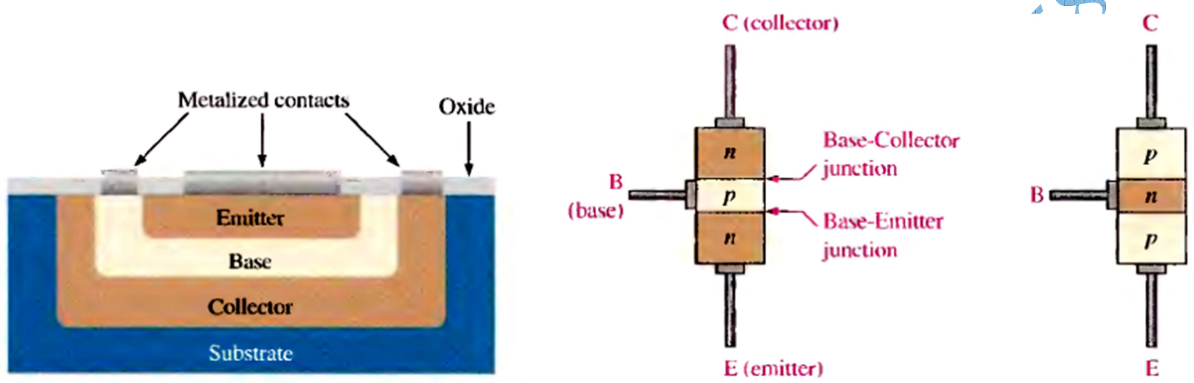
TRANSISTOR

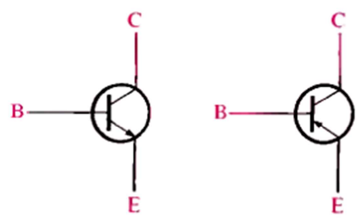
Transistor

The BJT (bipolar junction transistor) is constructed with three doped semiconductor regions separated by two pn junctions. The three regions are called emitter, base, and collector. One type consists of two n regions separated by a p region (npn), and the other type consists of two p regions separated by an n region (pnp). The term bipolar refers to the use of both holes and electrons as carriers in the transistor structure.



(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

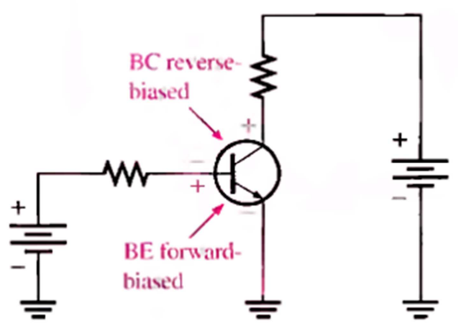
The pn junction joining the base region and the emitter region is called the base-emitter junction. The pn junction joining the base region and the collector region is called the base-collector junction. The base region is lightly doped and very thin compared to the heavily doped emitter and the moderately doped collector regions. The schematic symbols for the npn and pnp bipolar junction transistors is shown in the figure:



(a) *npn* (b) *pnp*

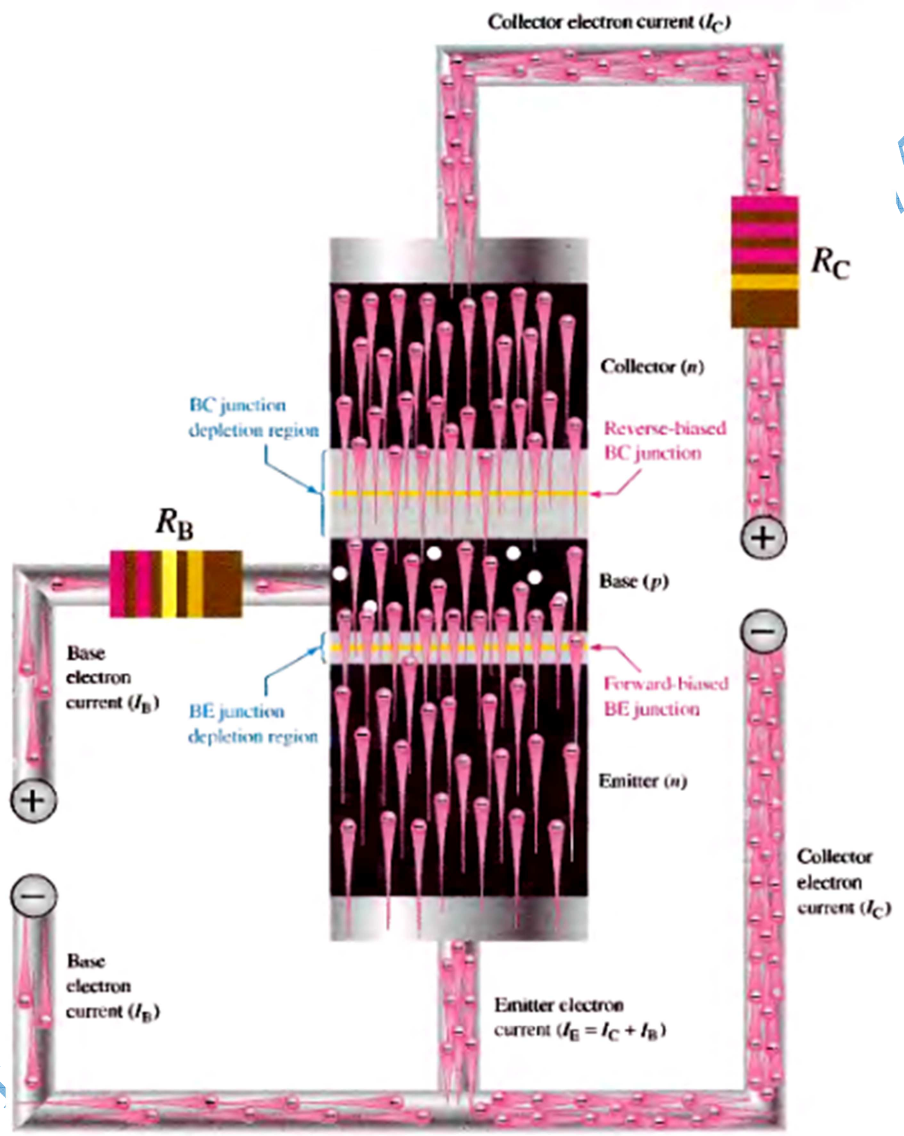
Transistor biasing

For the normal operation of a transistor, its emitter base junction is always forward biased and collector base junction is always reversed biased.



(a) *npn*

To illustrate transistor action, let's examine what happens inside the npn transistor. The forward bias from base to emitter narrows the BE depletion region, and the reverse bias from base to collector widens the BC depletion region. The heavily doped n type emitter region is teeming with conduction-band (free) electrons that easily diffuse through the forward-biased BE junction into the p-type base region. The base region is lightly doped and very thin so that it has a limited number of holes. Thus, only a small percentage of all the electrons flowing through the BE junction can combine with the available holes in the base. These relatively few recombined electrons flow out of the base lead as valence electrons, forming the small base electron current.



Most of the electrons flowing from the emitter into the thin, lightly doped base region do not recombine but diffuse into the BC depletion region. Once in this region they are pulled through the reverse-biased BC junction by the electric field set up by the force of attraction between the positive and negative ions. The electrons now move through the collector region, out through the collector lead, and into the positive terminal of the collector voltage source.

Transistor Currents

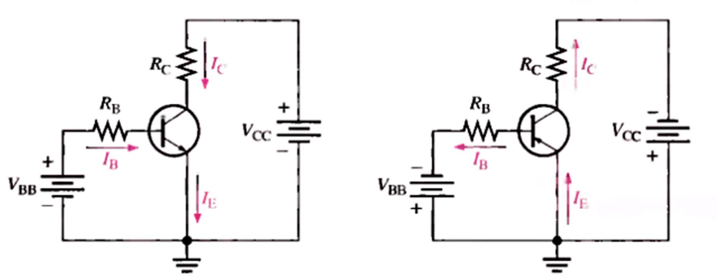
The arrow on the emitter of the transistor symbols points in the direction of conventional current.

This diagrams shows that the emitter current (I_E) is the sum of the collector current (I_C) and the base current (I_B), expressed as follows:

$I_E = I_C + I_B$

Transistor Parameters

Consider a transistor is connected to dc bias voltages for both npn and pnp types. V_{BB} forward-biases the base-emitter junction, and V_{cc} reverse-biases the base-collector junction.



(a) *npn* (b) *pnp*

DC Beta (β_{dc})

The ratio of the dc collector current (I_C) to the dc base current (I_B) is the dc beta (β_{dc}), which is the dc current gain of a transistor. Typical values of β_{dc} lies in the range of 50 to 400.

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

DC Alpha (α_{dc})

The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc alpha. Typically, values of α_{dc} range from 0.95 to 0.99 or greater, but α_{dc} is always less than 1.

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

Transistor in a Circuit

Transistor has three terminals:

(i) Emitter (ii) Base (iii) Collecor

When we put the transistor in a circuit, one terminal acts as input terminal and the other as output terminal. The third terminal acts as a common terminal to both input and output circuits. Any one of the three terminals can be made common. So a transistor con be connected in a circuit in three ways.

(i) Common Base Configuration

(ii) Common Emitter Configuration

(iii) Common Collector Configuration

Common Emitter Configuration

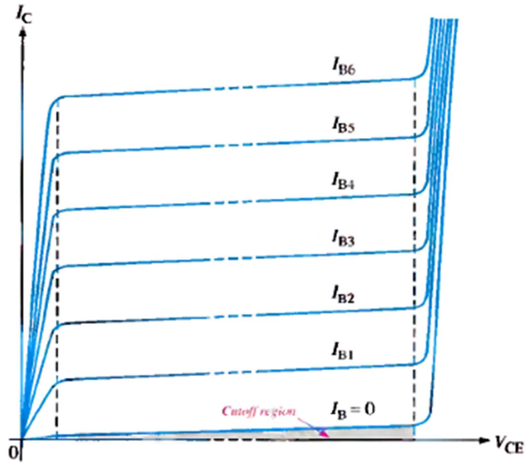
Figure shows the common emitter configuration of pnp transistor. It is called common emitter configuration because emitter is common to both input and output circuits. Two sets of curves are required to completely describe the behavior of CE configuration. One set of curves are called input characteristics and the other set is called output characteristics.

Input Characteristics

The input characteristics show a relationship between input current I_B and input voltage V_{BE} for different values of output voltage V_{CE}. The set of curves obtained from input characteristics is called base curves.

Base Curves

These are the curves obtained by plotting I_B against V_{BE} with V_{CE} as parameter as shown in the figure. The characteristics are similar to that of a forward biased diode. This is because of the reason that base emitter region is forward biased. We obtain two hybrid parameters or transistor constants from the input characteristics.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$ etc.)

Input Resistance

It is the ratio of the change in base-emitter voltage (ΔV_{BE}) to the change in base current (ΔI_B) at constant V_{CE}. i.e.,

$$R_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$$

Voltage Gain

It is the ratio of the change in collector-emitter voltage (ΔV_{CE}) to the change in base-emitter voltage (ΔV_{BE}) at the constant values of I_B.

$$\text{Voltage Gain} = \left(\frac{\Delta V_{CE}}{\Delta V_{BE}}\right)_{I_B}$$

Output Characteristics

The output characteristics show a relation between the output current (I_C) and the output voltage (V_{CE}) for the different values of input current I_B. the set of curves obtained from input characteristics are called collector curves.

Collector Curves

These are the curves obtained by plotting I_C against V_{CE} with I_B used as parameter. These curves shows

- I_C increases rapidly with increase in V_{CE}
- These curves also show that for a fixed values of V_{CE}, I_C increases with increase in I_B.

The hybrid parameters obtained from output characteristics are

Output Resistance

It is the ratio of change in collector-emitter voltage ΔV_{CE} to the change in collector current ΔI_C at constant I_B.

$$R_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

Current Gain or Current Amplification Factor β

The ratio of change in collector current ΔI_C to the change in base current ΔI_B at constant V_{CE}. i.e.,

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}}$$

Relation Between α and β

α is the ratio of collector current ΔI_C and emitter current ΔI_E. i.e.,

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad \text{-------------} \ (1)$$

β is the current amplification factor for CE configuration, which is described as:

$$\beta = \frac{\Delta I_C}{\Delta I_B} \qquad \text{-------------} \ (2)$$

Now as

$$I_E = I_B + I_C$$

$$\Longrightarrow \Delta I_E = \Delta I_B + \Delta I_C$$

$$\Longrightarrow \Delta I_B = \Delta I_E - \Delta I_C$$

Putting values in (2), we get:

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

Dividing the numerator and denominator by ΔI_E

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

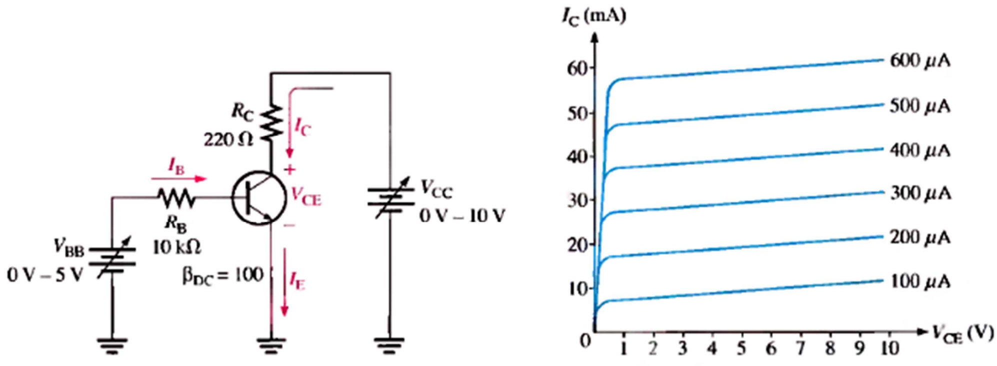
$$\beta = \frac{\Delta I_C / \Delta I_E}{1 - \frac{\Delta I_C}{\Delta I_E}}$$

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

This is the relation between α and β.

DC Load Line

It is the line on the output characteristics of a transistor circuit which gives the values of I_C and V_{CE} when no signal is applied. Consider an npn transistor used as a common emitter amplifier as shown in the figure below:



(a) DC biased circuit (b) Collector characteristic curves

From the output circuit, we have:

$$V_{CC} = V_{CE} + I_C R_L$$

$$V_{CE} = V_{CC} - I_C R_L \quad \text{------------ (1)}$$

This is the equation of dc load line in V_{CE} - I_C plane. The dc load line can be plotted the two end points on the straight line.

To get the 1st end point on the I_C axis, we put $V_{CE} = 0$ in equation (1). So

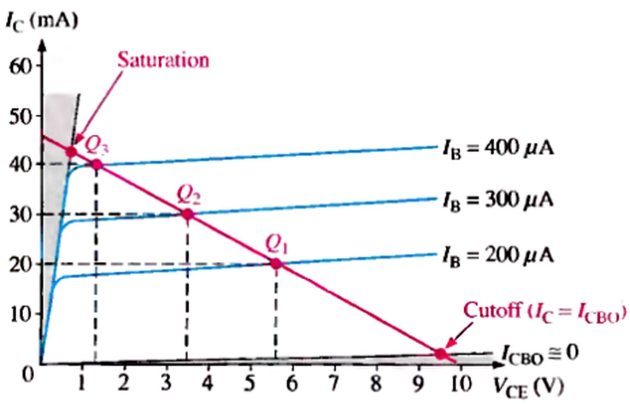
$$0 = V_{CC} - I_C R_L$$

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

To get the 2nd end point on V_{CE} axis, we put $I_C = 0$ in equation (1).

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

By joining the both end points, dc load line is obtained.



With the construction of dc load line on the output characteristics, we get the complete information about the output circuit of transistor amplifier in the zero signal condition.

Operating Point

The zero signal values of I_C and V_{CE} are called the operating points. It is also called Q point or quiescent point. It is the point where the load line intersects the collector curve for a given base current. It is usually selected at the middle of the load line.

Cut Off Region

If the signal voltage is made negative then the base current decreases and point Q moves downward along the load line. If the signal voltage is made very much negative, such that the base current $I_B = 0$, then the transistor is said to be in cut off region.
So the point where the load line intersects $I_B = 0$ curve is called the cut off point.

Saturation region

If the signal voltage is made positive then the base current increase and point Q moves upward along the load line. If the signal voltage is made very much positive such that $I_B = I_B(saturation)$, then the transistor is said to be in saturation region. So point where the load line intersects the $I_B = I_B(saturation)$ curve is called the saturation point.

Active region

The region between the cut off and saturation region is called active region. A transistor is normally operated in active region.

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