Transistor Biasing & Stabilization

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Transistor Biasing

The basic function of transistor is amplification. The process of raising the strength of weak signal without any change in its general shape is referred as faithful amplification. For faithful amplification it is essential that:-

1. Emitter-Base junction is forward biased
2. Collector- Base junction is reversed biased
3. Proper zero signal collector current

The circuit used for proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of signal is called transistor biasing.

WHY BIASING?

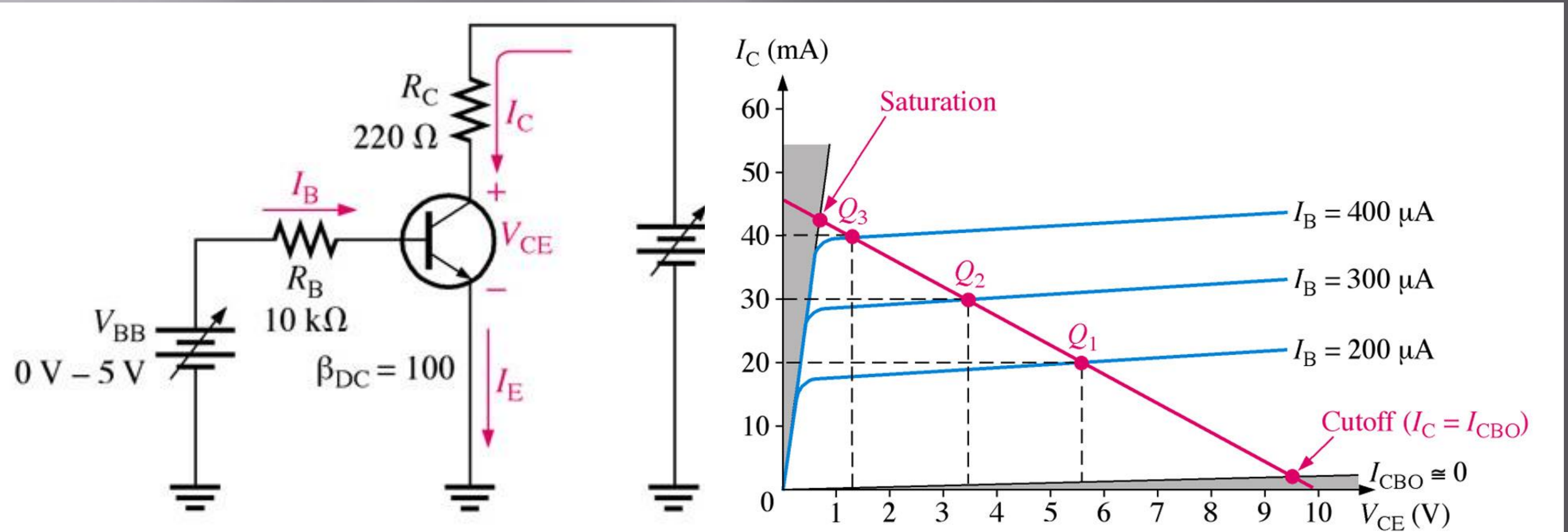
If the transistor is not biased properly, it would work inefficiently and produce distortion in output signal.

HOW A TRANSISTOR CAN BE BIASED?

A transistor is biased either with the help of battery or associating a circuit with the transistor. The later method is more efficient and is frequently used. The circuit used for transistor biasing is called the biasing circuit.

The DC Operating Point

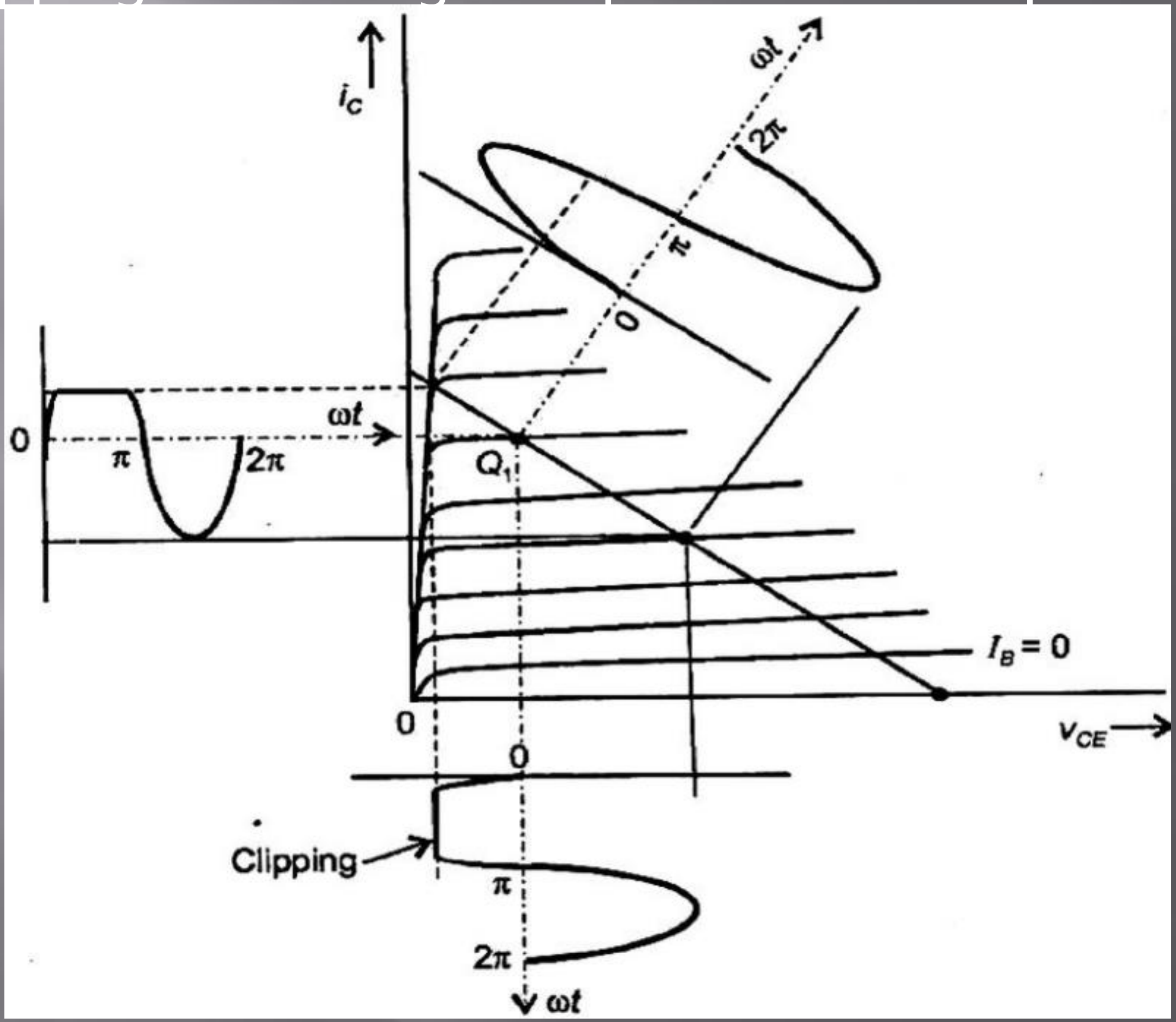
For a transistor circuit to amplify it must be properly biased with dc voltages. The dc operating point between saturation and cutoff is called the **Q-point.** The goal is to set the Q-point such that it does not go into saturation or cutoff when an ac signal is applied.



(a) DC biased circuit

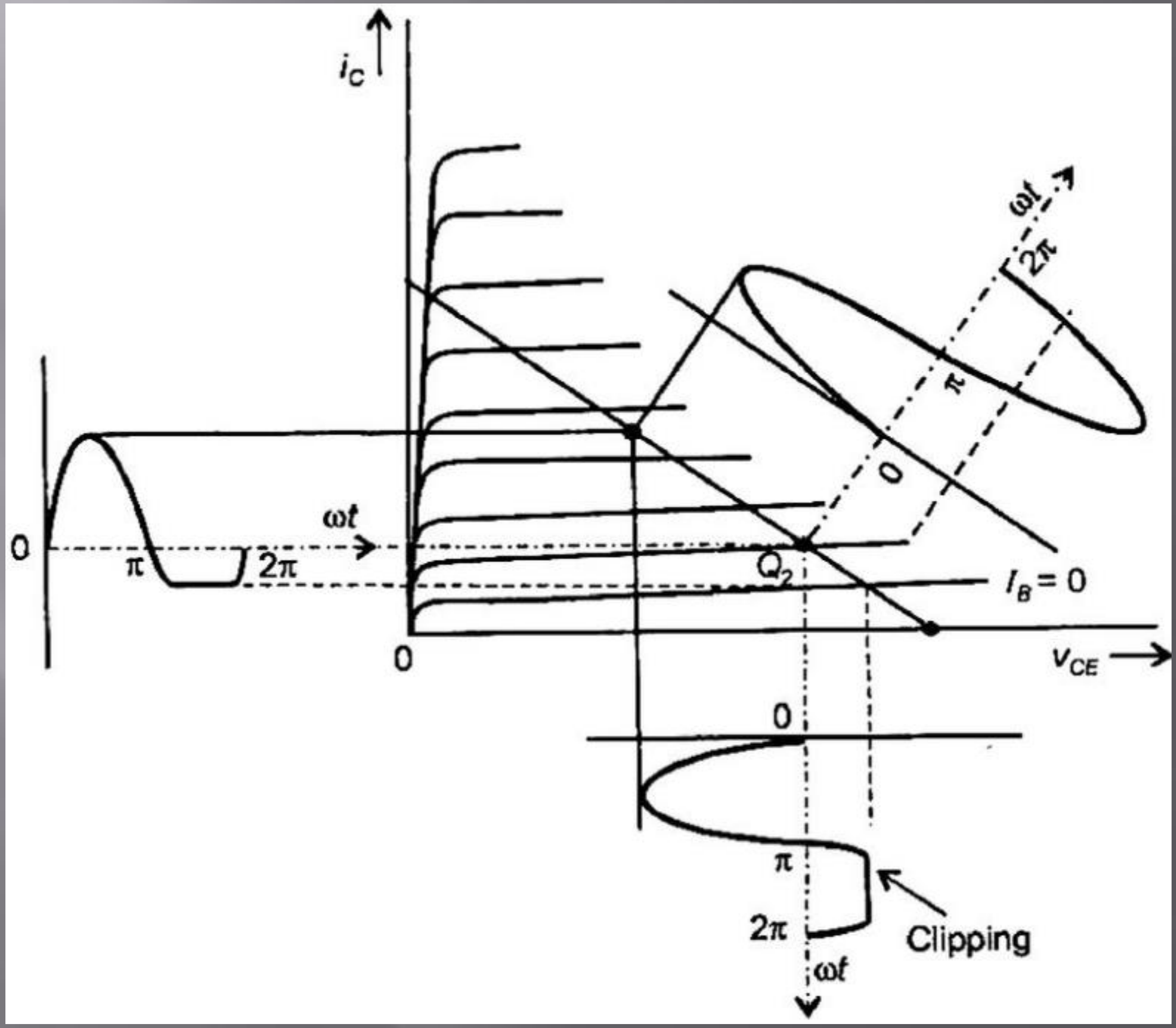
Selection of the Operating Point

Operating point (Q_1) near the saturation region results in clipping of the negative peak of the output signal.



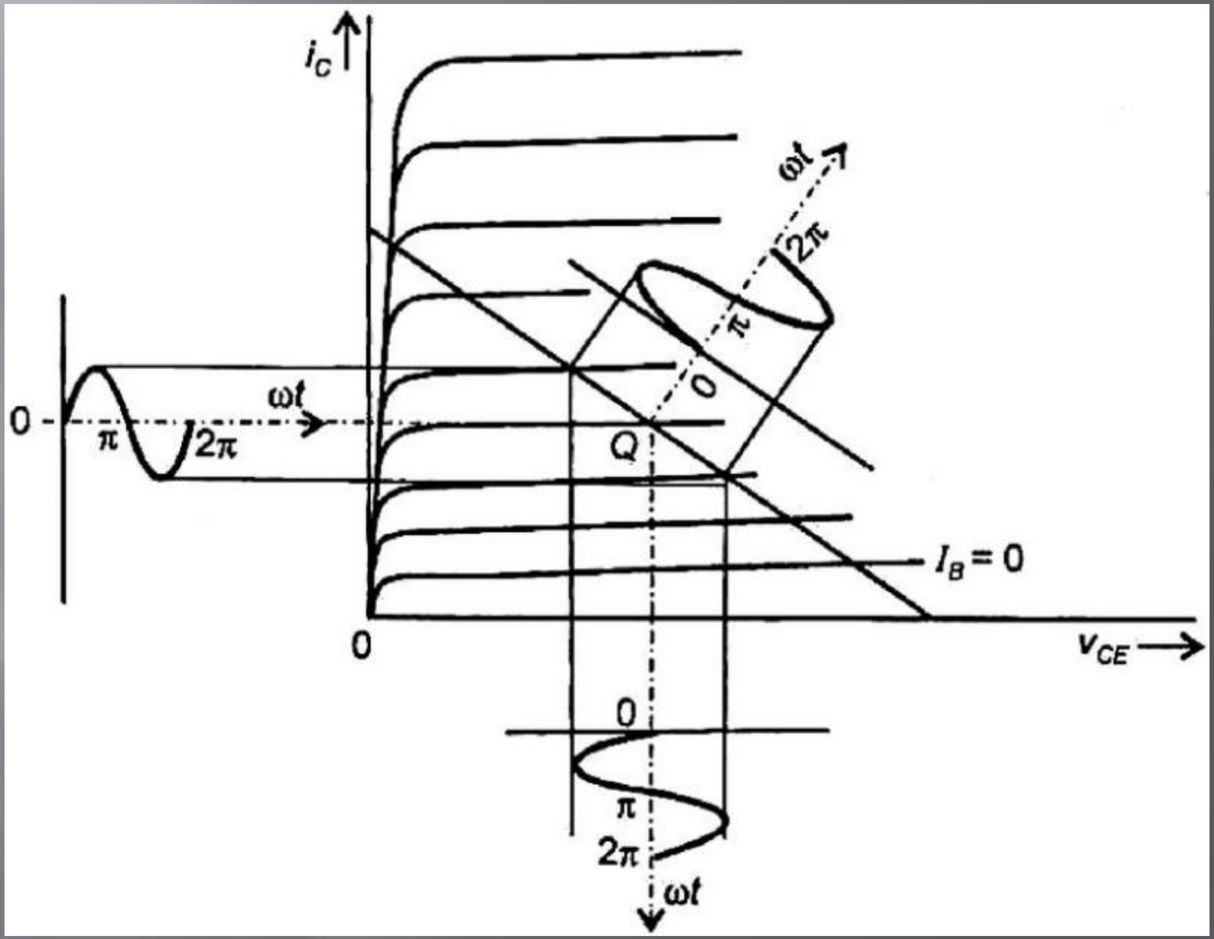
Selection of the Operating Point

Operating point (Q_2) near the cut-off region results in clipping of the positive peak of the output signal.



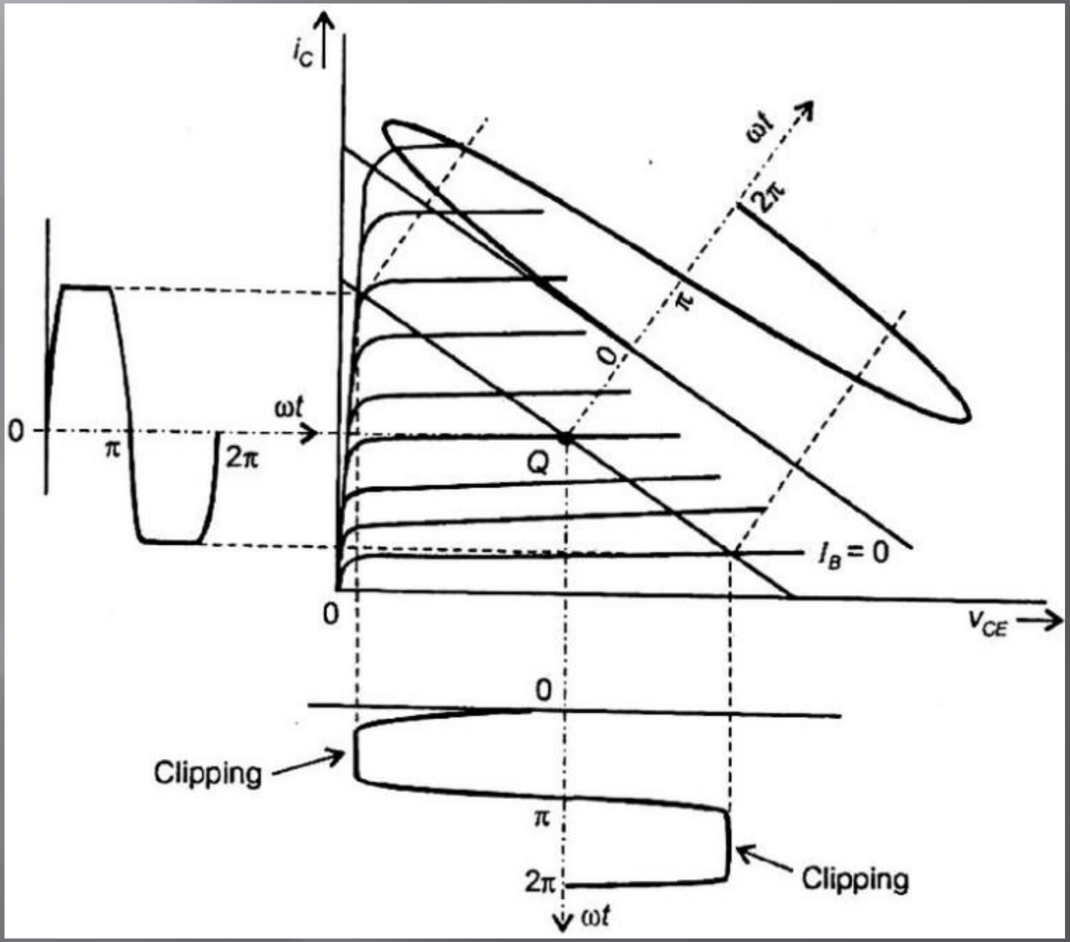
Selection of the Operating Point

Operating point (Q-point) selected in the middle active region gives the best results of the output signal.



Selection of the Operating Point

Even if the operating point (Q) is selected in the middle of the active region, distortion (clipping) occurs, if the input signal is too large.



BIAS STABILITY

- Through proper biasing, a desired quiescent operating point of the transistor amplifier in the active region (linear region) of the characteristics is obtained. It is desired that once selected the operating point should remain stable. The maintenance of operating point stable is called Stabilization.

❖ The selection of a proper quiescent point generally depends on the following factors:

(a) The amplitude of the signal to be handled by the amplifier and distortion level in signal

(b) The load to which the amplifier is to work for a corresponding supply voltage

❖ The operating point of a transistor amplifier shifts mainly with changes in temperature, since the transistor parameters — *β, I_{CO} and V_{BE} (where the symbols carry their usual meaning) – are functions of* temperature.

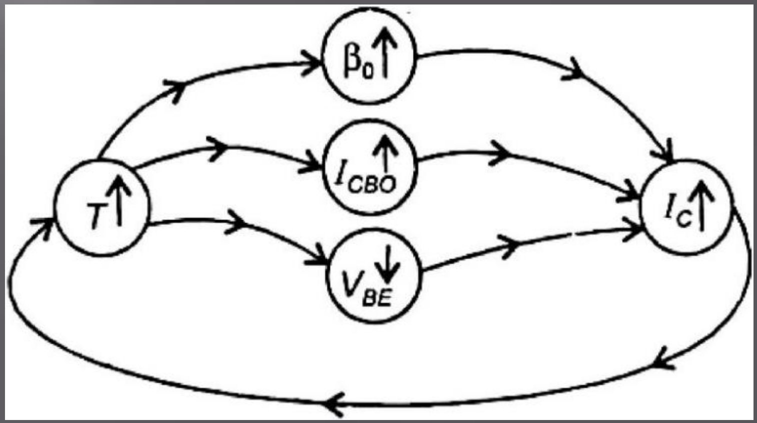
Factors Affecting Stability of *Q*-Point:

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

➢ Flow of collector current produces heat at the collector junction. This increases the temperature of the junction. As a result, following changes in parameters take place:

1. Reverse saturation current or leakage current I_{CBO} (and hence I_{CEO}) increases.
2. Threshold voltage at base-emitter junction V_{BE} decreases.
3. Current gain β increases.

➢ Overall effect – collector current increases which in turn produces more heat.



➢ Temperature further rises, and whole sequence of events repeats.

➢ If not checked, temperature may rise so high that transistor may be burnt or damaged permanently.

Such a situation is known as ***thermal runaway***.

1. Collector current is given by:
$I_C = \beta\, I_B + I_{CEO} = \beta I_B + (\beta+1)\, I_{CBO}$

2. Threshold voltage at base-emitter junction V_{BE} decreases at the rate 2.5 mV/°C; i.e. the device starts operating at lower voltages. Thus, I_B changes which in turn changes I_C (as $I_C=\beta I_B$).

3. Current gain β is temperature and device dependent. β increases with increase in temperature. If the transistor is replaced another transistor even of the same type, value of β is different. Hence, the collector current I_C changes.

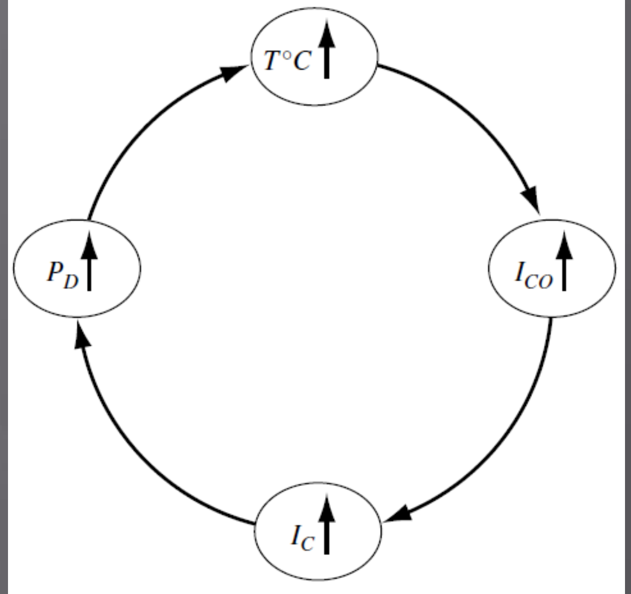


Fig. 1.22 *Thermal Runaway*

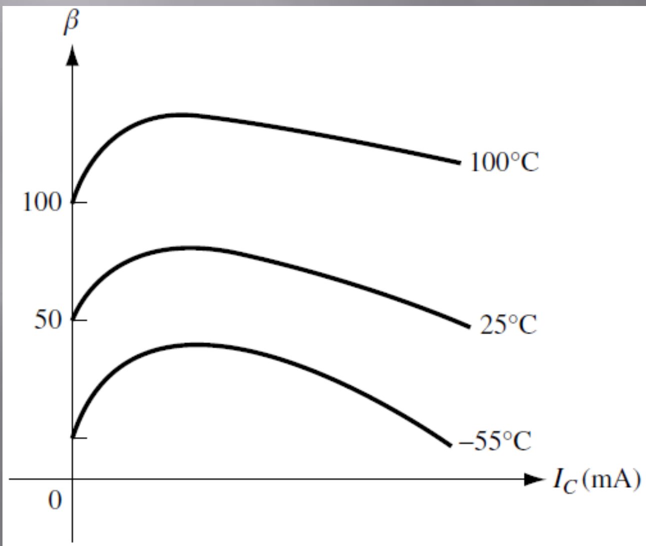


Fig. 1.24 *Variation in β with Temperature*

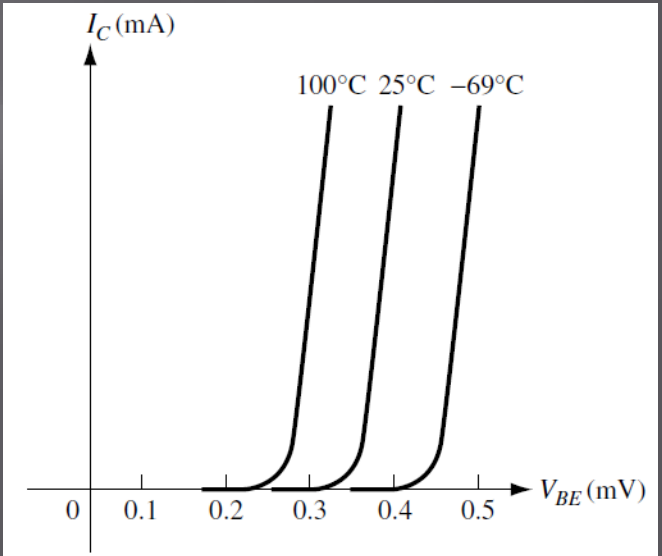


Fig. 1.23 *Variation of V_{BE} with Temperature*

1. Thermal Stability Factor (S_I):

$$S_I = \frac{\partial I_C}{\partial I_{CO}} \quad \dots \quad \dots (1)$$

This equation signifies that I_c changes S_I times as fast as I_{co}

Differentiating the equation of collector current, $I_C = \beta I_B + (1+\beta) I_{co}$, we get

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

Thus, rearranging the terms we can write

$$S_I = \frac{1}{\partial I_{CO} / \partial I_C} = \frac{1+\beta}{1-\beta\left(\partial I_B / \partial I_C\right)} \quad \dots \quad \dots (2)$$

2. The Bias Stability Factor (S_V):

$$S_V = \frac{\partial I_C}{\partial V_{BE}} \quad \dots \quad \dots (3)$$

3. The β Stability Factor (S_β):

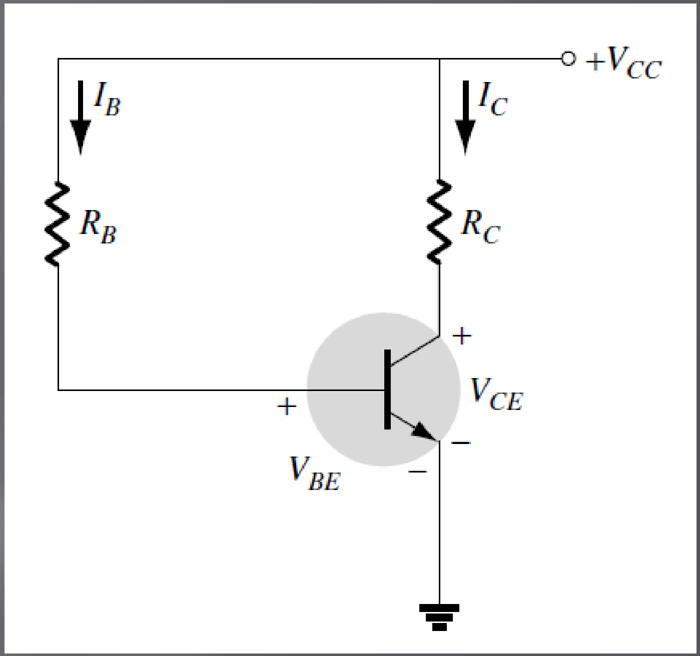
$$S_\beta = \frac{\partial I_C}{\partial \beta} \quad \dots \quad \dots (4)$$

Various Biasing Circuits

- **Fixed Bias Circuit**
- **Fixed Bias with Emitter Resistor**
- **Collector to Base Bias Circuit**
- **Potential Divider Bias Circuit**

Fixed (Base) Bias Circuit

Fig. shows the fixed-bias circuit. It is the simplest transistor dc bias circuit.



Base-Emitter Loop (Input Section):

Applying KVL to this loop one can write,

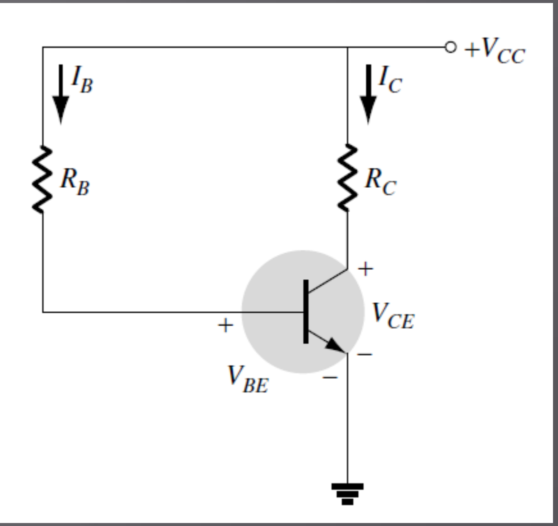
$$V_{CC} = I_B R_B + V_{BE} \quad \dots \quad \dots (1)$$

Solving for base current, one obtain

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad \dots \quad \dots (2)$$

Since, V_{CC} and V_{BE} are fixed values of voltages, selection of base resistor R_B fixes the base current I_B. Hence, the name ***fixed-bias circuit***.

Fixed (Base) Bias Circuit



Collector-Emitter Loop (Output Section):

Applying KVL to this loop one can write,

$$V_{CC} = I_C R_C + V_{CE} \quad \dots \quad \dots (3)$$

Solving for collector –emitter voltage V_{CE}, one obtain

$$V_{CE} = V_{CC} - I_C R_C \quad \dots \quad \dots (4)$$

Collector current I_C that flows through R_C is

$$I_C = \beta I_B + I_{CEO} = \beta I_B + (\beta + 1) I_{CBO} \quad \dots \quad \dots (5)$$

Note: It is clear from above equation that V_{CC} provides the voltages across resistor R_C and also across collector-emitter terminals. Obviously, voltage drop $I_C R_C$ can never be more than V_{CC}, or

$$I_C \leq \frac{V_{CC}}{R_C} \quad \dots \quad \dots (6) \qquad I_{C(sat)} = \frac{V_{CC}}{R_C} \quad \dots \quad \dots (7)$$

I_C is limited due to saturation, and its value remains at its maximum (given by (6)) whatever value of I_B.

When transistor in saturation, V_{CE} ,is almost zero (actually a few tenth of a volt), and then collector saturation current $I_{C(sat)}$ is given by (7).

The collector current I_C is given by

$$I_C = \beta I_B + (\beta + 1)I_{CBO} = \beta\frac{V_{CC} - V_{BE}}{R_B} + (\beta + 1)I_{CO}$$

Thus, the stability factors are obtained as:

Thermal stability factor S_I:

$$S_I = \frac{\partial I_C}{\partial I_{CO}} = \beta + 1$$

Bias stability factor S_V:

$$S_V = \frac{\partial I_C}{\partial V_{BE}} = -\frac{\beta}{R_B}$$

***β* stability factor S_β:**

$$S_\beta = \frac{\partial I_C}{\partial \beta} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO} = I_B + I_{CO} \approx \frac{I_C}{\beta}$$

Merits:

- It is very easy to fix the quiescent operating point anywhere in the active region of the output characteristics by simply changing the base resistor (R_B).
- It uses very few number of components (only two resistors and one batter supply).
- It provides maximum flexibility in the design.

Demerits:

- The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.
- When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.

Demerits:

When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.

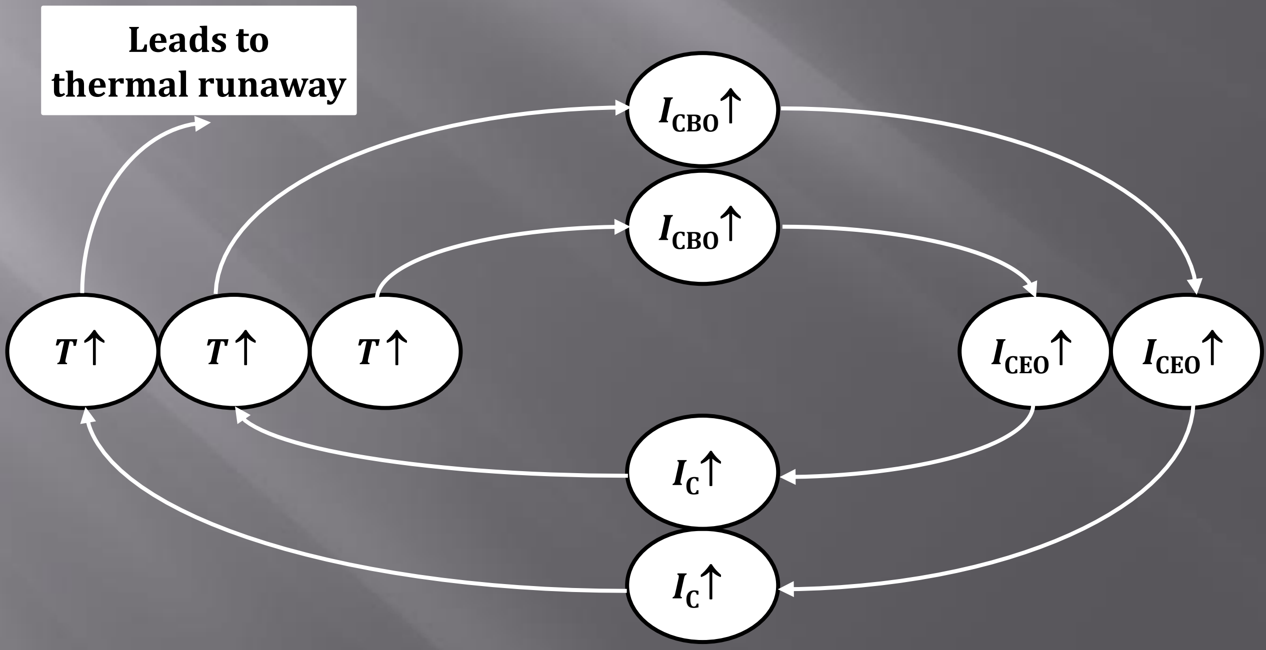
- For small-signal transistors (e.g., not power transistors) with relatively high values of β (i.e., between 100 and 200), this configuration will be prone to thermal runaway. In particular, the thermal stability factor, which is a measure of the change in collector current with changes in reverse saturation current, is approximately (β+1). To ensure absolute stability of the amplifier, a stability factor of less than 25 is preferred, and so small-signal transistors have large stability factors. Due to this large thermal stability factor in fixed bias circuit, it has poor thermal stability.

Usage: Due to the above inherent drawbacks, fixed bias is rarely used in linear circuits (i.e., those circuits which use the transistor as a current source). Instead, it is often used in circuits where transistor is used as a switch. However, one application of fixed bias is to achieve crude automatic gain control in the transistor by feeding the base resistor from a DC signal derived from the AC output of a later stage.

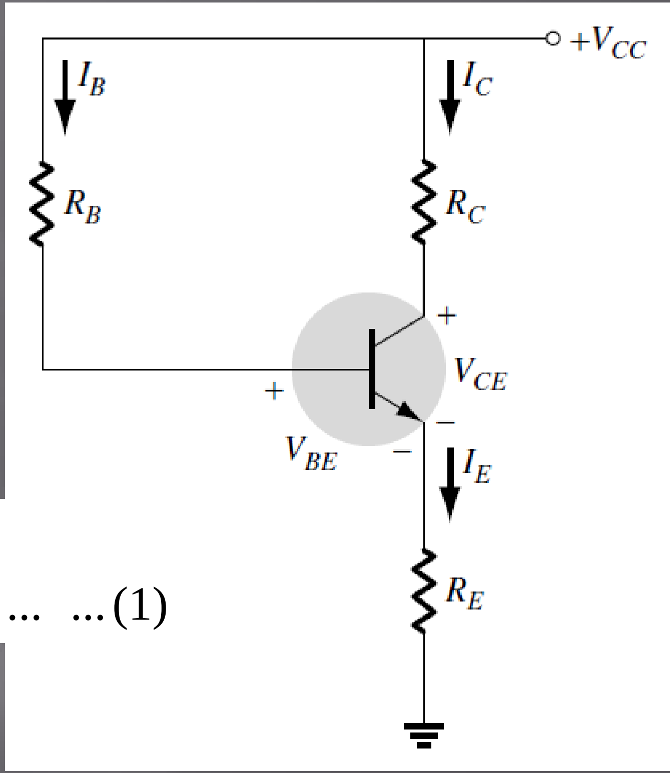
Fixed-Bias Circuit is seldom used:

In spite of its all the merits, fixed bias circuit is seldom used in practice for the following reason:

With rise in temperature, a cumulative action takes place, and the collector current goes on increasing. The circuit provides no check on the increase in collector current. The operating point is not stable. This situation can be shown as in Fig.



Fixed Bias with Emitter Resistor



The fixed bias circuit is modified by attaching an external resistor to the emitter. This resistor introduces negative feedback that stabilizes the *Q*-point.

Base-Emitter Loop (Input Section):

Applying KVL to this loop one can write,

$$V_{CC} = I_B R_B + V_{BE} + I_E R_E = I_B R_B + V_{BE} + (I_B + I_C) R_E$$
$$= I_B (R_B + R_E) + V_{BE} + I_C R_E = I_B R_B + V_{BE} + (\beta + 1) I_B R_E \quad \dots \quad \dots (1)$$

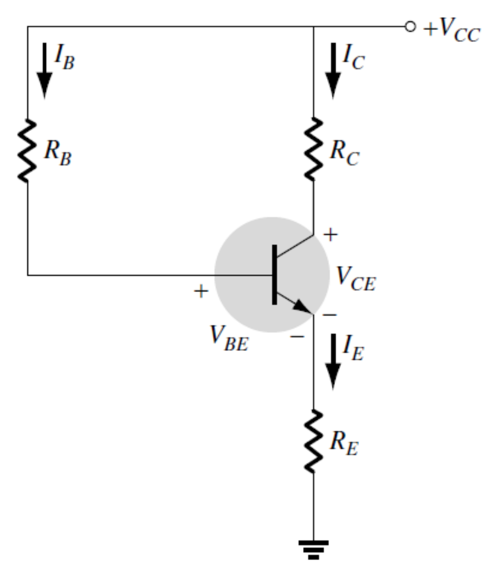
Solving for base current, one obtain

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_E}{R_B + R_E} = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} \quad \dots \quad \dots (2)$$

Fixed Bias with Emitter Resistor

Collector-Emitter Loop (Output Section): Applying KVL to this loop one can write,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E = I_C R_C + V_{CE} + (I_B + I_C) R_E \quad \ldots \quad \ldots (3)$$



Solving for collector–emitter voltage V_{CE} , one obtain

$$V_{CE} = V_{CC} - I_C R_C - (I_B + I_C) R_E \quad \ldots \quad \ldots (4)$$

Collector current I_C is

$$I_C = \beta I_B + I_{CEO} = \beta \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E} + (\beta + 1) I_{CBO} \quad \ldots \quad \ldots (5)$$

Assuming, $I_E \approx I_C$, from (3)

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \quad \ldots \quad \ldots (6)$$

The collector saturation current is given by

$$I_{C(sat)} = \frac{V_{CC}}{R_C + R_E} \quad \ldots \quad \ldots (7)$$

Note: The addition emitter resistor reduces collector saturation below that obtained with the fixed-bias circuit using the same collector resistor.

The collector current I_C is given by

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

$$\text{or,} \quad I_C \left(1 + \frac{\beta R_E}{R_B + R_E}\right) = \frac{\beta V_{CC} - V_{BE}}{R_B + R_E} + (\beta+1) I_{CO}$$

Thus, the stability factors are obtained as:

Thermal stability factor S_I:

$$S_I = \frac{\partial I_C}{\partial I_{CO}} = \frac{\beta+1}{1+\beta R_E/(R_B+R_E)}$$

Bias stability factor S_V:

$$S_V = \frac{\partial I_C}{\partial V_{BE}} = -\frac{\beta}{R_B + (\beta+1) R_E}$$

β stability factor S_β:

$$I_C\left(1+\frac{\beta R_E}{R_B+R_E}\right)=\beta\frac{V_{CC}-V_{BE}}{R_B+R_E}+(\beta+1)I_{CO}$$

$$\frac{\partial I_C}{\partial\beta}+\frac{\beta R_E}{R_B+R_E}\frac{\partial I_C}{\partial\beta}+\frac{I_C R_E}{R_B+R_E}=\frac{V_{CC}-V_{BE}}{R_B+R_E}+I_{CO}$$

$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}\left(1+\frac{\beta R_E}{R_B+R_E}\right)=\frac{V_{CC}-V_{BE}-I_C R_E}{R_B+R_E}+I_{CO}$$

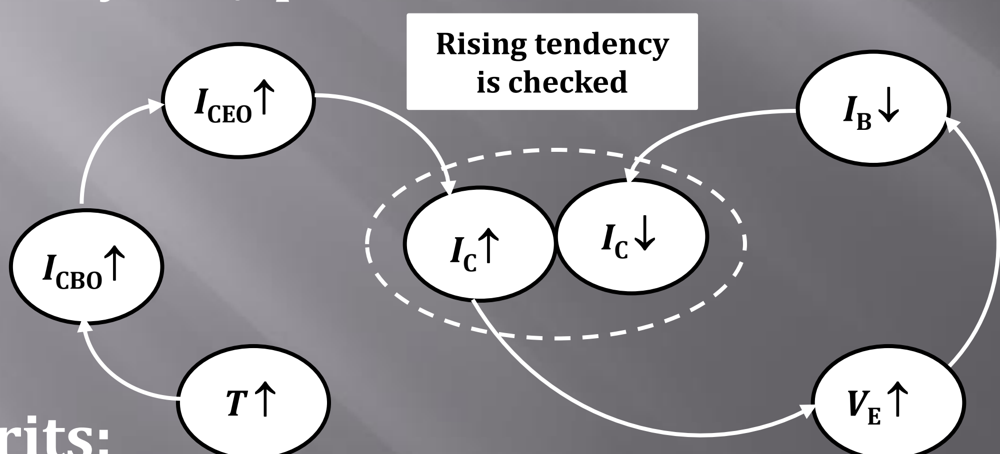
$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}=\frac{V_{CC}-V_{BE}-I_C R_E}{R_B+(\beta+1)R_E}+\frac{I_{CO}(R_B+R_E)}{R_B+(\beta+1)R_E}$$

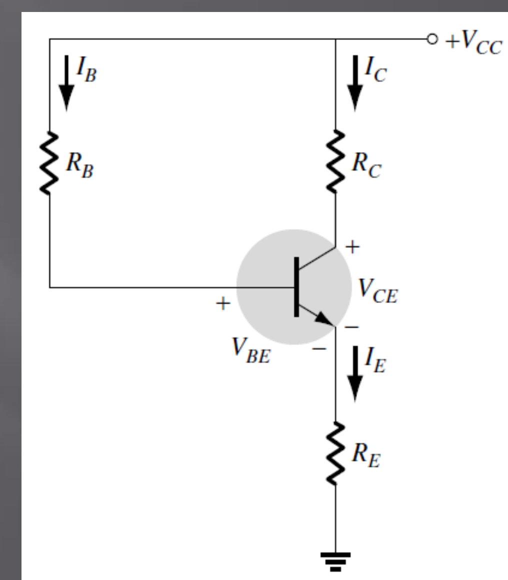
$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}=\left[\frac{V_{CC}-V_{BE}-I_C R_E}{R_B+R_E}+I_{CO}\right]\frac{R_B+R_E}{R_B+(\beta+1)R_E}$$

$$\therefore\quad S_\beta=\frac{\partial I_C}{\partial\beta}\approx\frac{I_C}{\beta}\frac{R_B+R_E}{R_B+(\beta+1)R_E}$$

Fixed-Bias with Emitter Resistor Improves *Q*-point Stability:

With rise in temperature, reverse saturation current I_{CO} increases, thus collector current I_C increases. Hence, voltage drop across R_E , i.e. voltage at the emitter terminal V_E increases which decreases base current I_B as voltage at the base terminal V_B increases. This 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.





Merits:

The circuit has the tendency to stabilize operating point against changes in temperature and β-value.

Demerits: In this configuration, to keep I_C independent of β, the required condition is,

$I_C = \beta I_B = \beta(V_{CC} - V_{RB})/(R_B + (\beta+1)R_E = (V_{CC} - V_{BE})/R_E$, which is approximately the case if $(\beta + 1)R_E >> R_B$.

As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E very large, or making R_B very low.

If R_E is of large value, high V_{cc} is necessary. This increases cost as well as precautions necessary while handling.

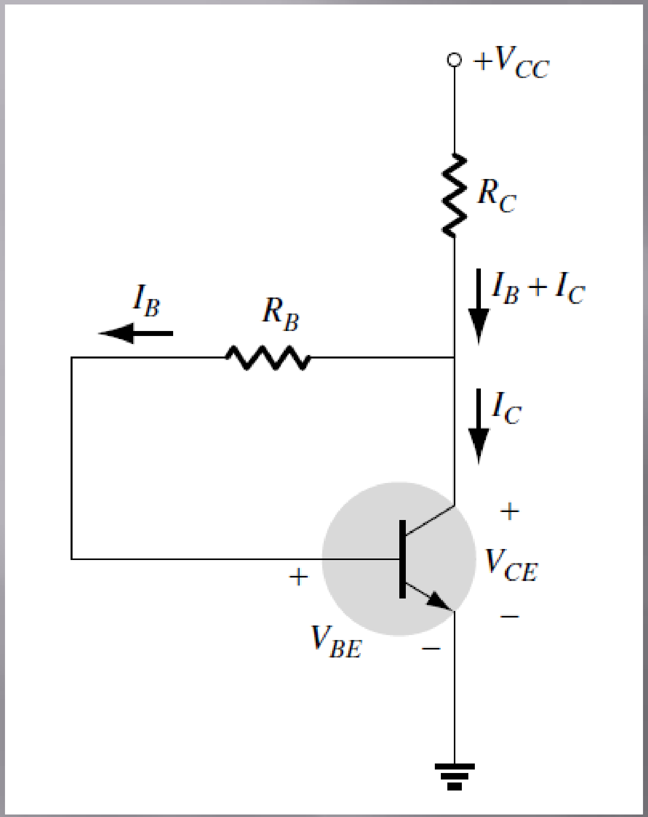
If R_B is low, a separate low voltage supply should be used in the base circuit. Using two supplies of different voltages is impractical.

In addition to the above, R_E causes ac feedback which reduces the voltage gain of the amplifier.

Usage:

The feedback also increases the input impedance of the amplifier when seen from the base, which can be advantageous. Due to the above disadvantages, this type of biasing circuit is used only with careful consideration of the trade-offs involved.

Collector to Base Bias Circuit



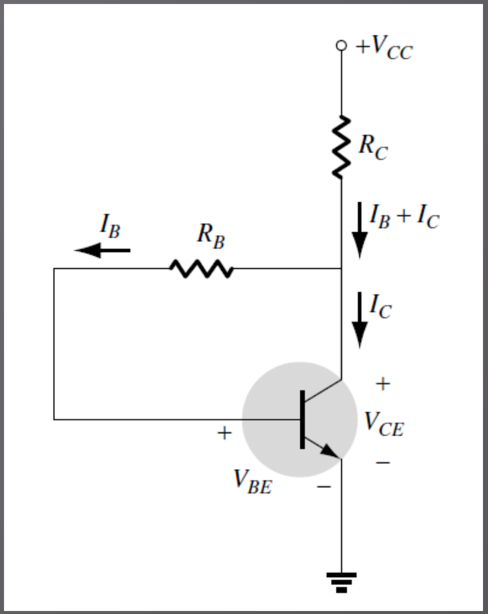
This configuration employs negative feedback to prevent thermal runaway and stabilize the operating point. In this form of biasing, the base resistor R_F is connected to the collector instead of connecting it to the DC source V_{CC}. So any thermal runaway will induce a voltage drop across the R_C resistor that will throttle the transistor's base current.

Usage: The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability is warranted.

Base-Emitter Loop (Input Section):

Applying KVL to this loop, it is obtained that

$$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE}$$
$$= (\beta+1)I_B R_C + I_B R_B + V_{BE} \quad \ldots \quad \ldots(1)$$



Solving for base current, it is found that

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_C}{R_B + R_C} = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_C} \quad \ldots \quad \ldots(2)$$

Thus, the collector current is given by

$$I_C = \beta \frac{V_{CC} - V_{BE} - I_C R_E}{R_B + R_C} + (\beta+1)I_{CBO} = \beta \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_C} + (\beta+1)I_{CBO} \quad \ldots \quad \ldots(3)$$

Collector-Emitter Loop (Output Section):

Applying KVL to this loop, it can be written that

$$V_{CC} = (I_B + I_C)R_C + V_{CE} \quad \ldots \quad \ldots(4)$$

Thus, the collector-emitter voltage is given by

$$V_{CE} = V_{CC} - (I_B + I_C)R_C \quad \ldots \quad \ldots(5)$$

The collector current I_C is given by

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

$$\therefore \quad I_C \left(1 + \frac{\beta R_C}{R_B + R_C} \right) = \beta \frac{V_{CC} - V_{BE}}{R_B + R_C} + (\beta+1) I_{CO}$$

Thus, the stability factors are obtained as:

Thermal stability factor S_I:

$$S_I = \frac{\partial I_C}{\partial I_{CO}} = \frac{\beta + 1}{1 + \beta R_C / (R_B + R_C)}$$

Bias stability factor S_V:

$$S_V = \frac{\partial I_C}{\partial V_{BE}} = -\frac{\beta}{R_B + (\beta+1) R_C}$$

β stability factor S_β:

$$I_C\left(1+\frac{\beta R_C}{R_B+R_C}\right)=\beta\frac{V_{CC}-V_{BE}}{R_B+R_C}+(\beta+1)I_{CO}$$

$$\frac{\partial I_C}{\partial\beta}+\frac{\beta R_C}{R_B+R_C}\frac{\partial I_C}{\partial\beta}+\frac{I_C R_C}{R_B+R_C}=\frac{V_{CC}-V_{BE}}{R_B+R_C}+I_{CO}$$

$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}\left(1+\frac{\beta R_C}{R_B+R_C}\right)=\frac{V_{CC}-V_{BE}-I_C R_C}{R_B+R_C}+I_{CO}$$

$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}=\frac{V_{CC}-V_{BE}-I_C R_C}{R_B+(\beta+1)R_C}+\frac{I_{CO}(R_B+R_C)}{R_B+(\beta+1)R_C}$$

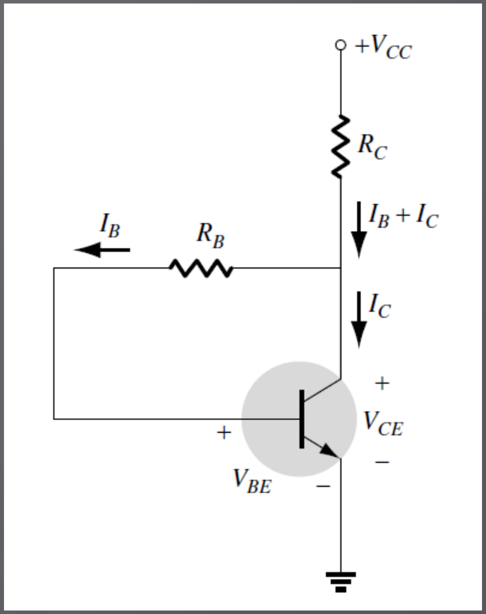
$$\text{or,}\quad \frac{\partial I_C}{\partial\beta}=\left[\frac{V_{CC}-V_{BE}-I_C R_C}{R_B+R_C}+I_{CO}\right]\frac{R_B+R_C}{R_B+(\beta+1)R_C}$$

$$\therefore\quad S_\beta=\frac{\partial I_C}{\partial\beta}\approx\frac{I_C}{\beta}\frac{R_B+R_C}{R_B+(\beta+1)R_C}$$

Better Q-point Stability of Collector to Base Bias Circuit:

Applying KVL to the base-emitter loop, the base current I_B is obtained as

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



With rise in temperature, reverse saturation current I_{CO} increases, thus collector current I_C increases. That causes voltage drop across R_C to increase which decreases base current I_B. This 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.

Collector current can be expressed as $$I_C \approx \beta I_B = \beta \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_C}$$

Generally, $(\beta+1)R_C >> R_B$ and $(\beta+1)R_C \approx \beta R_C$, then

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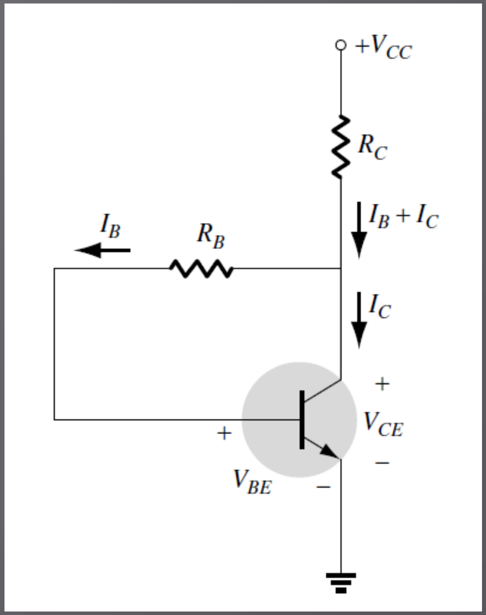


Generally, $(\beta+1)R_C >> R_B$ and $(\beta+1)R_C \approx \beta R_C$, then

$$I_C \approx \beta I_B = \beta \frac{V_{CC} - V_{BE}}{\beta R_C} = \frac{V_{CC} - V_{BE}}{R_C}$$

Therefore, I_C is independent of β. Hence, the variation I_C with β is minimized and stability of Q-point is achieved.

Merits:

This circuit stabilizes the operating point against variations in temperature and β (i.e. replacement of transistor).

Demerits:

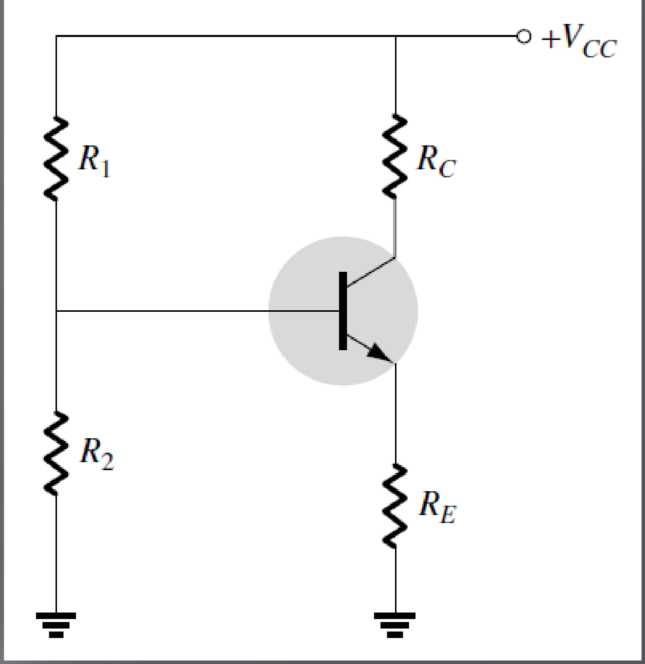
In this circuit, to keep I_C independent of β

$I_C = \beta I_B = \beta(V_{CC} - V_{BE})/(R_B + R_C + \beta R_C = (V_{CC} - V_{BE})/R_C$, which is approximately the case if $(\beta+1)R_C >> R_B$.

- As β-value is fixed (and generally unknown) for a given transistor, this relation can be satisfied either by keeping R_C fairly large or making R_B very low.
- If R_c is large, a high V_{CC} is necessary, which increases cost as well as precautions necessary while handling.
- If R_B is low, the reverse bias of the collector–base region is small, which limits the range of collector voltage swing that leaves the transistor in active mode.
- The resistor $\boldsymbol{R_B}$ causes an AC feedback, reducing the voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

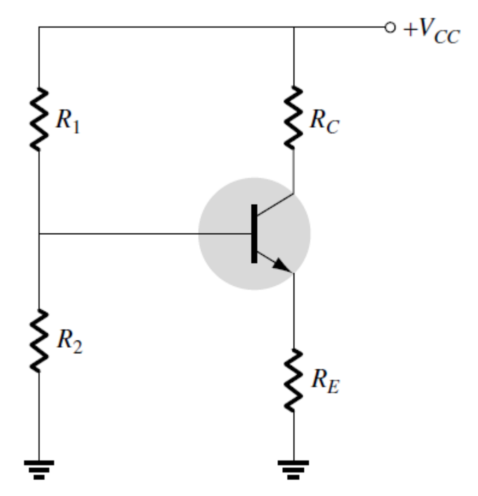
Potential Divider Bias Circuit

This is the most commonly used arrangement for biasing as it provide good bias stability. In this arrangement the emitter resistance R_E provides stabilization. The resistance R_E cause a voltage drop in a direction so as to reverse bias the emitter junction. Since the emitter-base junction is to be forward biased, the base voltage is obtained from R_1-R_2 network. The net forward bias across the emitter base junction is equal to V_E - dc voltage drop across R_E. The base voltage is set by V_{cc} and R_1 and R_2. The dc bias circuit is independent of transistor current gain. In case of amplifier, to avoid the loss of ac signal, a capacitor of large capacitance is connected across R_E. The capacitor offers a very small reactance to ac signal and so it passes through the condenser.



Potential Divider (Self) Bias Circuit

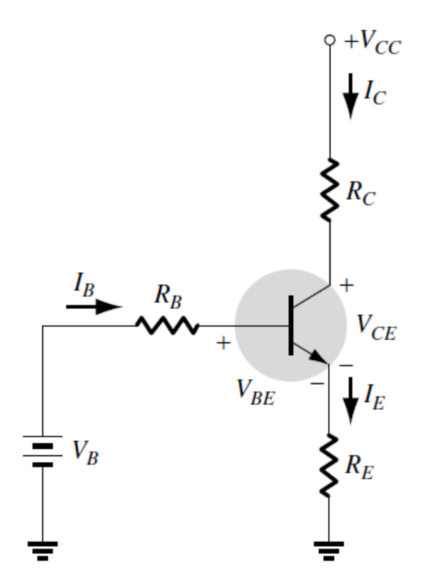
Fig. shows a voltage-divider bias circuit. Resistors R_1 and R_2 form a voltage-divider circuit. In this configuration, the sensitivity to changes in β is quite small. If the circuit parameters are properly chosen, the bias collector current I_C and collector-emitter voltage V_{CE} are almost independent β.



The base circuit can be converted into Thevenin's equivalent circuit as shown in Fig.

$$V_{TH} = V_B = \frac{R_2}{R_1 + R_2} V_{CC} \quad \dots \quad \dots (1)$$

$$R_{TH} = R_B = R_1 \,//\, R_2 = \frac{R_1 R_2}{R_1 + R_2} \quad \dots \quad \dots (2)$$



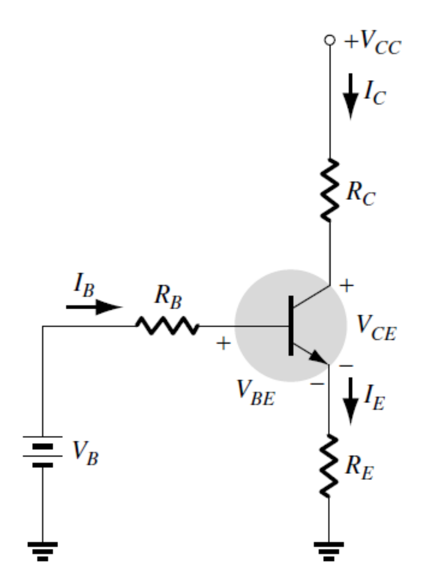
Since R_1 and R_2 divide the voltage V_{CC} at the base, the circuit is called voltage divider bias.

Potential Divider (Self) Bias Circuit

Base-Emitter Loop (Input Section):

Applying KVL to this loop, it is obtained that

$$V_B = I_B R_B + V_{BE} + I_E R_E = I_B R_B + V_{BE} + (I_B + I_C) R_E$$
$$= I_B R_B + V_{BE} + (\beta + 1) I_B R_E \quad \dots \quad \dots (3)$$



Solving for base current, it is found that

$$I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1) R_E} \quad \dots \quad \dots (4)$$

Thus, the emitter resistor, which is part of the collector–emitter circuit, appears as $(\beta+1)R_E$ in the base-emitter circuit.

For the base-emitter circuit, the net voltage is $(V_B - V_{BE})$ and the total resist$[R_B + (\beta+1)R_E]$.

The collector current is given by

$$I_C \approx \beta I_B = \beta \frac{V_B - V_{BE}}{R_B + (\beta + 1) R_E} \quad \dots \quad \dots (5)$$

Potential Divider (Self) Bias Circuit

Collector-Emitter Loop (Output Section):

Applying KVL to this loop, it can be written that

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E = I_C R_C + V_{CE} + (I_B + I_C) R_E$$
$$= I_C R_C + V_{CE} + (\beta + 1) I_B R_E \quad \dots \quad \dots (6)$$

Thus, the collector-emitter voltage is given by

$$V_{CE} = V_{CC} - I_C R_C - (I_B + I_C) R_E$$
$$= V_{CC} - I_C R_C (\beta + 1) I_B R_E \quad \dots \quad \dots (7)$$

Stability of Q-Point:

From (3), base current can be expressed as

$$I_B = \frac{V_B - V_{BE} - I_C R_E}{R_B + R_E} \quad \dots \quad \dots (8)$$

With rise in temperature as the reverse saturation current I_{CO} increases, collector current I_C increases That causes voltage drop across R_E to increase, which decreases base current I_B. This 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.

Potential Divider (Self) Bias Circuit

Stability Factor :

Base current I_B is given by $I_B = \dfrac{V_{CC} - V_{BE} - I_C R_E}{R_B + R_E}$

As collector current I_C is

$$I_C = \beta I_B + (\beta + 1) I_{CO} = \beta \left(\frac{V_{CC} - V_{BE} - I_C R_E}{R_B + R_E} \right) (\beta + 1) I_{CO}$$

$$\therefore \quad I_C \left(1 + \frac{\beta R_E}{R_B + R_E} \right) = \frac{\beta V_B}{R_B + R_E} - \frac{\beta V_{BE}}{R_B + R_E} + (\beta + 1) I_{CO}$$

From the above equation, it is clear that collector current I_C is function of I_{CO}, V_{BE}, and β.

Thermal stability factor S_I:

Collector current I_C can be expressed as

$$I_C\left(1+\frac{\beta R_E}{R_B+R_E}\right)=\frac{\beta V_B}{R_B+R_E}-\frac{\beta V_{BE}}{R_B+R_E}+(\beta+1)I_{CO}$$

Differentiating, the thermal stability factor is obtained as

$$\frac{dI_C}{dI_{CO}}\left[1+\frac{\beta R_E}{R_B+R_E}\right]=\beta+1$$

$$\therefore \quad S_I=\frac{dI_C}{dI_{CO}}=\frac{\beta+1}{1+\dfrac{\beta R_E}{R_B+R_E}}$$

This shows that *SI* is inversely proportional to *RE* and is less than (β+1), signifying better thermal stability.

Bias stability factor S_V:

Differentiating, the bias stability factor is given by

$$\frac{dI_C}{dV_{BE}}\left(1+\frac{\beta R_E}{R_B+R_E}\right)=-\frac{\beta}{R_B+R_E}$$

$$\therefore \quad S_V=\frac{\partial I_C}{\partial V_{BE}}=-\frac{\beta}{R_B+(\beta+1)R_E}$$

β stability factor S_β:

$$I_C\left(1+\frac{\beta R_E}{R_B+R_E}\right)=\beta\frac{V_B-V_{BE}}{R_B+R_E}+(\beta+1)I_{CO}$$

Differentiating, the β stability factor is obtained as

$$\frac{dI_C}{d\beta}\left(1+\frac{\beta R_E}{R_B+R_E}\right)+\frac{I_C R_E}{R_B+R_E}=\frac{V_B}{R_B+R_E}-\frac{V_{BE}}{R_B+R_E}+I_{CO}$$

$$\text{or,}\quad \frac{dI_C}{d\beta}\left(1+\frac{\beta R_E}{R_B+R_E}\right)=\frac{V_B-V_{BE}-I_C R_E}{R_B+R_E}+I_{CO}$$

$$=\left(\frac{V_B-V_{BE}-I_C R_E}{R_B+R_E}+I_{CO}\right)\frac{R_B+R_E}{R_B+(\beta+1)R_E}$$

$$\therefore\quad S_\beta=\frac{dI_C}{dI\beta}\approx\frac{I_C}{\beta}\frac{R_B+R_E}{R_B+(\beta+1)R_E}$$

Merits:

- Operating point is almost independent of β variation.
- Operating point stabilized against shift in temperature.

Demerits:

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E fairly large, or making $R_1||R_2$ very low.
- If R_E is of large value, high VCC is necessary. This increases cost as well as precautions necessary while handling.
- If $R_1||R_2$ is low, either R_1 is low, or R_2 is low, or both are low. A low R_1 raises V_B closer to V_C, reducing the available swing in collector voltage, and limiting how large R_C can be made without driving the transistor out of active mode. A low R_2 lowers V_B, reducing the allowed collector current. Lowering both resistor values draws more current from the power supply and lowers the input resistance of the amplifier as seen from the base.
- AC as well as DC feedback is caused by R_E, which reduces the AC voltage gain of the amplifier.

Usage:

The circuit's stability and merits as above make it widely used for linear circuits.

Summary

- The Q-point is the best point for operation of a transistor for a given collector current.
- The purpose of biasing is to establish a stable operating point (Q-point).
- The linear region of a transistor is the region of operation within saturation and cutoff.
- Out of all the biasing circuits, potential divider bias circuit provides highest stability to operating point.

Example-1 : *For the fixed-bias circuit shown in Fig. 1, find* I_C, V_{CE} *and* S_I.

Solution:

(i) Applying *KVL* to the base-emitter circuit,

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{500 \times 10^3} = 18.6\ \mu\text{A}$$

$$I_C = \beta I_B = \ = 100 \times 18.6 \times 10^{-6} = 1.86\ \text{mA}$$

(ii) Applying *KVL* to the collector-emitter circuit,

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

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

$$= 10 - 1.86 \times 10^{-3} \times 3 \times 10^3 = 4.42\ \text{V}$$

(iii) $S_I = \beta + 1 = 101$

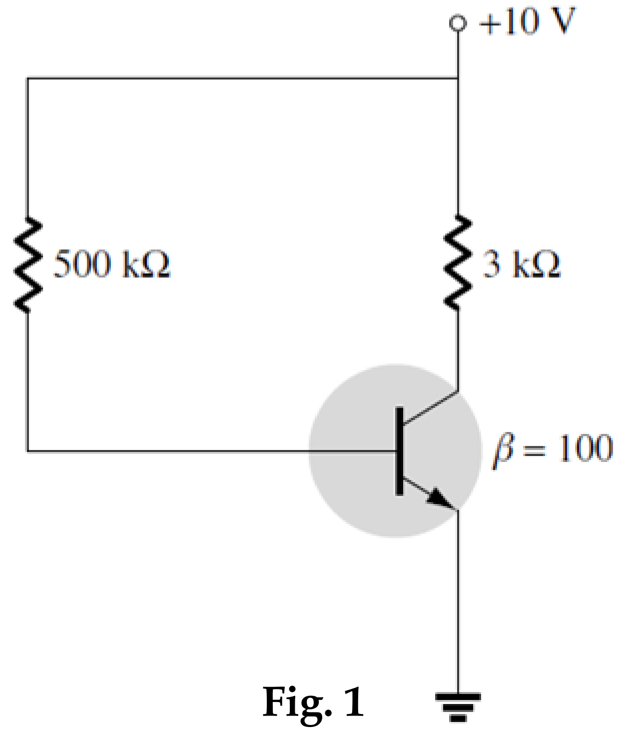


Fig. 1

Example-2 : *For the fixed-bias circuit shown in Fig. 2, determine* R_B, I_C, R_C, *and* V_{CE} *where* V_{CC} *= 12 V,* V_C *= 6 V,* β *= 80 and IB = 40* μA.

Solution:

(i) Applying *KVL* to the base-emitter circuit,

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

$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{12 - 0.7}{40 \times 10^{-6}} = 282.5\ k\Omega$$

(ii) $I_C = \beta I_B = 80 \times 40 \times 10^{-6} = 3.2$ mA

(iii) Applying *KVL* to the collector-emitter circuit,

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

$$R_C = \frac{V_{CC} - V_C}{I_C} = \frac{12 - 0.7}{3.2 \times 10^{-3}} = 1.875\ k\Omega$$

(iv) $V_{CE} = V_C = 6$ V

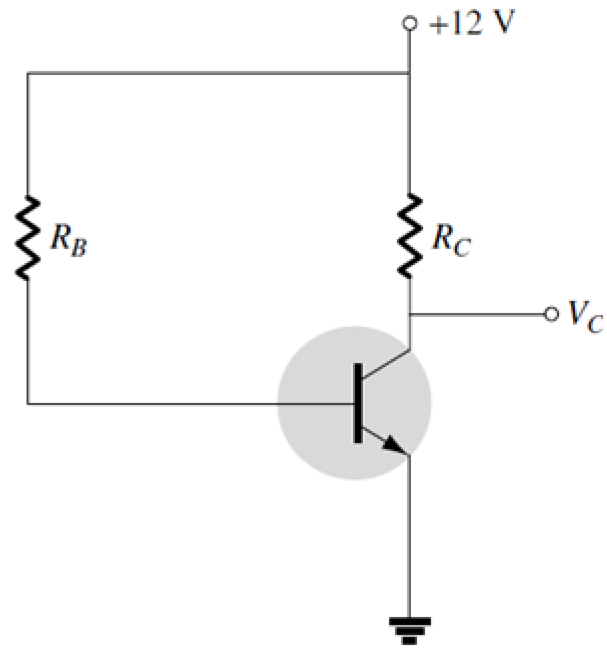


Fig. 2

Example-3 : *For the fixed-bias circuit shown in Fig. 3, where* $\alpha = 0.98$, $I_{CBO} = 10\ \mu A$, $R_C = 4\ k\Omega$, $R_B = 820\ k\Omega$, $V_{CC} = 12\ V$, *find* I_C *and* V_{CE} .

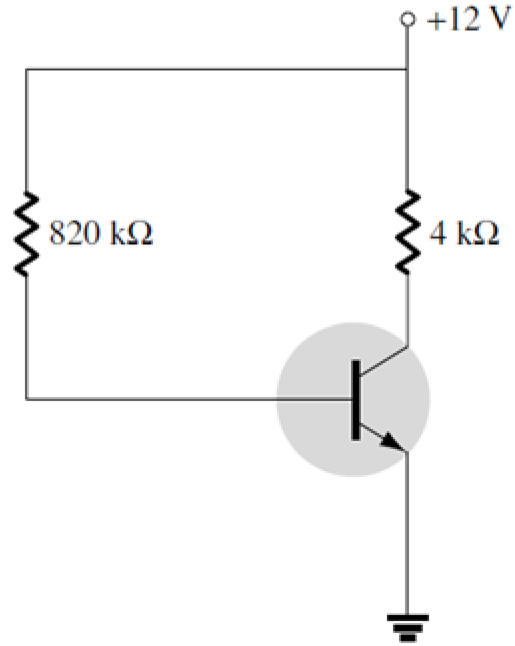


Fig. 3

Solution:

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

Applying *KVL* to the base-emitter circuit,

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.7}{820 \times 10^3} = 13.78\ \mu A$$

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

$$= 49 \times 13.78 \times 10^{-6} + (49 + 1) \times 10 \times 10^{-6} = 1.17\ mA$$

(ii) Applying *KVL* to the collector-emitter circuit,

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

$$V_{CE} = V_{CC} - I_C R_C = 12 - 1.17 \times 10^{-3} \times 4 \times 10^3 = 7.3\ V$$

Example-4 : *In the circuit shown in Fig. 4, find R_C , V_{CE} , R_B , V_B and R_E .*

Solution:

(i) Applying Kirchhoff's voltage law (*KVL*) to the collector circuit,

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

$$R_C = \frac{V_{CC} - V_C}{I_C} = \frac{12 - 7.6}{2 \times 10^{-3}} = 2.2\ \text{k}\Omega$$

(ii) Applying *KVL* to the collector-emitter circuit,

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

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

$$= 12 - 2 \times 10^{-3} \times 2 \times 10^{3} - 2.4 = 5.2\ \text{V}$$

(iii)

$$I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{80} = 25\ \mu\text{A}$$

Applying *KVL* to the base-emitter circuit,

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

$$R_B = \frac{V_{CC} - V_{BE} - V_E}{I_B} = \frac{12 - 0.7 - 2.4}{25 \times 10^{-6}} = 356\ \text{k}\Omega$$

(iv) $V_B = V_{BE} + V_E = 0.7 + 2.4 = 3.1$ V

(v) $I_E = I_B + I_C = 25 \times 10^{-6} + 2 \times 10^{-3} = 2.025$ mA

$$R_E = \frac{V_E}{I_E} = \frac{2.4}{2.025 \times 10^{-3}} = 1.185\ \text{k}\Omega$$

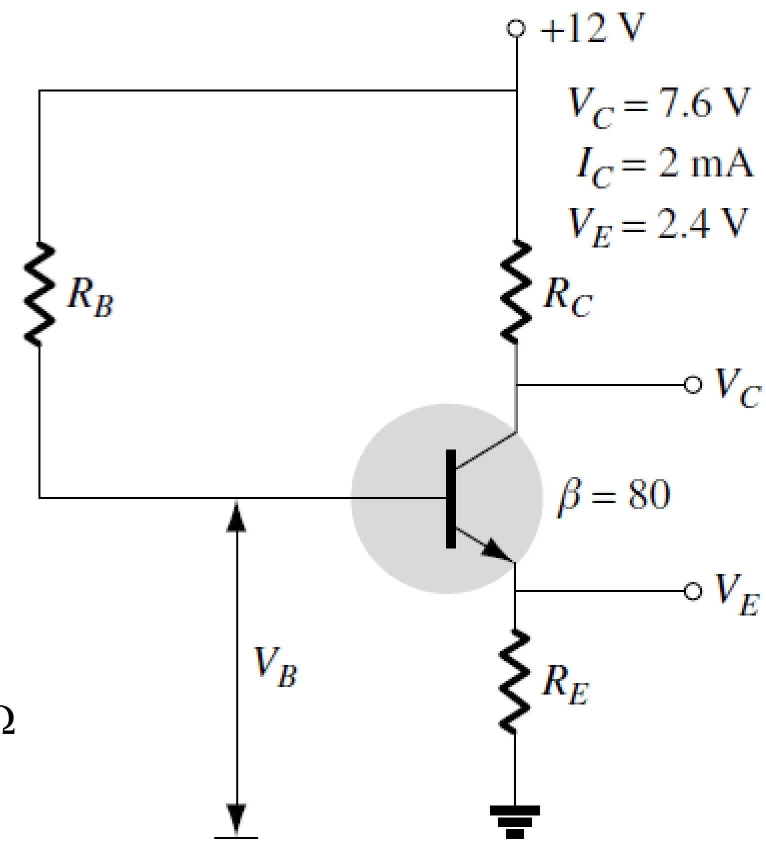


Fig. 4

Example-5: *For the collector-to-base bias circuit shown in Fig. 5, find R_C and R_B .*

Solution:

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

Applying Kirchhoff's voltage law (*KVL*) to the collector-emitter circuit,

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

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

$$R_C = \frac{V_{CC} - V_{CE}}{(\beta + 1)I_B} = \frac{12 - 6}{(100 + 1) \times 20 \times 10^{-6}} = 2.97\ \text{k}\Omega$$

(ii) Applying *KVL* to the base-emitter circuit,

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

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

$$= \frac{12 - 0.7 - (20 \times 10^{-6} + 2 \times 10^{3}) \times (2.97 \times 10^{3})}{20 \times 10^{-6}}$$

$$= 265.4\ \text{k}\Omega$$

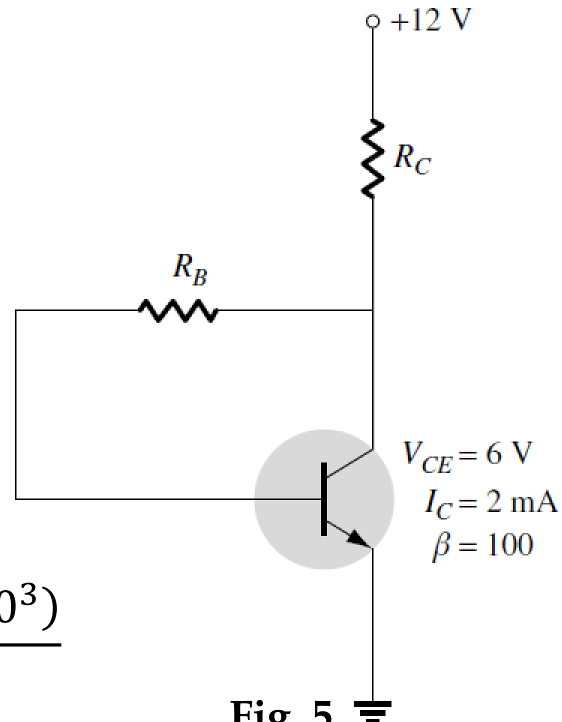


Fig. 5

Example-6: *For the circuit shown in Fig. 6, find R_C and R_B .*

Solution:

(i) Applying Kirchhoff's voltage law (*KVL*) to the base-emitter circuit,

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

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

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

$$= \frac{10 - 0.7}{220 \times 10^3 + (100 + 1)(2.5 \times 10^3 + 1 \times 10^3)}$$

$$= 16.21\ \mu A$$

$I_C = \beta\, I_B = 100 \times 16.21 \times 10^{-6} = 1.621$ mA

(ii) Applying *KVL* to the collector-emitter circuit,

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

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

$= 10 - (16.21 \times 10^{-6} + 1.621 \times 10^{-3}) \times (2.5 \times 10^3 + 1 \times 10^3)$

$= 4.27$ V

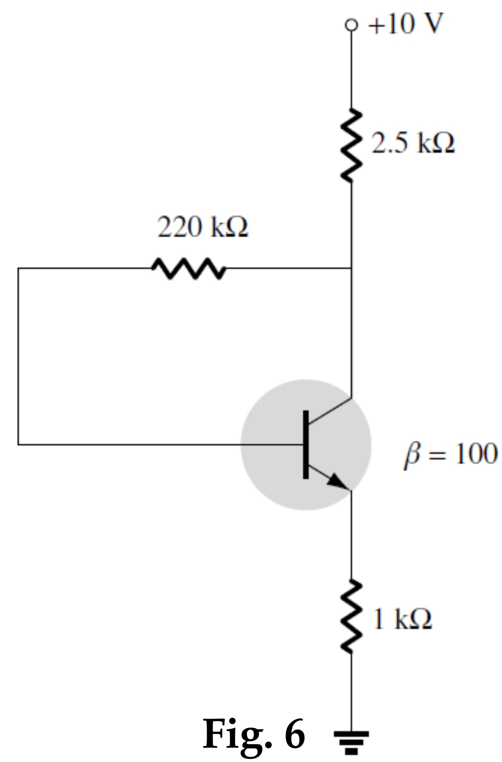


Fig. 6

Example-7: *For the circuit shown in Fig. 6, find I_C and V_{CE}.*

Solution:

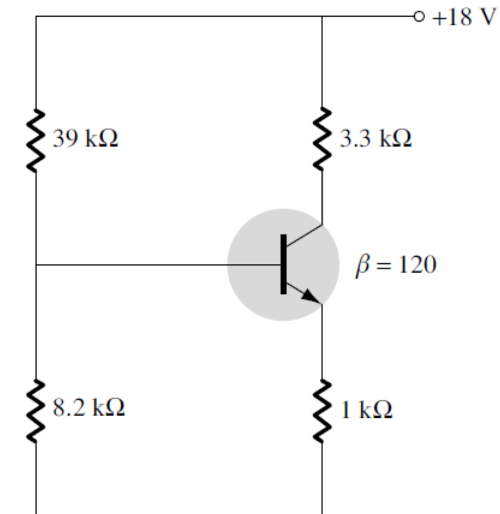


Fig. 7(a)

(i) Replacing the base circuit by its Thevenin's equivalent circuit (Fig. 6(b)),

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{8.2 \times 10^3}{39 \times 10^3 \times 8.2 \times 10^3} \times 18 = 3.13 \text{ V}$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = \frac{39 \times 10^3 \times 8.2 \times 10^3}{39 \times 10^3 \times 8.2 \times 10^3} = 6.78 \text{ k}\Omega$$

Applying *KVL* to the base-emitter circuit,

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

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

$$I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1) R_E} V_{CC} = \frac{3.13 - 0.7}{6.78 \times 10^3 + (120 + 1) \times 1 \times 10^3} = 19.02\ \mu\text{A}$$

$$I_C = \beta I_B = 120 \times 19.02 \times 10^{-6} = 2.28 \text{ mA}$$

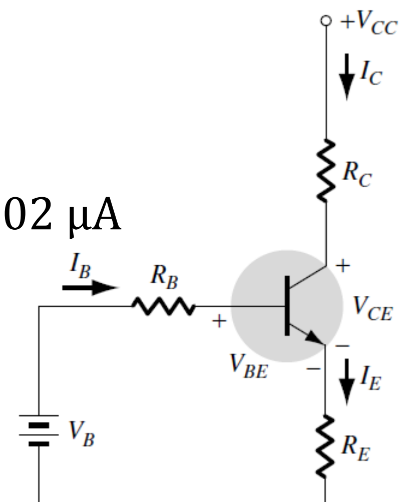


Fig. 7(b)

(ii) Applying *KVL* to the collector-emitter circuit,

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

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

$$= 18 - 2.28 \times 10^{-3} \times 3.3 \times 10^3 - (19.02 \times 10^{-6} + 2.28 \times 10^{-3}) \times 1 \times 10^3$$

$$= 8.18 \text{ V}$$

THANK YOU!