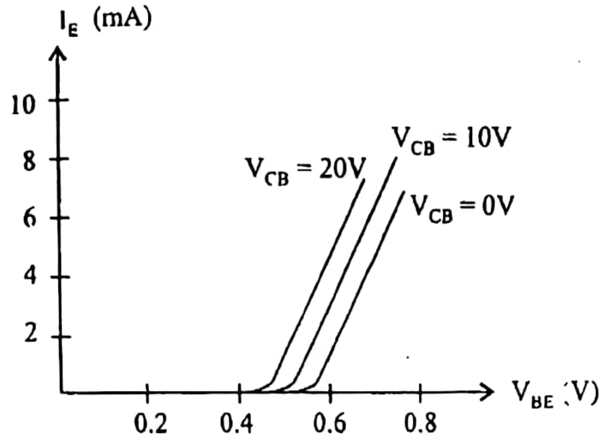


Fig. 1.7

Output characteristics

It is the graph of output current I_C versus output voltage V_{CB} for given values of I_E.

There are three different regions in output characteristics :

(i) Cut-off region : In this region, both the junctions are reverse biased. When emitter-base junction is reverse biased, the current due to majority carrier i.e. I_E is zero. Since collector-base junction is reverse biased, current due to minority carriers flows from collector to base which is represented as I_{CBO}.

(ii) Active region : In this region, emitter-base junction is forward biased and collector base junction is reverse biased. Once V_{CB} reaches a value large enough to ensure a large portion of electrons enter the collector, collector current I_C remains constant as shown by horizontal lines. As I_E increases, I_C increases.

(iii) Saturation region : In this region, both the junctions are forward biased. When V_{CB} is negative, collector base junction is actually forward biased. Thus the graphs are drawn on negative side of V_{CB}. In this region, there is large change in collector current with small increase in voltage V_{CB}.

Output resistance $\qquad r_o = \left.\dfrac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E = \text{constant}}$

Current gain $\qquad \alpha_{ac} = \left.\dfrac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{constant}}$

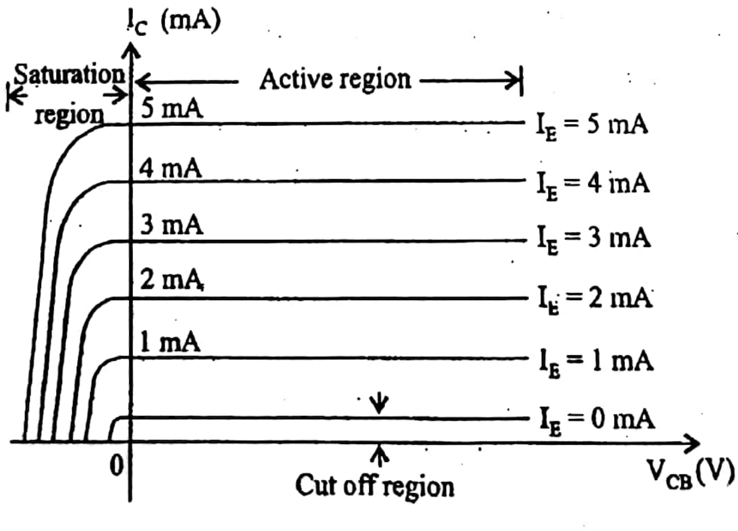


Fig. 1.8

1.8.2 Common Emitter Configuration Characteristics

Fig 1.9 shows the experimental set up to draw input and output characteristics in CE configuration.

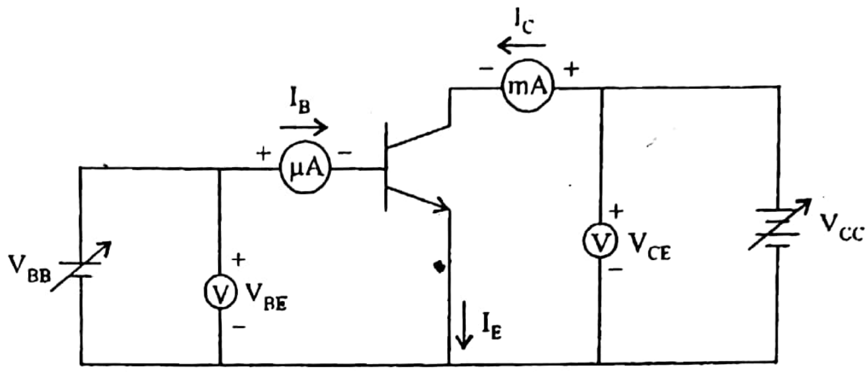


Fig. 1.9

Input characteristics

It is the graph of input current I_B versus input voltage V_{BE} at a constant output voltage V_{CE}. It resembles the characteristics of forward biased diode. Input current I_B increases as input voltage V_{BE} increases for fixed value of V_{CE}.

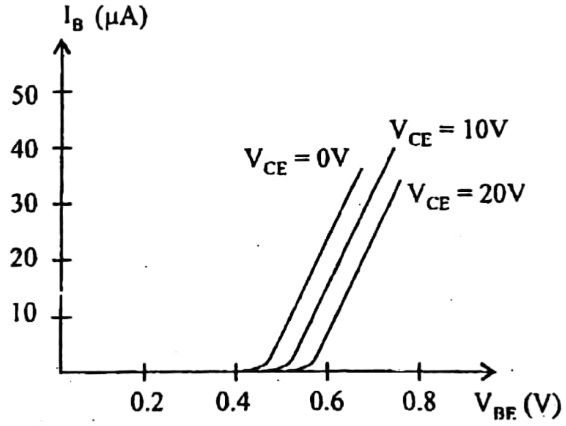


Fig. 1.10

As reverse bias voltage V_{CE} increases, depletion region in collector base increases. Hence the width of base available for conduction decreases. Hence I_B decreases due to early effect and graph shift towards X-axis.

Dynamic input resistance $r_i = \left.\dfrac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE} = \text{constant}}$

Output characteristics

It is the graph of output current I_C versus output voltage V_{CE} for given values of I_B. The output characteristics has three different regions :

(i) Cut-off region : In this region, both the junctions are reverse biased. When emitter base junction is reverse biased, the current due to majority carrier i.e. I_B is zero. Since collector-base junction is reverse biased, the current due to minority carriers flows from collector to emitter which is represented as I_{CEO}.

(ii) Active region : In this region, emitter base junction is forward biased and collector-base junction is reverse biased. As I_B is maintained constant, current I_C increases as reverse bias voltage V_{CE} increases.

(iii) Saturation region : In this region, both the junctions are forward biased. When V_{CE} is reduced to a small value such as 0.2 V, collector base junction is actually forward biased ($V_{CB} = V_{CE} - V_{BE} = 0.2 - 0.7 = -0.5$ V). In this region, there is large change in collector current I_C with small change in V_{CE}.

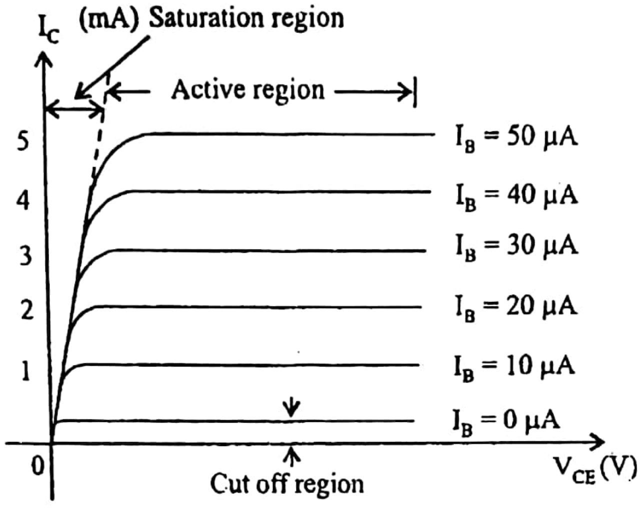


Fig. 1.11

Output resistance $r_o = \left.\dfrac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B} = \text{constant}$

Current gain $\beta_{ac} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}} = \text{constant}$

1.9 ANALYSIS OF TRANSISTOR AMPLIFIER

The basic function of a transistor is to do amplification. The weak signal is given to the transistor and amplified output is obtained from collector. The process of raising the strength of weak signal without any change in its general shape is known as faithful amplification.

Fig. 1.12 shows basic CE amplifier. The battery V_{BB} forward biases emitter base junction and V_{CC} reverse biases collector base junction. R_B is current limiting resistor. Capacitor C_{C2} is used to couple ac output of the amplifier to load resistance R_L. Capacitor C_{C1} is dc blocking capacitor.

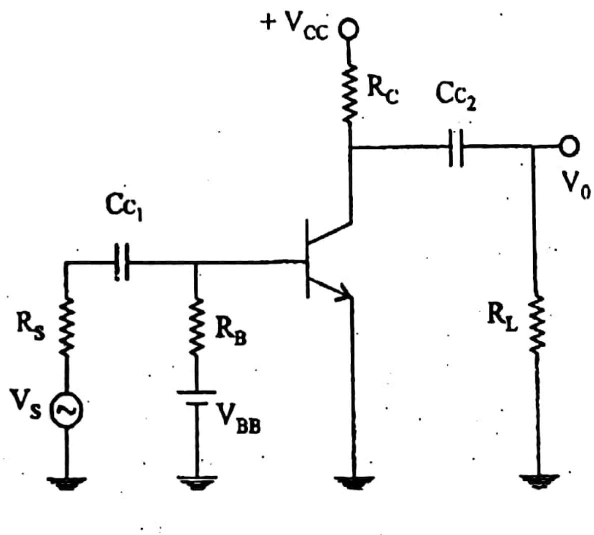


Fig. 1.12

DC analysis

For dc, $f = 0$

$$X_C = \frac{1}{2\pi fc} = \infty$$

Hence capacitors act as open circuits.

DC load line

Applying KVL to the output,

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

$$I_C = -\frac{1}{R_C} V_{CE} + \frac{V_{CC}}{R_C} \quad \text{... (1.3)}$$

Equation (1.3) represents dc load line with slope of $-\frac{1}{R_C}$ and y-intercept of $\frac{V_{CC}}{R_C}$

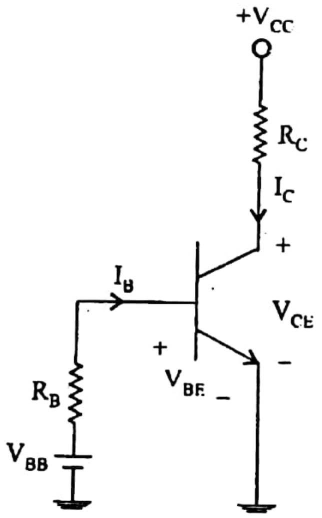


Fig. 1.13

Putting $I_C = 0$ in equation (1.3),

$$V_{CE} = V_{CC}$$

Putting $V_{CE} = 0$ in equation (1.3),

$$I_C = \frac{V_{CC}}{R_C}$$

Thus two end points are $(V_{CC}, 0)$ and $\left(0, \frac{V_{CC}}{R_C}\right)$. A line passing through these points is called dc load line as the slope of this line depends on the dc load R_C.

Quiescent point

Applying KVL to the input,

$$V_{BB} = I_B R_B + V_{BE}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{V_{BB}}{R_B} \quad (V_{BE} \text{ is very small})$$

This equation gives the value of base current. For this value of base current, output characteristic of the amplifier is plotted which intersects the dc load line at Q point. Hence Q point indicates quiescent (inactive, still) value of collector -emitter voltage V_{CE} and collector current I_C.

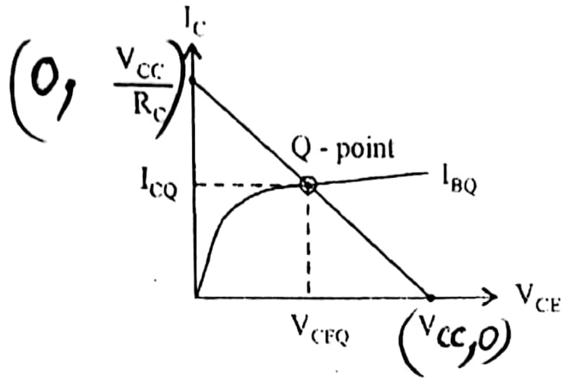


Fig. 1.14

While fixing the Q-point it has to be seen that the output of the amplifier is a proper sinusoidal waveform for sinusoidal input without distortion. By fixing the Q-point at different positions we can observe the variation in collector current and collector-emitter voltage corresponding to a given variation of base current.

When Q-point is located in the middle of the d.c. load line as shown in Fig. 1.15, sinusoidal waveform without distortion is obtained at the output.

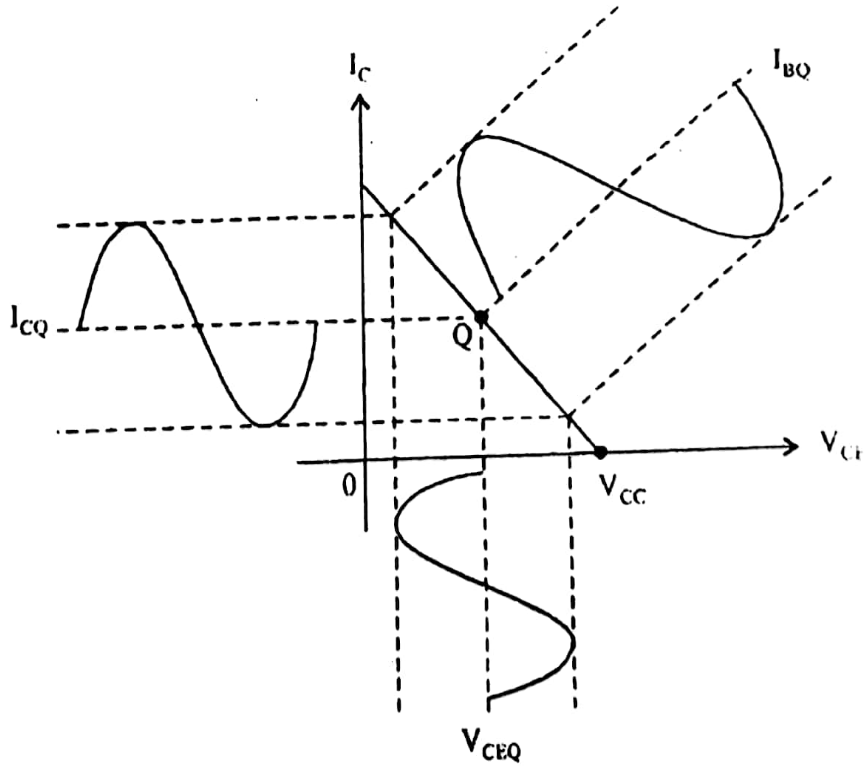


Fig. 1.15

When Q-point is located near saturation region as shown in Fig. 1.16, the collector current is clipped at the positive half cycle.

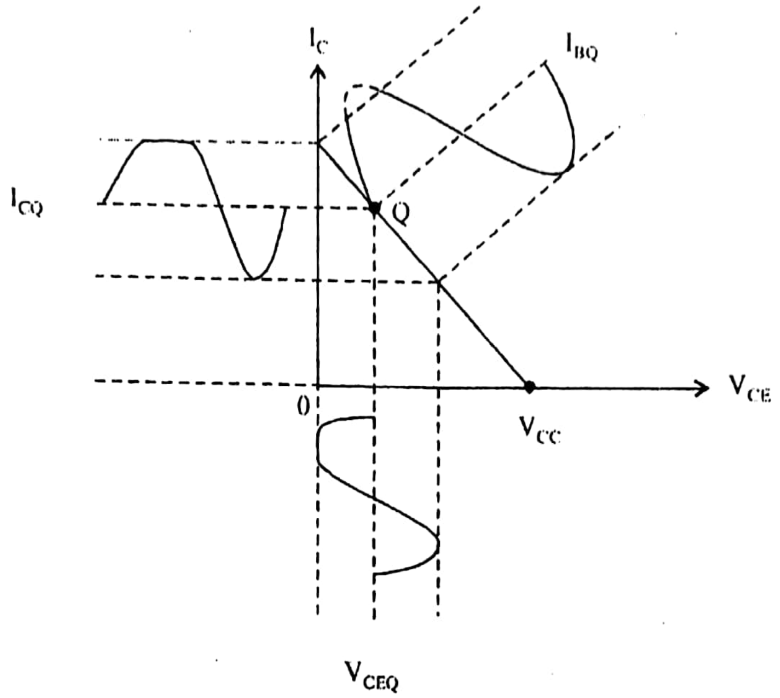


Fig. 1.16

When Q-point is located near the cut-off region, as shown in Fig.1.17, the collector current is clipped at the negative half cycle.

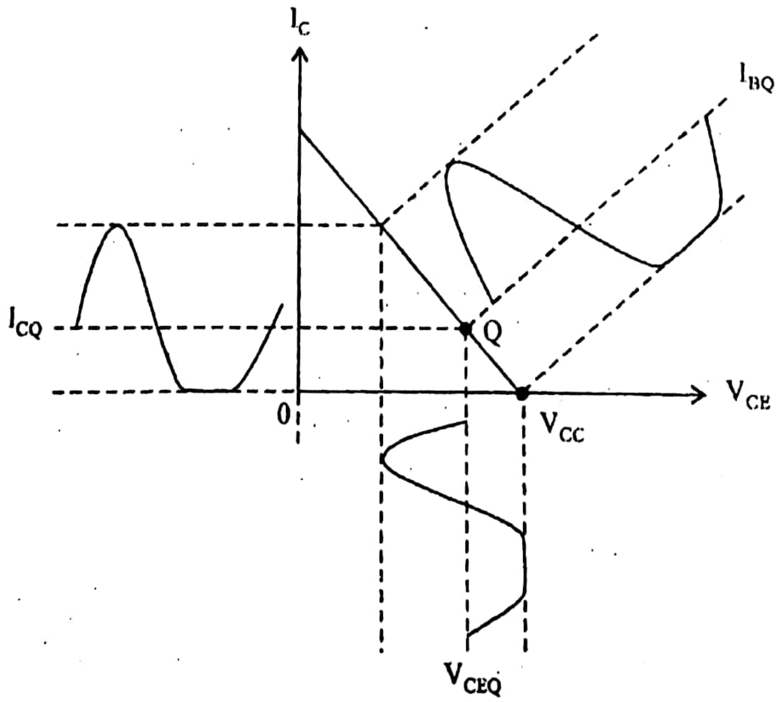


Fig. 1.17

1.10 TRANSISTOR BIASING

The basic function of a transistor is to do amplification. The weak signal is given to the transistor and amplified output is obtained from collector. The process of raising the strength of weak signal without any change in its general shape is known as faithful amplification. The basic problems involved in the design of transistor circuits is establishing and maintaining the proper collector to emitter voltage and collector current in the circuit.This condition is known as transistor biasing. The biasing conditions must be maintained despite variations in temperature, variations in gain and leakage current and variation in supply voltages.

1.10.1 Necessity of Biasing

For faithful amplification, following conditions must be satisfied:

(i) Proper zero signal collector current (I_C)

(ii) Proper base emitter voltage (V_{BE})

(iii) Proper collector-emitter voltage (V_{CE})

The value of I_C and V_{CE} is expressed in terms of operating point or quiescent point Q. For faithful amplification, Q point must be selected properly. The fulfillment of the above conditions is known as transistor biasing.

1.10.2 Need For Stabilization (Why Q-Point Changes) (Bias Stabilization)

The collector current I_C depends on reverse saturation current I_{CO}, current gain β and base emitter voltage V_{BE}. These parameters are temperature dependent i.e. as temperature changes, these parameters change. Hence collector current I_C changes. Due to this, Q point changes. Hence Q point has to be stabilized against temperature variation.

(1) I_{CO} : The collector current is given by

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

The collector leakage current I_{CO} doubles for every 10 °C rise in temperature. The flow of collector current produces heat at the collector junction. This increases the temperature, therefore leakage current I_{CO} increases. Hence, collector current I_C again increases. This increase in I_C increases temperature of collector junction which increases I_{CO} again. The effect is cumulative and at one stage I_C is so large which damages the transistor. This process is known as **thermal runaway.**

(2) β : The transistor parameter β is temperature and device dependent. β increases with the increase in temperature. Value of β is different even for transistors of same type. If transistor is replaced by another transistor even of the same type, the value of β is different. Hence, collector current changes. Therefore, Q-point changes.

(3) V_{BE} : The base emitter voltage V_{BE} decreases at the rate of 2.5 mV/°C i.e. device starts operating at lower voltages. Hence, base current changes which changes collector current and hence the Q-point.

The process of stabilizing Q-point is called as thermal stabilization.There are three methods to bias the BJT.

(1) Fixed bias

(2) Collector to base bias

(3) Voltage divider bias

1.10.3 Stability Factor (S)

The rate of change of collector current w.r.t. collector leakage current I_{CO} at constant β and V_{BE} is called as stability factor.

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

Expression for stability factor

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

Differentiating w.r.t. I_C,

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

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

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

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

1.11 FIXED BIAS CIRCUIT

Fig 1.18 shows a fixed bias circuit.

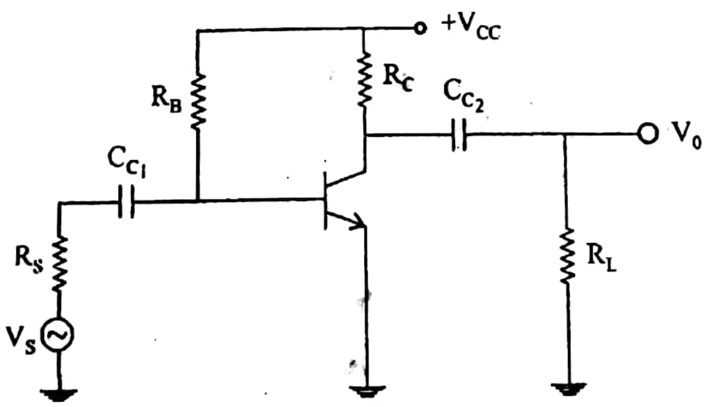


Fig. 1.18

DC analysis

For dc, $f = 0$, $X_C = \frac{1}{2\pi fC} = \infty$

Hence capacitors act as open circuits.

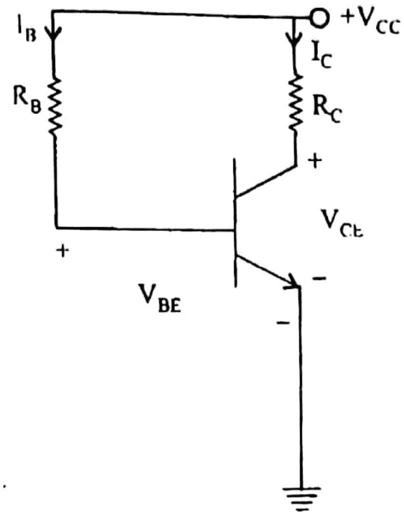


Fig. 1.19

Collector current I_C

Applying KVL to the input,

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

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

$$V_{CC} > V_{BE} \qquad (V_{BE} = 0.7V)$$

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

When V_{CC} and R_B is selected for a circuit, I_B is fixed. Hence, the circuit is called as fixed bias circuit.

$$I_C = \beta I_B$$

Collector-emitter voltage V_{CE}

Applying KVL to the output,

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

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

Stability factor (Bias stabilization for fixed bias)

We know that,

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

Applying KVL to the input,

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

Differentiating w.r.t. I_C,

$$0 - R_B \frac{\partial I_B}{\partial I_C} - 0 = 0$$

$$\frac{\partial I_B}{\partial I_C} = 0$$

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

If $\beta = 100$, then $S = 101$.

i.e. If I_{CO} changes by 1 %, I_C will change by 101% i.e. very large change in collector current occurs even for small changes in I_{CO}. Thus stability of the circuit is very poor.

1.12 FIXED EMITTER BIAS CIRCUIT

Fig 1.20 shows a fixed emitter bias circuit. Here R_E is connected between emitter and ground. Hence stability of the fixed bias circuit improves.

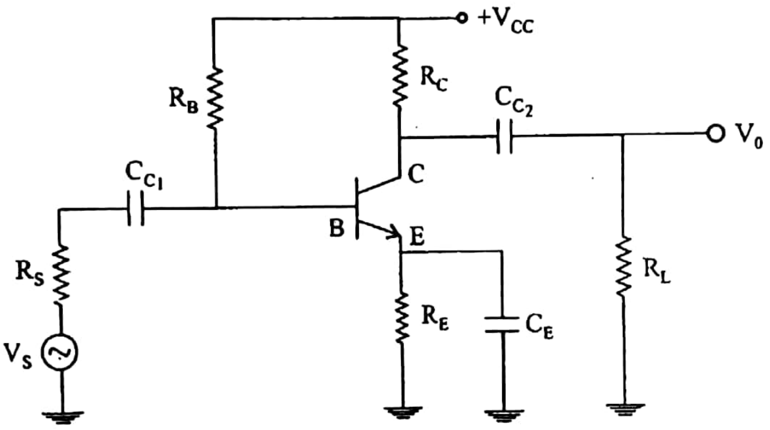


Fig. 1.20

DC analysis

For dc, $f = 0$, $X_C = \frac{1}{2\pi fc} = \infty$

Hence capacitors act as open circuits.

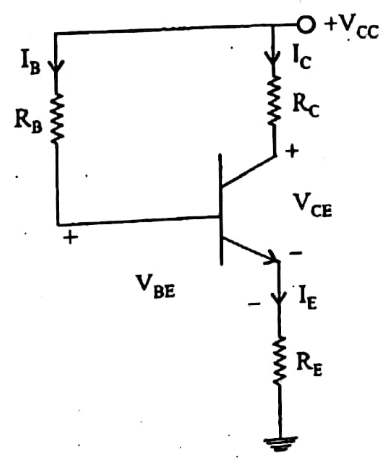


Fig. 1.21

Collector current I_C

Applying KVL to the input,

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

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

$$V_{CC} - I_B R_B - V_{BE} - (I_B + \beta I_B) R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (1 + \beta) I_B R_E = 0$$

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

$$I_C = \beta I_B$$

Collector-emitter voltage V_{CE}

Applying KVL to the output,

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

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

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

Stability factor (Bias stabilization)

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

Applying KVL to the input,

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

Differentiating w.r.t. I_C,

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

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

Negative sign indicates that I_C increases with decrease in I_B and vice-versa.

$$S = \frac{\beta + 1}{1 - \beta \frac{\partial I_B}{\partial I_C}} = \frac{\beta + 1}{1 + \beta \frac{R_E}{R_B + R_E}}$$

when R_E is not connected,

$$S = \beta + 1$$

Thus it is clear that when R_E is added, stability factor reduces i.e. stability of Q-point increases.

How stability is achieved?

Applying KVL to the input,

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

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

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

If temperature increases, collector current I_C tends to increase. As a result voltage drop across R_E increases which decreases base current I_B. As I_C depends on I_B, decrease in I_B reduces the original increase in I_C. Hence variation in I_C with temperature is **minimized** and stability of Q-point is achieved.

Example 1.1 For the circuit shown in Fig.1.22, find I_C, V_{CE} and S.

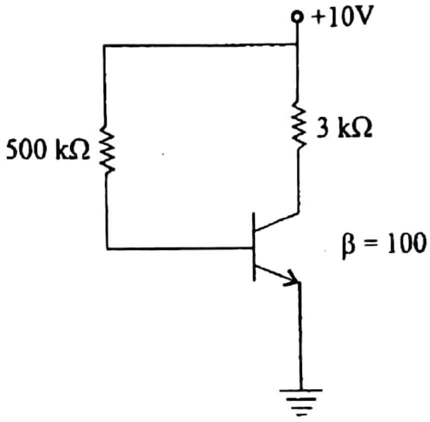


Fig. 1.22

Solution :

Applying KVL to the input,

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

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

$$= \frac{10 - 0.7}{500 \times 10^3}$$

$$= 18.6\ \mu A$$

$$I_C = \beta I_B$$

$$= 100 \times 18.6 \times 10^{-6}$$

$$= 1.86\ mA$$

Applying KVL to the output,

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

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

$$= 10 - 1.86 \times 10^{-3} \times 3 \times 10^3$$

$$= 4.42\ V$$

$$S = \beta + 1$$

$$= 100 + 1$$

$$= 101$$

Example 1.2 Design a fixed bias circuit with $I_C = 2\text{ mA}$, $V_{CE} = 6\text{ V}$, $V_{CC} = 12\text{ V}$, $\beta = 100$.

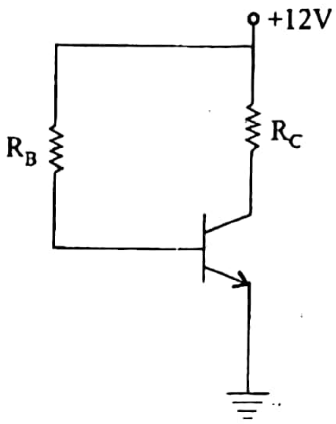


Fig. 1.23

Solution :

$$I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{100} = 20\ \mu A$$

Applying KVL to the input,

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

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

$$= \frac{12 - 0.7}{20 \times 10^{-6}} = 566\ k\Omega$$

Applying KVL to the output,

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

$$R_C = \frac{V_{CC} - V_{CE}}{I_C}$$

$$= \frac{12 - 6}{2 \times 10^{-3}} = 3\ k\Omega$$

Example 1.5 For the fixed bias circuit, $\alpha = 0.98$, $I_{CBO} = 10\ \mu A$, $R_C = 4\ k\Omega$, $R_B = 820\ k\Omega$, $V_{CC} = 12\ V$, Find I_C and V_{CE}.

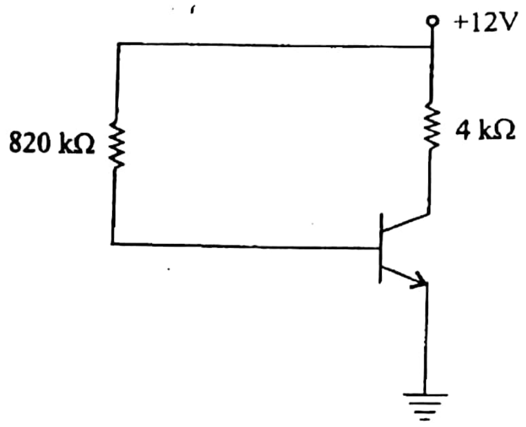


Fig. 1.26

Solution :

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

Applying KVL to the input,

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12-0.7}{820 \times 10^3}$$

$$= 13.78\ \mu A$$

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

$$= 49 \times 13.78 \times 10^{-6} + (49+1) \times 10 \times 10^{-6}$$

$$= 1.17\ mA$$

Applying KVL to the output,

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

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

$$= 12 - 1.17 \times 10^{-3} \times 4 \times 10^3$$

$$= 7.3\ V$$

Example 1.6 For the circuit shown in Fig. 1.27, find I_C, V_{CE} and S.

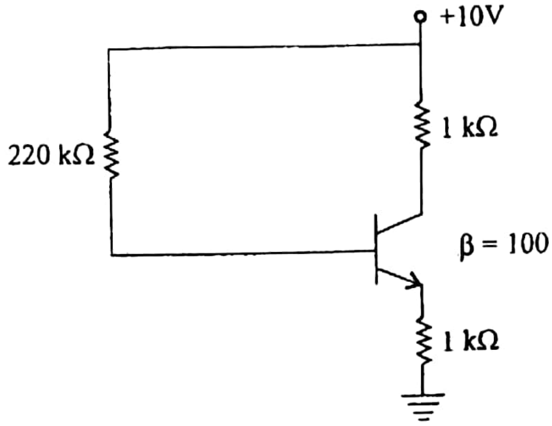


Fig. 1.27

Solution :

Applying KVL to the input,

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

$$V_{CC} - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0$$

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

$$= \frac{10 - 0.7}{220 \times 10^3 + 101 \times 1 \times 10^3}$$

$$= 28.9\ \mu A$$

$$I_C = \beta I_B = 100 \times 28.9 \times 10^{-6}$$

$$= 2.89\ mA$$

Applying KVL to the output,

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

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

$$= 10 - 2.89 \times 10^{-3} \times 1 \times 10^3 - (28.9 \times 10^{-6} + 2.89 \times 10^{-3}) \times 1 \times 10^3$$

$$= 4.19\ V$$

$$S = \frac{\beta + 1}{1 + \beta \frac{R_E}{R_B + R_E}} = \frac{100 + 1}{1 + \frac{100 \times 1 \times 10^3}{220 \times 10^3 + 1 \times 10^3}}$$

$$= 69.53$$

Example 1.8 **In a fixed emitter bias circuit, find R_C and R_B such that $V_{CE} = 5$ V, $I_C = 2$ mA, $V_{CC} = 10$ V, $\beta = 100$, $R_E = 1$ kΩ.**

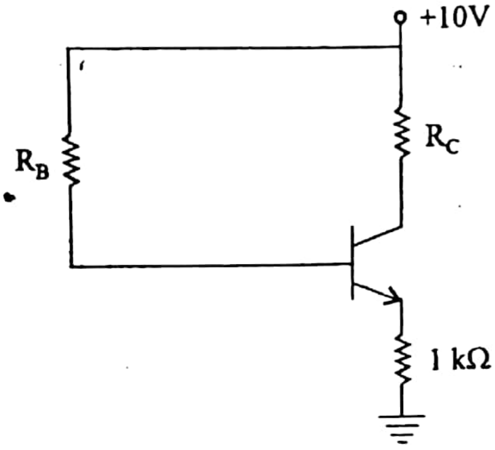


Fig. 1.29

Solution :

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

$$= \frac{2 \times 10^{-3}}{100} = 20\ \mu A$$

Applying KVL to the output,

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

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

$$= \frac{10 - 5 - (2 \times 10^{-3} + 20 \times 10^{-6}) 1 \times 10^3}{2 \times 10^{-3}}$$

$$= 1.49\ k\Omega$$

Applying KVL to the input,

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

$$R_B = \frac{V_{CC} - V_{BE} - (I_C + I_B) R_E}{I_B}$$

$$= \frac{10 - 0.7 - (2 \times 10^{-3} + 20 \times 10^{-6}) 1 \times 10^3}{20 \times 10^{-6}}$$

$$= 364\ k\Omega$$

Example 1.10 Find R_C and R_E in the circuit of Fig. 1.32.

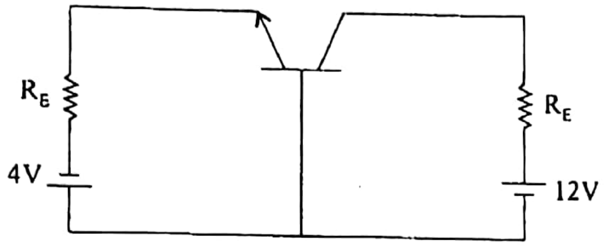


Fig. 1.32

$\alpha = 0.99$
$V_{EE} = 4\ V$
$V_{CC} = 12\ V$
$I_E = 1.1\ mA$
$V_{CE} = 7\ V$

Solution :

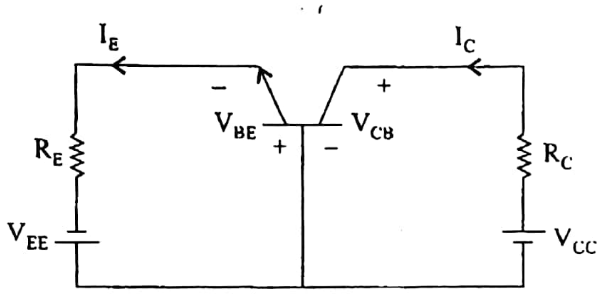


Fig. 1.33

Applying KVL to the input,

$$V_{EE} - I_E R_E - V_{BE} = 0$$

$$R_E = \frac{V_{EE} - V_{BE}}{I_E}$$

$$= \frac{4 - 0.7}{1.1 \times 10^{-3}}$$

$$= 3\ \Omega$$

Applying KVL around transistor terminal,

$$V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = V_{CE} - V_{BE} = 7 - 0.7 = 6.3\ V$$

$$I_C = \alpha I_E$$

$$= 0.99\,(1.1 \times 10^{-3}) = 1.089\ mA$$

Applying KVL to the output,

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

$$R_C = \frac{V_{CC} - V_{CB}}{I_C}$$

$$= \frac{12 - 6.3}{1.089 \times 10^{-3}}$$

$$= 5.234\ k\Omega$$

1.13 COLLECTOR TO BASE BIAS CIRCUIT

Fig. 1.34 shows collector to base bias circuit. In this method, resistor R_B is connected between base and collector. Hence the circuit is called as collector-to-base bias.

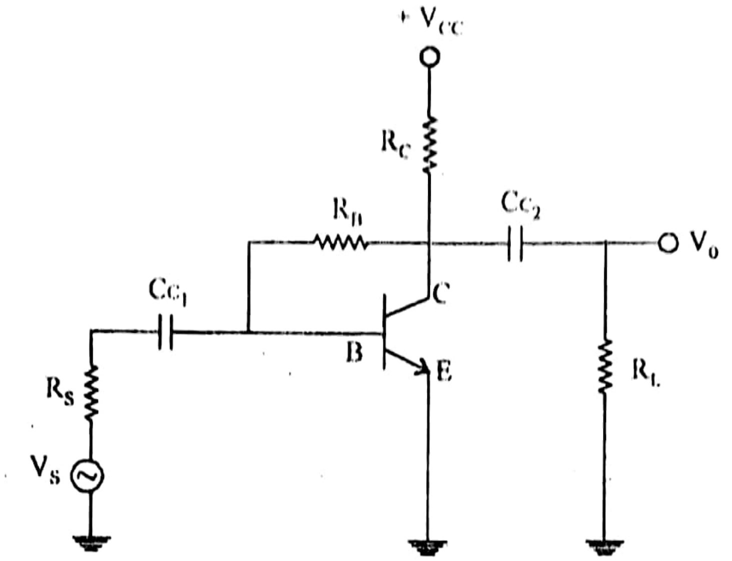


Fig. 1.34

DC analysis

For dc, $f = 0$, $X_C = \frac{1}{2\pi fC} = \infty$

Hence capacitors act as open circuits.

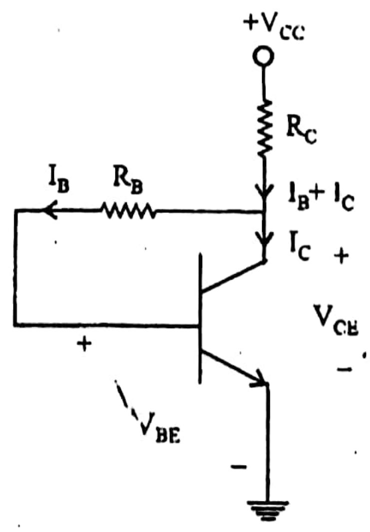


Fig. 1.35

Collector current I_C

Applying KVL to the input,

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

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

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

$$I_C = \beta I_B$$

Collector-emitter voltage V_{CE}

Applying KVL to the output,

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

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

Stability factor (Bias stabilization for C to B bias)

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

Applying KVL to the input,

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

Differentiating w.r.t. I_C

$$0 - R_C \frac{\partial I_B}{\partial I_C} - R_C - R_B \frac{\partial I_B}{\partial I_C} - 0 = 0$$

$$\frac{\partial I_B}{\partial I_C} = -\frac{R_C}{R_C + R_B}$$

Negative sign indicates that as I_C increases I_B decreases and vice versa.

$$S = \frac{\beta + 1}{1 - \beta \frac{\partial I_B}{\partial I_C}} = \frac{\beta + 1}{1 + \beta \frac{R_C}{R_B + R_C}}$$

Hence stability factor S is smaller than $(\beta + 1)$ which is obtained from fixed bias circuit. Thus stability is improved.

How stability is achieved?

Applying KVL to the input,

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

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

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

If temperature increases, collector current I_C tends to increase. As a result voltage drop across R_C increases which decreases base current I_B. As I_C depends on I_B, decrease in I_B reduces the original increase in I_C. Hence variation in I_C with temperature is **minimized** and stability of Q-point is achieved.

Drawback

This circuit provides negative feedback which reduces the gain of the amplifier.

1.14 COLLECTOR TO BASE BIAS CIRCUIT WITH EMITTER RESISTOR

Fig. 1.38 shows collector to base bias circuit with emitter resistor. Emitter resistor R_E is connected in the emitter terminal.

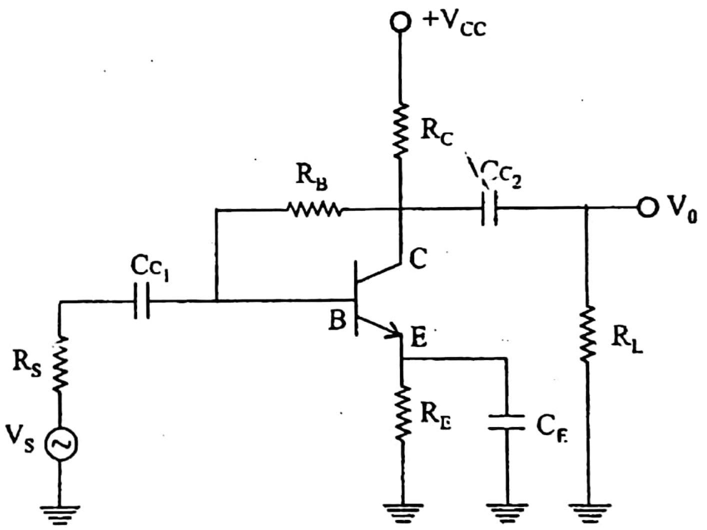


Fig. 1.38

DC analysis

For dc, $f = 0$, $X_C = \frac{1}{2\pi fC} = \infty$

Hence capacitors act as open circuits.

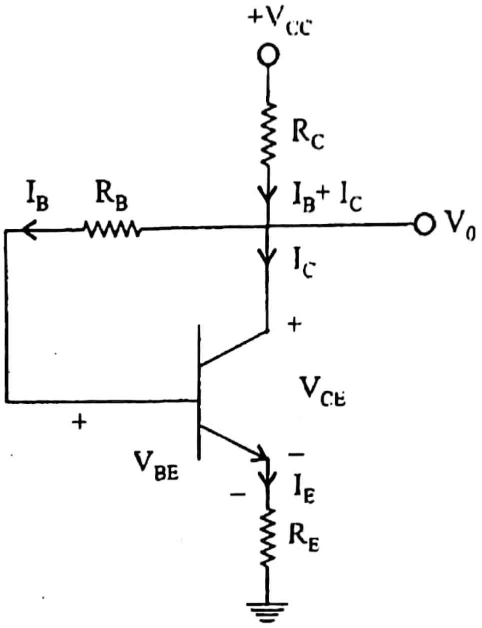


Fig. 1.39

Collector current I_C

Applying KVL to the input,

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

$$I_E = I_B + I_C = I_B + \beta I_B = (\beta + 1) I_B$$

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

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

$$I_C = \beta I_B$$

Collector-emitter voltage V_{CE}

Applying KVL to the output,

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

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

Example 1.12 Determine I_B, I_C, V_{CE} and stability factor.

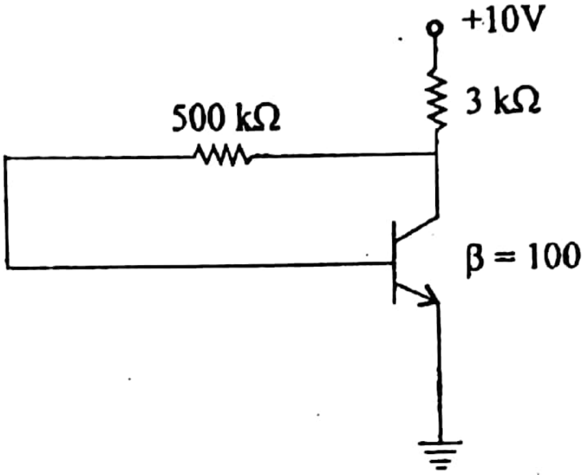


Fig. 1.41

Solution :

Applying KVL to the input,

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

$$V_{CC} - (\beta + 1) I_B R_C - I_B R_B - V_{BE} = 0$$

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

$$= \frac{10 - 0.7}{500 \times 10^3 + 101 \times 3 \times 10^3}$$

$$= 11.58 \ \mu A$$

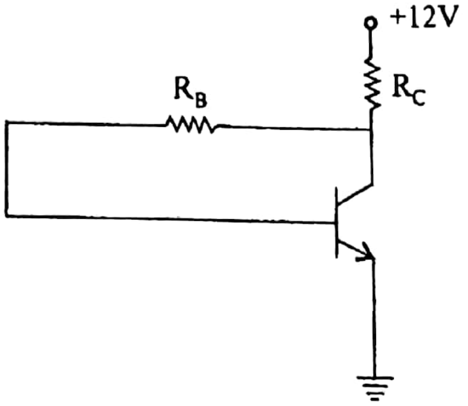
$$I_C = \beta I_B = 100 \times 11.58 \times 10^{-6}$$

$$= 1.158 \text{ mA}$$

$$S = \frac{\beta + 1}{1 + \beta \frac{R_C}{R_B + R_C}} = \frac{100 + 1}{1 + \frac{100 \times 3 \times 10^3}{500 \times 10^3 + 3 \times 10^3}}$$

$$= 63.26$$

Example 1.13 For the circuit shown in Fig. 1.42, find R_B and R_C,



$$V_{CE} = 6\text{ V}$$
$$I_C = 2\text{ mA}$$
$$V_{CC} = 12\text{ V}$$
$$V_{BE} = 0.7\text{ V}$$
$$\beta = 100$$

Fig. 1.42

Solution :

$$I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{100}$$
$$= 20\ \mu\text{A}$$

Applying KVL to the output,

$$V_{CC} - (I_B + I_C) R_C - V_{CE} = 0$$
$$V_{CC} - (\beta + 1) I_B R_C - V_{CE} = 0$$
$$R_C = \frac{V_{CC} - V_{CE}}{(\beta + 1) I_B} = \frac{12 - 6}{101 \times 20 \times 10^{-6}} = 2.97\text{ k}\Omega$$
$$V_{CC} - (I_B + I_C) R_C - I_B R_B - V_{BE} = 0$$
$$R_B = \frac{V_{CC} - V_{BE} - (I_B + I_C) R_C}{I_B}$$
$$= \frac{12 - 0.7 - 6}{20 \times 10^{-6}}$$
$$= 265.4\text{ k}\Omega$$

Example 1.16 Calculate dc collector current I_C and voltage V_C for the bias circuit shown in Fig. 1.45.

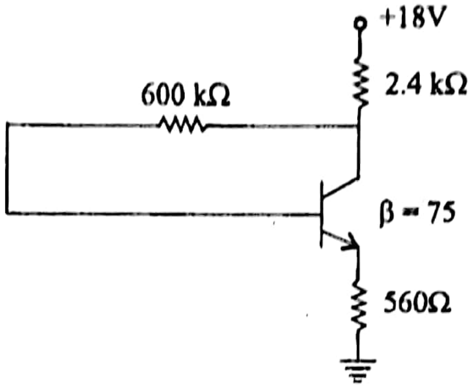


Fig. 1.45

Solution :

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

$$= \frac{18 - 0.7}{600 \times 10^3 + 76(2.4 + 0.56) \times 10^3}$$

$$= 20.9\ \mu A$$

$$I_C = \beta I_B = 75 \times 20.9 \times 10^{-6}$$

$$= 1.57\ mA$$

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

$$= 18 - (20.9 \times 10^{-6} + 1.57 \times 10^{-3})(2.4 + 0.56) \times 10^3$$

$$= 13.29\ V$$

1.15 VOLTAGE DIVIDER BIAS CIRCUIT

Fig. 1.52 shows voltage divider bias circuit. Resistors R_1 and R_2 form a voltage divider network.

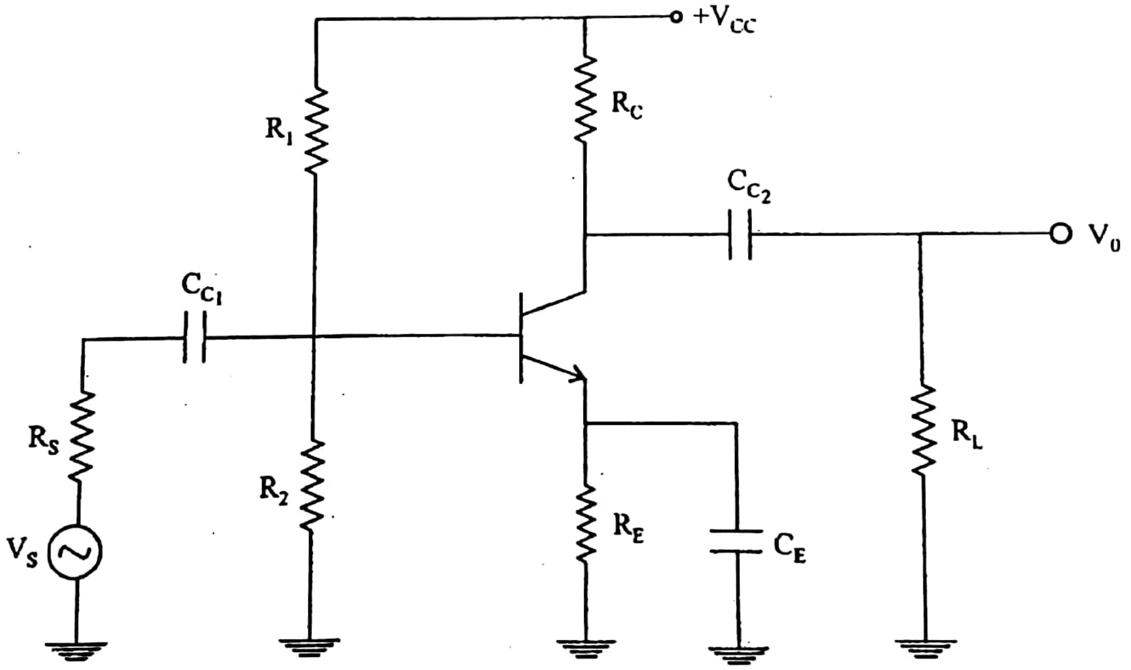


Fig. 1.52

DC analysis

For dc, f = 0, $X_C = \frac{1}{2\pi fC} = \infty$

Hence capacitors act as open circuits.

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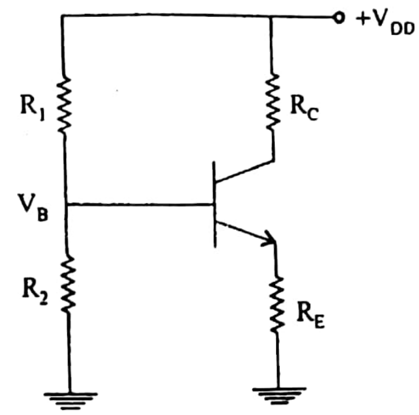


Fig. 1.53

The input circuit can be converted into Thevenin's equivalent as follows :

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

$$R_{Th} = R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

As R_1 and R_2 divides the voltage V_{CC} at the base, the circuit is called as voltage divider bias.

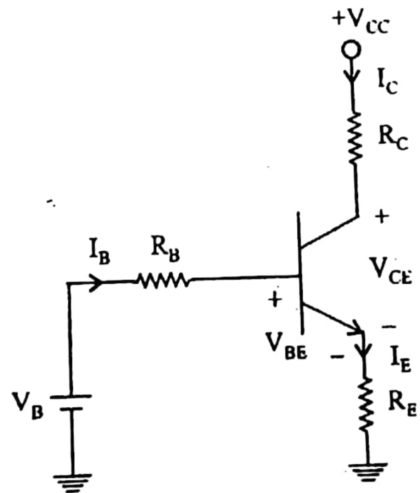


Fig. 1.54

Collector current I_C

Applying KVL to the input,

$$V_B - I_B R_B - V_{BE} - I_E R_E = 0$$

Now,

$$I_E = I_B + \beta I_B = (\beta + 1) I_B$$

$$V_B - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0$$

$$V_B - V_{BE} = [R_B + (\beta + 1) R_E] I_B$$

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

$$I_C = \beta I_B$$

Collector-emitter voltage V_{CE}

Applying KVL to the output,

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

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

Stability factor (Bias stabilization for Voltage divider bias)

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

Applying KVL to the input,

$$V_B - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

Differentiating. w.r.t. I_C,

$$0 - R_B \frac{\partial I_3}{\partial I_C} - 0 - R_E \frac{\partial I_B}{\partial I_C} - R_E = 0$$

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

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

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

How stability is achieved?

Applying KVL to the input,

$$V_B - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

$$I_B = \frac{V_B - V_{BE} - I_C R_E}{R_B + R_E}$$

If temperature increases, collector current I_C tends to increase. As a result voltage drop across R_E increases which decreases base current I_B. As I_C depends on I_B, decrease in I_B reduces the original increase in I_C. Hence variation in I_C with temperature is minimized and stability of Q-point is achieved.

How stability is achieved?

Applying KVL to the input,

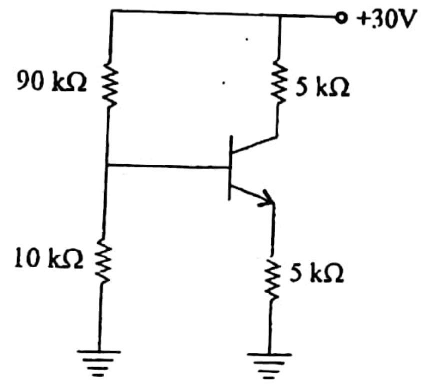
$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

$$-I_B R_B - V_{BE} - I_C R_E - I_B R_E + V_{EE} = 0$$

$$I_B = \frac{V_{EE} - V_{BE} - I_C R_E}{R_B + R_E}$$

If temperature increase, collector current I_C tends to increase. As a result voltage drop across R_E increases which decreases base current I_B. As I_C depends on I_B, decrease in I_B reduces the original increase in I_C. Hence variation in I_C with temperature is **minimized** and stability of Q-point is achieved.

Example 1.20 Find I_C, V_{CE} and stability factor S.



$$\beta = 100$$

$$I_{CBO} = 10\ \mu A$$

Fig. 1.56

Solution :

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{10k}{10k + 90k} \times 30 = 3V$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = \frac{90k \times 10k}{90k + 10k} = 9\ k\Omega$$

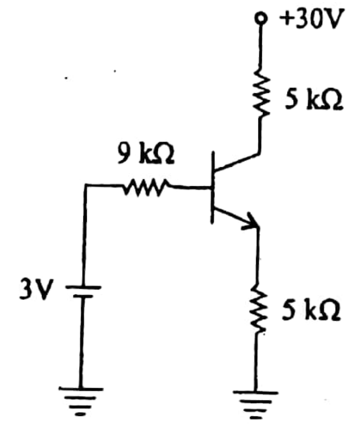


Fig. 1.57

Applying KVL to the input,

$$V_B - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

$$V_B - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0$$

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

$$= \frac{3 - 0.7}{9\times 10^3 + (101)\, 5\times 10^3}$$

$$= 4.47\ \mu A$$

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

$$= 100\,(4.47\times 10^{-6}) + (101)\, 10\times 10^{-6}$$

$$= 1.457\ mA$$

Applying KVL to the output,

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

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

$$= 30 - 1.457 \times 10^{-3} \times 5 \times 10^3 - (4.47 \times 10^{-6} + 1.457 \times 10^{-3})\, 5 \times 10^3$$

$$= 15.4\ V$$

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

$$= \frac{100 + 1}{1 + 100 \times \dfrac{5k}{9k + 5k}}$$

$$= 2.75$$

Example 1.21 **Find R_1, R_2 and R_C of the circuit shown in Fig. 1.58 if $I_C = 1$ mA, $R_E = 1\ k\Omega$, $V_{CC} = 10$ V, $\beta = 100$, $S = 10$ and $V_{CE} = 5$ V.**

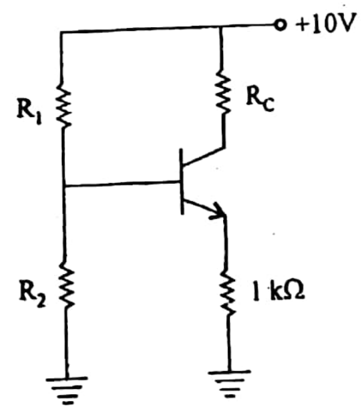


Fig. 1.58

Solution :

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

$$= \frac{1 \times 10^{-3}}{100} = 0.01\ mA$$

Applying KVL to the output,

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

$$10 - 1 \times 10^{-3} \times R_C - 5 - (0.01 + 1) \times 10^{-3} \times 1 \times 10^3 = 0$$

$$R_C = 3.99\ k\Omega$$

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

$$10 = \frac{100 + 1}{1 + 100 \times \dfrac{1k}{R_B + 1k}}$$

$$R_B = 9.98\ k\Omega$$

Replacing the base circuit by its Thevenin equivalent,

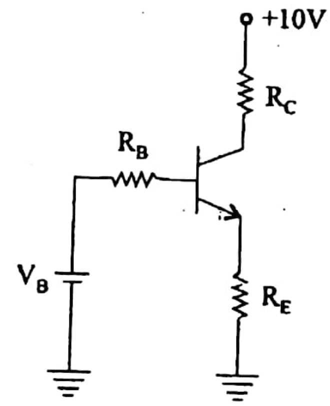


Fig. 1.59

Applying KVL to the input,

$$V_B - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

$$V_B - 0.01 \times 10^{-3} \times 9.98 \times 10^3 - 0.7 - (0.01 + 1) \times 10^{-3} \times 1 \times 10^3$$

$$V_B = 1.71\ V$$

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

Multiplying both the sides by R_1,

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

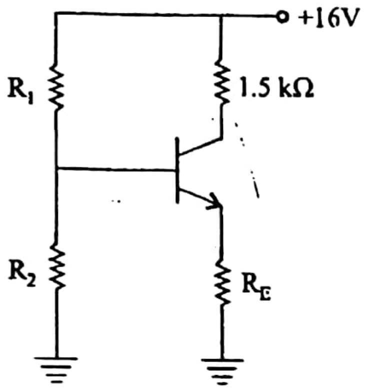
$$R_1 = \frac{R_B V_{CC}}{R_1} = \frac{9.98 \times 10^3 \times 10}{1.71} = 58.36\ k\Omega$$

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

$$9.98\times 10^3\ (58.36\times 10^3 + R_2) = 58.36\times 10^3\, R_2$$

$$R_2 = 12.04\ k\Omega$$

Example 1.22 For the circuit shown in Fig. 1.60, find R_1, R_2 and R_E.



$V_{CE} = 8\ V$

$I_C = 4\ mA$

$\beta = 50$

$S = 10$

$V_{BE} = 0.3\ V$

Fig. 1.60

Solution :

$$I_B = \frac{I_C}{\beta} = \frac{4\times 10^{-3}}{50} = 0.08\ mA$$

Applying KVL to the output,

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

$$16 - 4\times 10^{-3}\times 1.5\times 10^3 - 8 - (0.08 + 4)\times 10^{-3}\times R_E = 0$$

$$R_E = 0.49\ k\Omega$$

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

$$10 = \frac{51}{1 + 50\times \frac{0.49k}{R_B + 0.49k}}$$

$$R_B = 5.49\ k\Omega$$

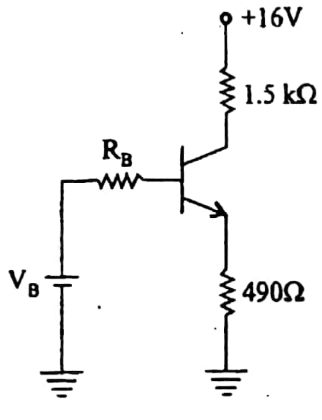


Fig. 1.61

Applying KVL to the input,

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

$$= 0.08 \times 10^{-3} \times 5.49 \times 10^3 + 0.3 + (0.08 + 4) \times 10^{-3} \times 0.49 \times 10^{-3}$$

$$= 2.53 \text{ V}$$

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

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

$$= R_B V_{CC}$$

$$R_1 = \frac{R_B V_{CC}}{R_1} = \frac{5.49 \times 10^3 \times 16}{2.53}$$

$$= 34.72 \text{ k}\Omega$$

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

$$5.49 \times 10^3 (R_1 + R_2) = R_1 R_2$$

$$5.49 \times 10^3 (34.72 \times 10^3 + R_2) = 34.72 \times 10^3 R_2$$

$$R_2 = 4.74 \text{ k}\Omega$$

Give Reasons

1. The base of transistor is lightly doped.

In BJT, base current flows when electrons from the emitter recombine in the base. If the base is heavily doped, then the more electrons will recombine in the base and less electrons will travel to the collector. This increases the base current but decreases the collector current. In BJT, it is required that collector current I_C should be very high. Hence, base is lightly doped. If base is lightly doped, then the number of recombination in the base will less and more electrons will travel to collector thereby increasing the collector current.

2. Base width in a transistor is kept small.

If the width of base is increased, then electrons travelling from emitter to collector will remain in the base from more time thereby increasing number of recombination with the electrons which increases base current and reduces collector current. To get more collector current, width of base should be very small.

3. Collector width is maximum in transistor.

Usually the collector base junction is reverse biased. To withstand large reverse voltage such that collector base junction is not broken, the collector width is maximum. It also helps in dissipating heat quickly to the surrounding.

4. The emitter of transistor is heavily doped.

When emitter is heavily doped, there is large number of electrons available for recombination.

5. Current gain β of BJT can be increased by decreasing the base width.

The current gain is given by $\beta = \frac{I_C}{I_B}$. If base width decreases, then number of recombination in the base decreases. Therefore base current I_B decreases but emitter current I_E and collector I_C increases. Hence, current gain β increases.

6. BJT is called as current controlled current source.

In BJT, current equation is given by $I_E = I_B + I_C$.

I_B controls the flow of emitter collector current. In other words input current controls the output current. Hence, BJT is called as current controlled current source.

7. In CE configuration, transistor is not cut-off when $I_B = 0$.

In CE configuration, when $I_B = 0$ i.e. in the cut-off region, collector current is not zero. But a small leakage current flows from collector to emitter. Hence, transistor is not cut-off.

$$I_C = \beta I_B + (\beta + 1) I_{CBO}$$
$$= (\beta + 1) I_{CBO} \qquad \text{when } I_B = 0$$
$$= I_{CEO}$$

8. Thermal runaway is of importance in BJT amplifiers than FET amplifiers.

In FET, drain current I_D decreases by 0.7%/°C.

In BJT, the collector current is $I_C = \beta I_B + (\beta + 1) I_{CO}$.

Due to increase in temperature, reverse saturation current I_{CO} increases, which increases collector current I_C. The increase in I_C, in turn increases junction temperature and hence I_{CBO}. This process continues, till I_C goes on increasing beyond limit and breakdown occurs, which is called as thermal runaway. Hence, it is important in BJT amplifiers.

9. Thermal stability of biasing is necessary in BJT amplifiers.

In order to use transistor as an amplifier, it is necessary to bias the transistor in active region of the characteristics. The biasing circuit should ensure that Q-point remains fixed with changes in temperature and transistor parameters.

If junction temperature increases, then I_{CBO} increases. Hence, I_C increases. If I_C continues to increase, Q-point moves to saturation region, which may distort the output signal. Hence thermal stability of Q-point is important.

10. Reverse saturation current in transistor increases with increase in temperature.

The reverse saturation current is due to thermally generated minority carriers. As temperature increases, more bonds are broken. Hence, more hole-electron pairs (thermally generated) are formed. Therefore, reverse saturation current also increases.

11. Fixed bias circuit cannot provide stable operating point.

In fixed bias circuit, $S = \beta + 1 = \frac{\partial I_C}{\partial I_{CO}}$ i.e. value of stability factor is very high. If $\beta = 50$ then $S = 57$. This indicates I_C will vary 51 times more than that of variations of I_{CO}. Hence, I_C goes on increasing with I_{CO} which leads to thermal runaway. Thus the circuit cannot provide stable operating point.