UNIT II

BIPOLAR JUNCTION TRANSISTORS

TRANSISTOR CHARACTERISTICS:

The basic of electronic system nowadays is semiconductor device.

The famous and commonly use of this device is BJTs

The transistor formed by back to back connection of two diodes.

Bipolar Junction Transistors : The operation of the transistor depends on both majority and minority carriers.

The voltage between two terminals controls the current through the third terminal. So it is called current controlled device.

It can be use as amplifier and logic switches.

BJT consists of three terminal:

- collector : C
- base : B
- emitter : E

Two types of BJT : pnp and npn

Transistor Construction

- 3 layer semiconductor device consisting:
    - 2 n- and 1 p-type layers of material - npn transistor
    - 2 p- and 1 n-type layers of material - pnp transistor
- The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material
- A single pn junction has two different types of bias:
    - forward bias
    - reverse bias
- Thus, a two-pn-junction device has four types of bias.

Position of the terminals and symbol of BJT.

- Base is located at the middle and more thin from the level of collector and emitter
- The emitter and collector terminals are made of the same type of semiconductor material, while the base of the other type of material

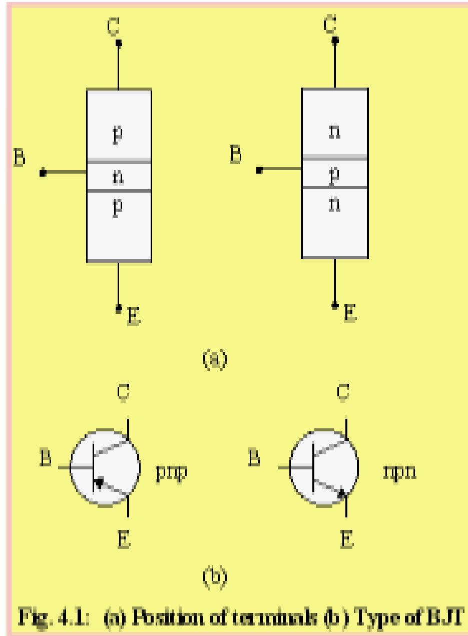
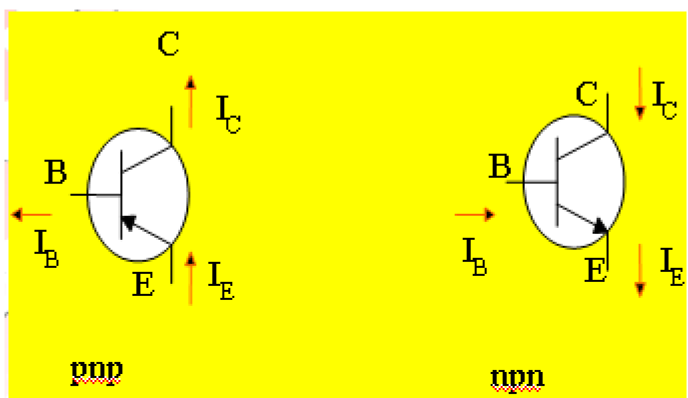


Fig. 4.1: (a) Position of terminals (b) Type of BJT

Transistor currents



- The arrow is always drawn on the emitter The arrow always point toward the n-type

- The arrow indicates the direction of the emitter current:

pnp:E-> B

npn: B-> E

I_C = the collector current

I_B = the base current

I_E = the emitter current

Transistor Operation

• The basic operation will be described using the pnp transistor. The operation of the pnp transistor is exactly the same if the roles played by the electron and hole are interchanged.

• One p-n junction of a transistor is reverse-biased, whereas the other is forward-biased

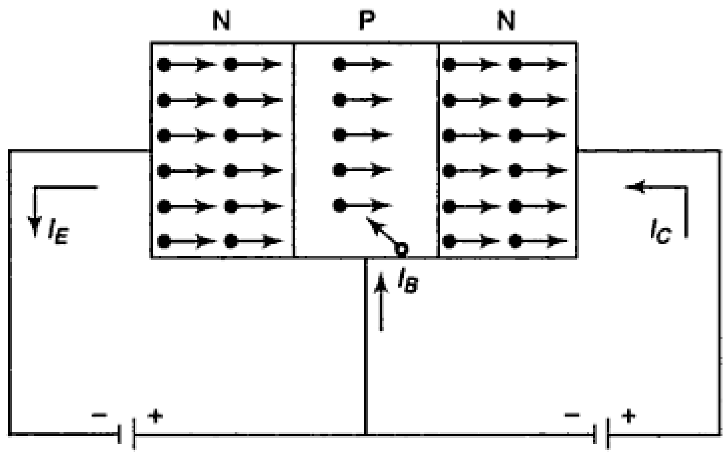


Fig. 6.4 Current in NPN transistor

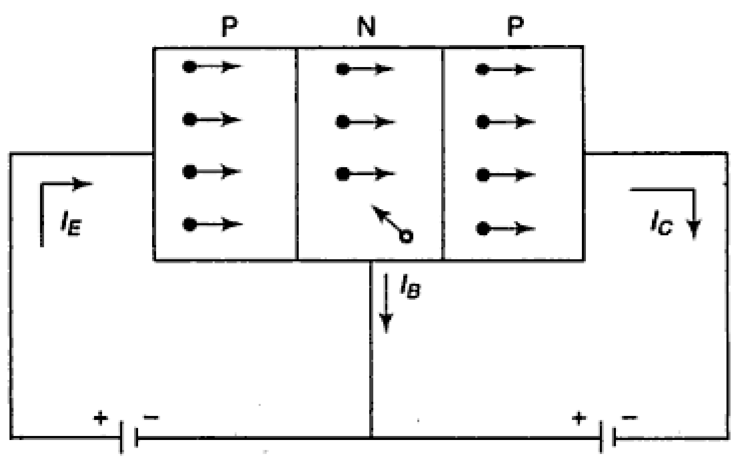


Fig. 6.5 Current in PNP transistor

• Both biasing potentials have been applied to a pnp transistor and resulting majority and minority carrier flows indicated.

• Majority carriers (+) will diffuse across the forward-biased p-n junction into the n-type material.

• A very small number of carriers (+) will through n-type material to the base terminal.

Resulting IB is typically in order of microamperes.

• The large number of majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal.

• Majority carriers can cross the reverse-biased junction because the injected majority carriers will appear as minority carriers in the n-type material.

• Applying KCL to the transistor :

$I_E = I_C + I_B$

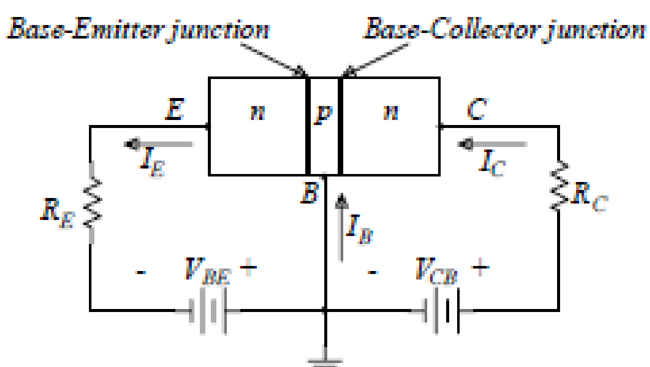
• The comprises of two components – the majority and minority carriers

$I_C = I_{Cmajority} + I_{COminority}$

• I_{CO} – I_C current with emitter terminal open and is called leakage current.

CURRENT EUATIONS

let's consider the BJT ***npn*** structure shown on Figure.



With the voltage V_{BE} and V_{CB} as shown, the Base-Emitter (B-E) junction is forward biased and the Base Collector (B-C) junction is reverse biased.

The current through the B-E junction is related to the B-E voltage as

$$I_E = I_s\left(e^{V_{BE}/V_T} - 1\right)$$

Due to the large differences in the doping concentrations of the emitter and the base regions the electrons injected into the base region (from the emitter region) results in the emitter current *EI*.

Furthermore the number of electrons injected into the collector region is directly related to the electrons injected into the base region from the emitter region.

Therefore, the collector current is related to the emitter current which is in turn a function of the B-E voltage.

The collector current and the base current are related by

$I_c = \beta I_B$

And by applying KCL we obtain

$I_E = I_c + I_B$

And thus from equations the relationship between the emitter and the base currents is

$I_E = (1+\beta)I_B$

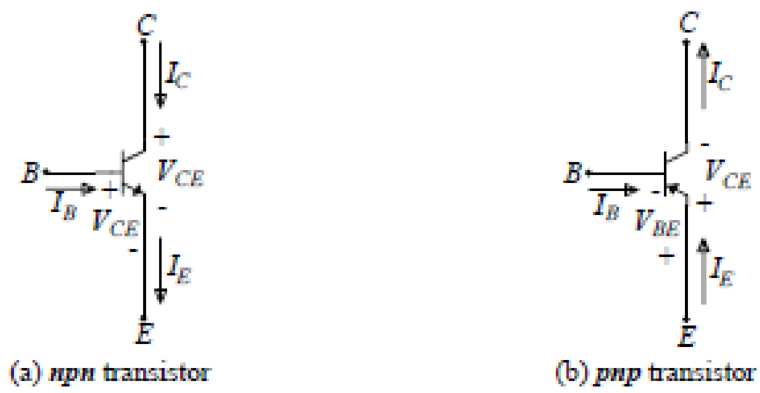
And equivalently

$$I_c = (\beta / 1+\beta)I_E$$

The fraction $(\beta / 1+\beta)$ is called α,

For the transistors of interest β=100 which corresponds to α= 0.99 and $I_c = I_B$

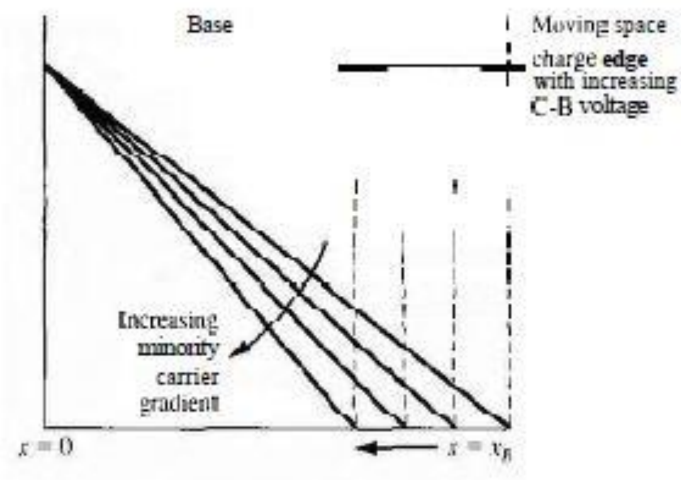
The direction of the currents and the voltage polarities for the npn and the pnp BJTs are shown in fig.



Current directions and voltage polarities for *npn* (a) and *pnp* (b) BJTs

EARLY EFFECT (Base width modulation)

As the voltages applied to the base-emitter and base-collector junctions are changed, the depletion layer widths and the quasi-neutral regions vary as well. This causes the collector current to vary with the collector-emitter voltage as illustrated in Figure .



Variation of the minority-carrier distribution in the base quasi-neutral region due to a variation of the base-collector voltage.

A variation of the base-collector voltage results in a variation of the quasi-neutral width in the base. The gradient of the minority-carrier density in the base therefore changes, yielding an increased collector current as the collector-base current is increased. This effect is referred to as the Early effect.

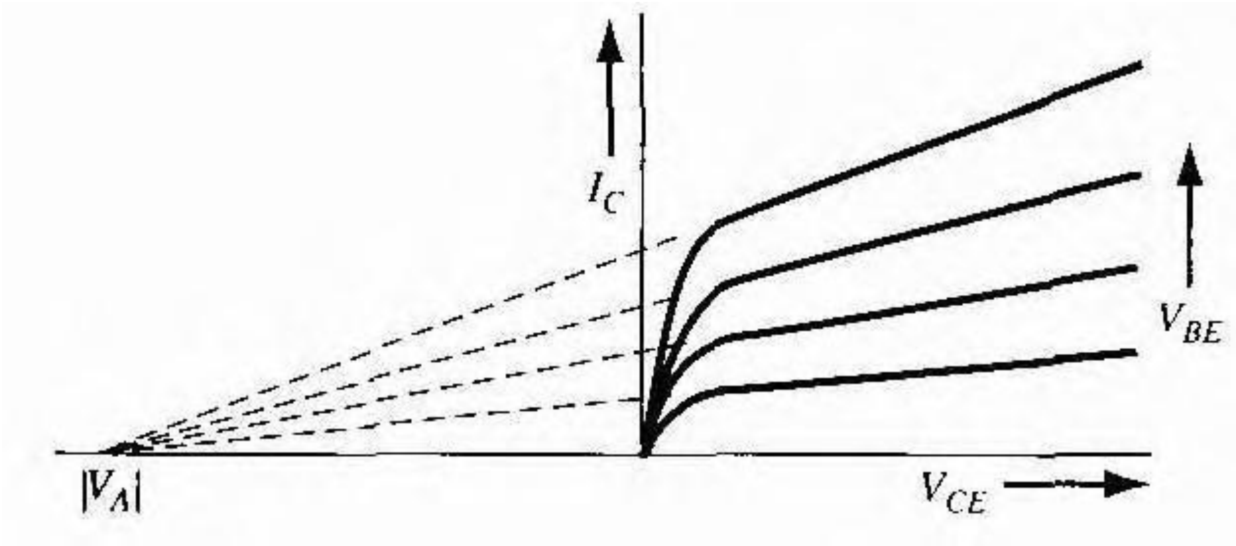
The Early effect is observed as an increase in the collector current with increasing collector-emitter voltage as illustrated with Figure. The Early voltage, V_A, is obtained by drawing a line tangential to the transistor *I-V* characteristic at the point of interest. The Early voltage equals the horizontal distance between the point chosen on the *I-V* characteristics and the intersection between the tangential line and the horizontal axis. It is indicated on the figure by the horizontal arrow.

The change of the collector current when changing the collector-emitter voltage is primarily due to the variation of the base-collector voltage, since the base-emitter junction is forward biased and a constant base current is applied. The collector current depends on the base-collector voltage since the base-collector depletion layer width varies, which also causes the quasi-neutral width, w_B', in the base to vary.

This variation can be calculated for a piece-wise uniformly-doped transistor using the ideal transistor mode.

(1)

$$\frac{dI_C}{dV_{CE}} \cong -\frac{dI_C}{dV_{BC}} = \frac{I_C}{w_B'}\frac{dw_B'}{dV_{BC}}$$



Collector current increase with an increase of the collector-emitter voltage due to the Early effect. The Early voltage, V_A, is also indicated on the figure.

This variation can be expressed by the Early voltage, V_A, which quantifies what voltage variation would result in zero collector current.

$$\frac{dI_C}{dV_{CE}} \overset{\Delta}{=} \frac{I_C}{|V_A|} \tag{2}$$

It can be shown that the Early voltage also equals the majority carrier charge in the base, Q_B, divided by the base-collector junction capacitance, $C_{j,BC} = \varepsilon_s/(x_{p,BC} + x_{n,BC})$, where $x_{p,BC}$ and $x_{n,BC}$ are given by (6) .

(3)
$$|V_A| = \frac{Q_{p,B}}{C_{j,BC}} = \frac{qN_B w_B'}{\dfrac{\varepsilon_s}{x_{p,BC} + x_{n,BC}}}$$

The Early voltage can also be linked to the output conductance, r_0, which equals:

$$r_0 \overset{\Delta}{=} \frac{dV_{CE}}{dI_C} = \frac{|V_A|}{I_C} \tag{4}$$

In addition to the Early effect, there is a less pronounced effect due to the variation of the base-emitter voltage, which changes the ideality factor of the collector current. However, the effect at the base-emitter junction is much smaller since the base-emitter junction capacitance is larger and the base-emitter voltage variation is very limited since the junction is forward biased. This effect does lead to a variation of the ideality factor, n, given by,

$$n = \frac{1}{V_t \frac{d \ln I_C}{dV_{BE}}} \cong 1 + \frac{V_t}{Q_{p,B}} C_{j,BE} = 1 + \frac{V_t}{|V_A|} \frac{C_{j,BE}}{C_{j,BC}} \tag{5}$$

The collector current is therefore of the following form:

$$I_C = I_{C,s}[\exp(\frac{V_{BE}}{nV_t}) - 1] \tag{6}$$

Where the $I_{C,s}$ is the collector saturation current.