UNIT II BIPOLAR JUNCTION TRANSISTORS

1 Introduction transistors and its types

2 NPN -PNP -Junctions and operation

3 Current equations

4 Early effect

5 Input and Output characteristics of CE, CB CC

6 Hybrid -π model

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1 INTRODUCTION

The transistor is the main building block “element” of electronics. It is a semiconductor device and it comes in two general types: the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET).

It is named as transistor which is an acronym of two terms: “transfer-of-resistor.” It means that the internal resistance of transistor transfers from one value to another values depending on the biasing voltage applied to the transistor. Thus, it is called TRANSfer resISTOR: i.e.

TRANSISTOR.

A bipolar transistor (BJT) is a three terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name bipolar.

The voltage between two terminals controls the current through the third terminal. So it is called current controlled device. This is the basic principle of the BJT.

It can be used as amplifier and logic switches. BJT consists of three terminals:

- Collector : C
- Base : B

- Emitter : E

TYPES

There are two types of bipolar transistors

- NPN transistor and
- PNP transistor.

TRANSISTOR CONSTRUCTION

PNP Transistor: In PNP transistor a thin layer of N-type silicon is sandwiched between two layers of P-type silicon.

NPN Transistor: In NPN transistor a thin layer of P-type silicon is sandwiched between two layers of N-type silicon. The two types of BJT are represented in figure 2.1

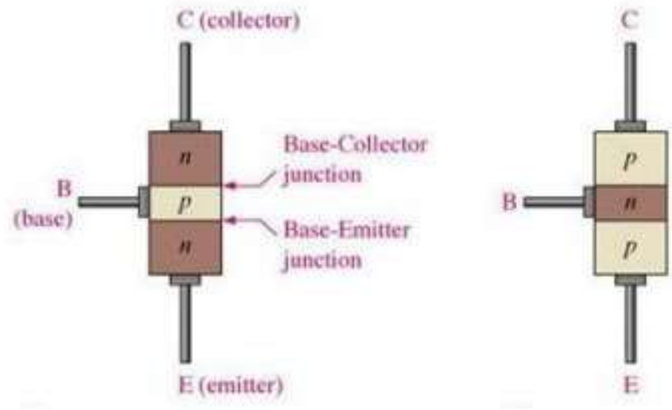


Figure 2.1 Transistors: NPN, PNP

The symbolic representation of the two types of the BJT is shown in figure 2.2

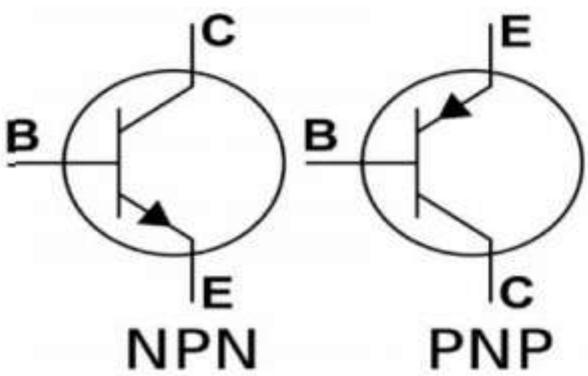


Figure 2.2 circuit symbol: NPN transistor ,PNP transistor

Area: [C>E>B]

- The area of collector layer is largest. So, it can dissipate heat quickly.
- Area of base layer is smallest, and it is very thin layer.
- Area of emitter layer is medium.

Doping level: [E>C>B]

- Collector layer is moderately doped. So, it has medium number of charges.
- Base layer is lightly do ped. So, it has a very few numbers of charges.
- Emitter layer is heavily doped. So, it has largest number of charges.

Junctions:

- There are two junctions in this transistor – junction J-1 and junction J-2.
- The junction between collector layer and base layer is called as collector-base junction or C-B junction.
- The junction between base layer and emitter layer is called a s base-emitter junction or B-E junction. The t wo junctions have almost same potential ba rrier voltage of 0.6V to 0.7V, just like in a diode.

TRANSISTOR BIASING

The states of the two pn junctions can be altered by the external circuitry connected to the transistor. This is called biasing the transistor.

Usually the emitter- base junction is forward biased and collector –base junction is reverse biased. Due to forward bias on the emitter- base junction an emitter current flows through the base into the collector. Though, the collector –base junction is reverse biased, almost the entire emitter current flows through the collector circuit.

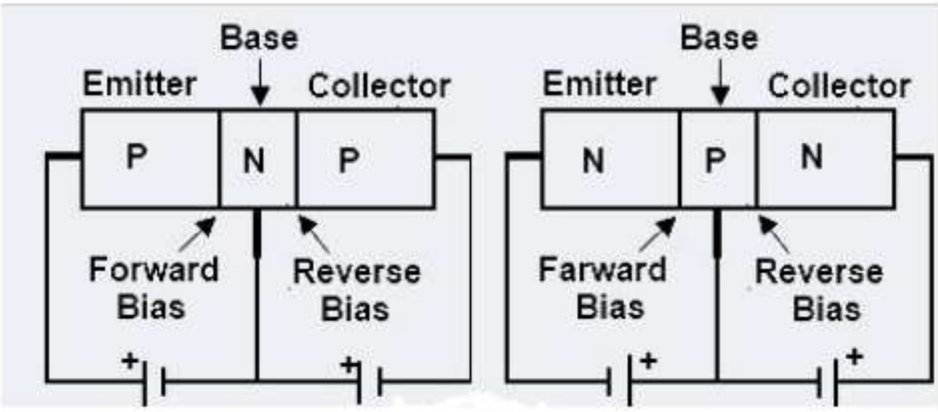


Figure 2.4 Transistor biasing: PNP transistor, NPN transistor

A single pn junction has two different types of bias:

- Forward bias
- Reverse bias

There are two junctions in bipolar junction transistor. Each junction can be forward or reverse biased independently. Thus, there are four modes of operations:

Table 2.1 Modes of operation of transistor

Modes	Emitter-Base junction	Collector- Base junction
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward
Reverse active	Reverse	Forward

Forward Active

In this mode of operation, emitter-base junction is forward biased, and collector base junction is reverse biased. Transistor behaves as a source. With controlled source characteristics the BJT can be used as an amplifier and in analog circuits.

Cut off

When both junctions are rever se biased it is called cut off mode. In this situation there is nearly zero current and transistor behaves as an open switch.

Saturation

In saturation mode both junctions are forward biased large collector current flows with a small voltage across collector base junction. Transistor behaves as an closed switch.

Reverse Active

It is opposite to forward active mode because in this emitter base junction is reverse biased and collector base junction is forward biased. It is called inverted mode. It is no suitable for amplification. However, the re verse active mode has application in digital circuits and certain analog switching circuits.

TRANSISTOR CURRENTS

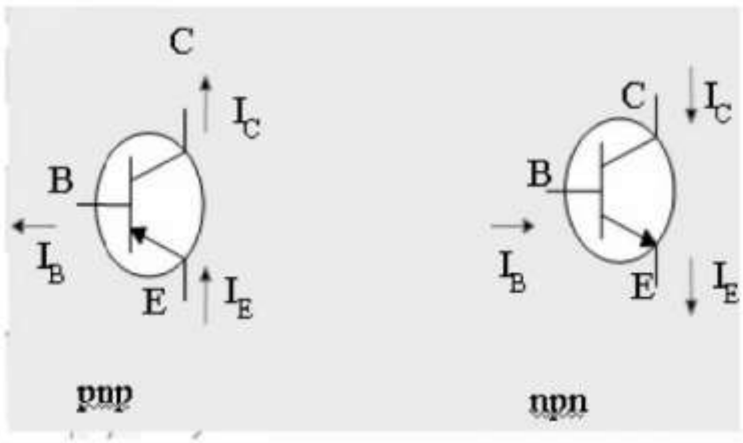


Figure 2.5 Transistor current flow directions

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

IC = the collector current, IB = the base current, IE = the emitter current

OPERATION OF AN NPN TRANSISTOR

Emitter base junction is forward biased and collector base junction is reverse biased. Due to emitter base junction is forward biased lot of electrons from emitter entering the base region.

Base is lightly doped with P-type impurity. So the number of holes in the base region is very small.

Due to this, electron- hole re combination is less (i.e,) few electrons (<5%) combine with holes to constitute base current (IB).

The remaining electrons (>95%) crossover into collector region, to constitute collector current (IC).

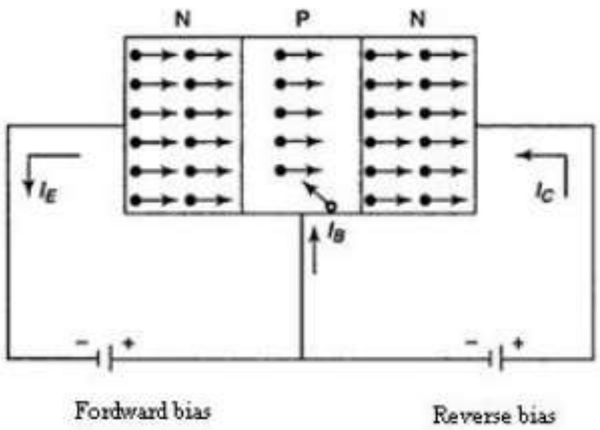


Figure 2.6 Current in NPN transistor

Total current In-terms of magnitude

$$I_E = I_C + I_B$$

OPERATION OF A PNP

Emitter base junction is forward biased and collector base junction is reverse biased. Due to emitter base junction is forward biased lot of holes from emitter entering the base region and electrons from base to emitter region.

Base is lightly doped with N-type impurity. So, the number of electrons in the base region is very small.

Due to this, electron- hole recombination is less (i.e,) few holes (<5%) combine with electrons to constitute base current (IB).

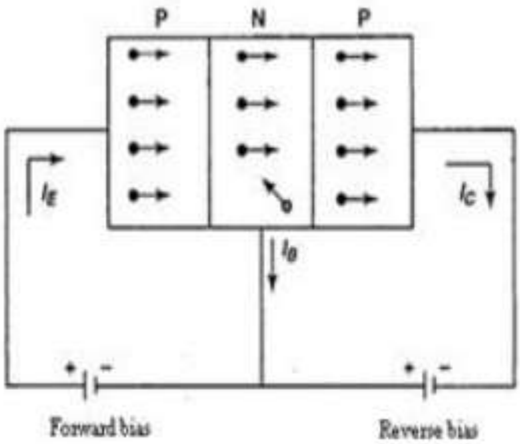


Figure 2.7 Current in PNP transistor

The remaining holes (>95%) crossover into collector region to constitute collector current (IC). Applying KCL to the transistor, the total current =in terms+ of magnitude.

$$I_E = I_C + I_B$$

EARLY EFFECT OR BASE WIDTH MODULATION

The early effect is the variation in the width of the base in a bipolar transistor due to a variation in the applied base-to-collector voltage. For example, a greater reverse bias across the collector –base junction increases the collector-base depletion width. If VCE increases VCB increases too.

The decrease in the base width by VCB has the following two consequences that affect the current:

- There is a lesser chance for recombination within the "smaller" base region.
- The charge gradient is increased across the base, and consequently, the current of minority carriers injected across the emitter junction increases.
- Punch through (or) Reach through: For extremely large reverse voltage is applied to the C-B junction, the “base width” is reduced to zero, causing voltage breakdown in a transistor. It is known as punch trough or reach through.

Both these factors increase the collector or "output" current of the transistor with an increase in the collector voltage. This increased current is shown in Figure 2.9 Tangents to the characteristics at large voltages extrapolate backward to intercept the voltage axis at a voltage called the Early voltage, often denoted by the symbol VA.

CONFIGURATION OF TRANSISTOR CIRCUIT

A transistor is a three-terminal device. But require '4' terminals for connecting it in a circuit. (i.e.) 2 terminals for input, 2 terminals for output.

Hence one of the terminals is made common to the input and output circuits. Common terminal is grounded.

TYPES OF CONFIGURATIONS

Three types of configuration is available

1) Common base (CB) configuration
2) Common emitter (CE) configuration
3) Common collector (CC) configuration

COMMON BASE (CB) CONFIGURATION

In common base configuration circuit is shown in figure. Here base is grounded and it is used as the common terminal for both input and output.

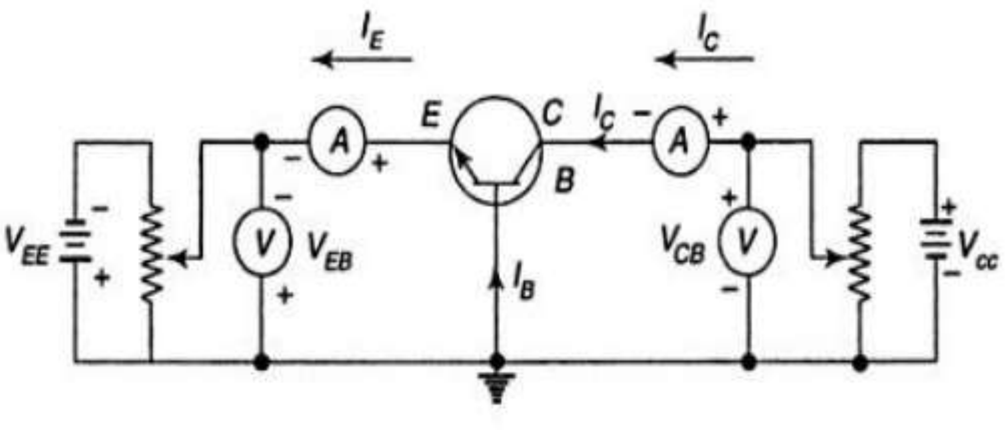


Figure 2.10 Circuit to determine CB static characteristics

It is also called as grounded base configuration. Emitter is used as a input terminal where as collector is the output terminal.

Input characteristics:

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the collector base voltage V_{CB} is kept constant at zero and emitter current IE is increased from zero by increasing V_{EB}. This is repeated for higher fixed values of V_{CB}.

A curve is drawn between emitter current and emitter base voltage at constant collector base voltage is shown in figure 2.11. When V_{CB} is zero EB junctions is forward biased. So it behaves as a diode so that emitter current increases rapidly.

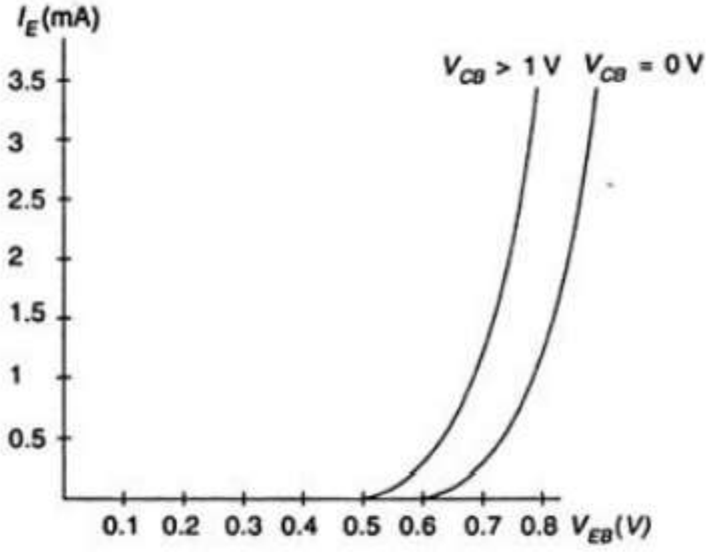


Figure 2.11 CB input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant. To determine output characteristics, the emitter current IE is kept constant at zero and collector current Ic is increased from zero by increasing V_{CB}. This is repeated for higher fixed values of I_E.

From the characteristic it is seen that for a constant value of I_E, Ic is independent of V_{CB} and the curves are parallel to the axis of V_{CB}. As the emitter base junction is forward biased the majority carriers that is electrons from the emitter region are injected into the base region.

In CB configuration 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.

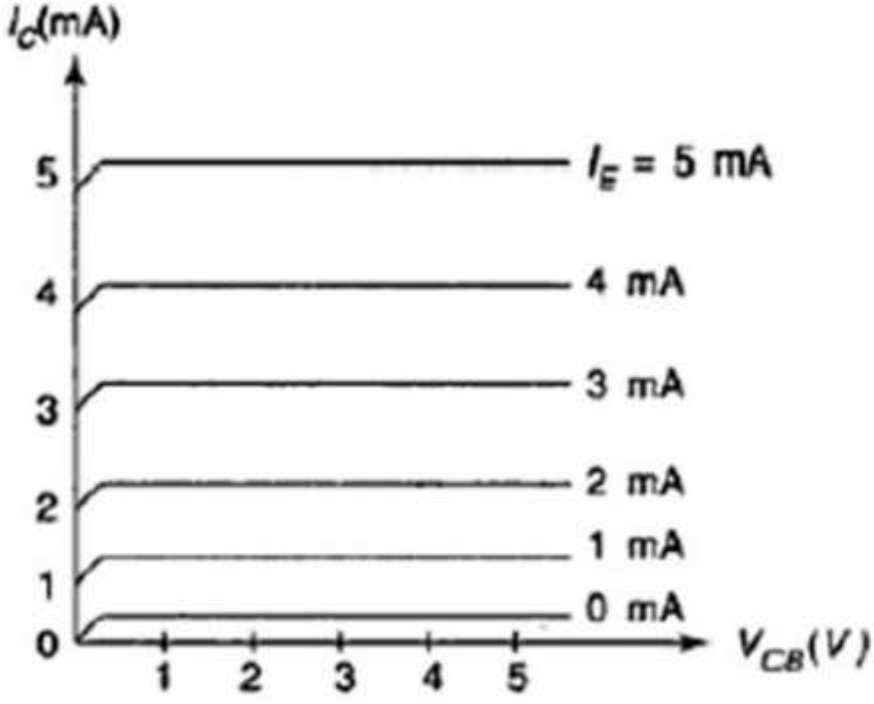


Figure 2.12 CB output characteristics

Transistor parameters in CB configuration

The slope of CB characteristics will give the following four transistor parameters. It is known as base hybrid parameters.

Input impedance (hib): It is defined as the ratio of change in input voltage (emitter voltage) to change in input current (emitter current) with the output voltage (collector voltage) is kept constant *h*=. Δ ,

This ranges from 20ohms to 50ohms.

$$h_{ib} = \frac{\Delta V_{EB}}{\Delta I_E}, V_{CB}\ constant$$

Output admittance (hob): It is defined as the ratio of change in output current (collector current) to change in output Δvoltage (collector voltage) with the input current (emitter current) is kept constant *h*. = Δ , This ranges from 0.1 to 10μ mhos.

$$h_{ob} = \frac{\Delta I_C}{\Delta V_{CB}}, I_E\ constant$$

Forward current gain (hfb): It is defined as the ratio of change in output current (collector current) to change in input current (emitter current) with the output voltage (collector voltage) is kept constantΔ.

$$h_{fb} = \frac{\Delta I_C}{\Delta I_E}, V_{CB}\ constant$$

Reverse voltage gain (hrb): It is defined as the ratio of change in input voltage (emitter voltage) to change in output voltage (collector voltage) with the input current (emitter current) is kept constant. Δ

$$h_{rb} = \frac{\Delta V_{EB}}{\Delta V_{CB}}, I_E\ constant$$

This ranges from 10^{-5} to 10^{-4}.

CE CONFIGURATION

In common emitter configuration circuit is shown in figure. Here emitter is grounded, and it is used as the common terminal for both input and output. It is also called as grounded emitter configuration. Base is used as a input terminal whereas collector is the output terminal.

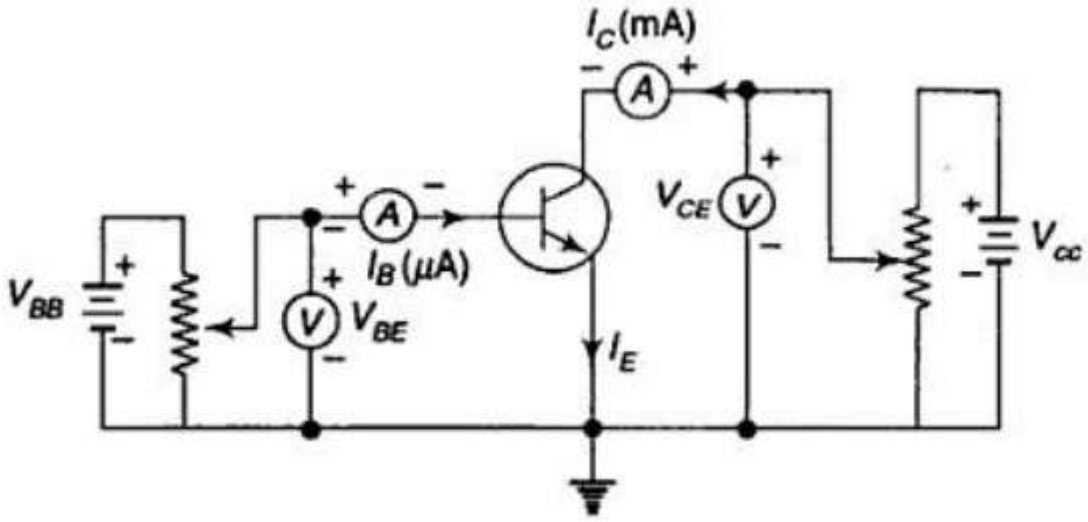


Figure 2.13 Circuit to determine CE static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltages to input current whereas output voltage is constant.

To determine input characteristics, the collector base voltage V_{CB} is kept constant at zero and base current IB is increased from zero by increasing V_{BE}. This is repeated for higher fixed values of V_{CE}.

A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown in figure2.14. Here the base width decreases. So curve moves right as VCE increases.

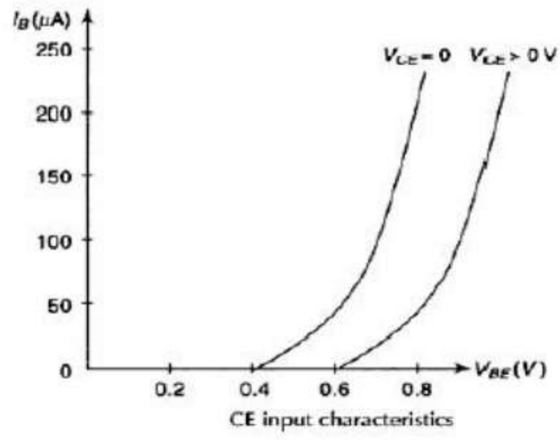


Figure 2.14 CE input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current IB is kept constant at zero and collector current Ic is increased from zero by increasing VCE. This is repeated for higher fixed values of IB.

From the characteristic it is seen that for a constant value of IB, Ic is independent of VCB and the curves are parallel to the axis of VCE.

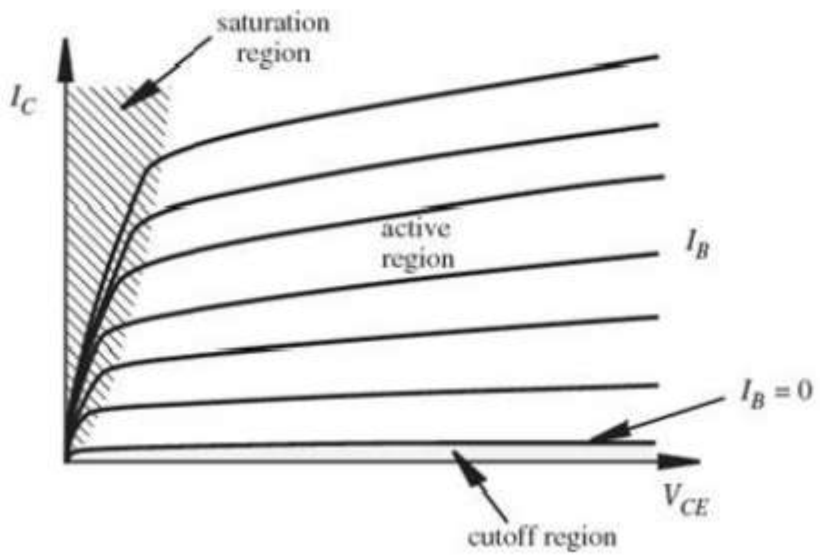


Figure 2.15 CE output Characteristics

The output characteristic has 3 basic regions:

- Active region –defined by the biasing arrangements.
- Cut-off region – region where the collector current is 0A
- Saturation region- region of the characteristics to the left of VCB = 0V.

Active region	Saturation region	Cut-off region
• I_E increased, I_C increased. • BE junction forward bias and CB junction reverse bias. • Refer to the graph, $I_C \approx I_E$ • I_C not depends on V_{CB} • Suitable region for the transistor working as amplifier.	• BE and CB junction is forward bias • Small changes in V_{CB} will cause big different to I_C • The allocation for this region is to the left of V_{CB}=0V.	• Region below the line of I_E=0 A • BE and CB is reverse biase • No current flow at collector, only leakage current.

Transistor parameters in CE configuration

The slope of CE characteristics will give the following four transistor parameters. It is known as emitter hybrid parameters.

Input impedance (hie): It is defined as the ratio of change in input voltage (base voltage) to change in input current (base current) with the output voltage (collector voltage) is kept constant.

$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B}, \ V_{CE} \text{ constant}$$

Output admittance (hoe): It is defined as the ratio of change in output current (collector current) to change in output voltage (collector voltage) with the input current (base current) is kept constant.

$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}, \ I_B \text{ constant}$$

Forward current gain (hfe): It is defined as the ratio of change in output current (collector current) to change in input current (base current) with the output voltage (collector voltage) is kept constant.

$$h_{fe} = \frac{\Delta I_C}{\Delta I_B},\ V_{CE} \text{ constant}$$

Reverse voltage gain (hre): It is defined as the ratio of change in input voltage (base voltage) to change in output voltage (collector voltage) with the input current (base current) is kept constant.

$$h_{re} = \frac{\Delta V_{BE}}{\Delta V_{CE}},\ I_B \text{ constant}$$

This ranges from 10^{-5} to 10^{-4}.

CC CONFIGURATION

In common collector configuration circuit is shown in figure. Here collector is grounded, and it is used as the common terminal for both input and output. It is also called as grounded collector configuration. Base is used as a input terminal whereas emitter is the output terminal.

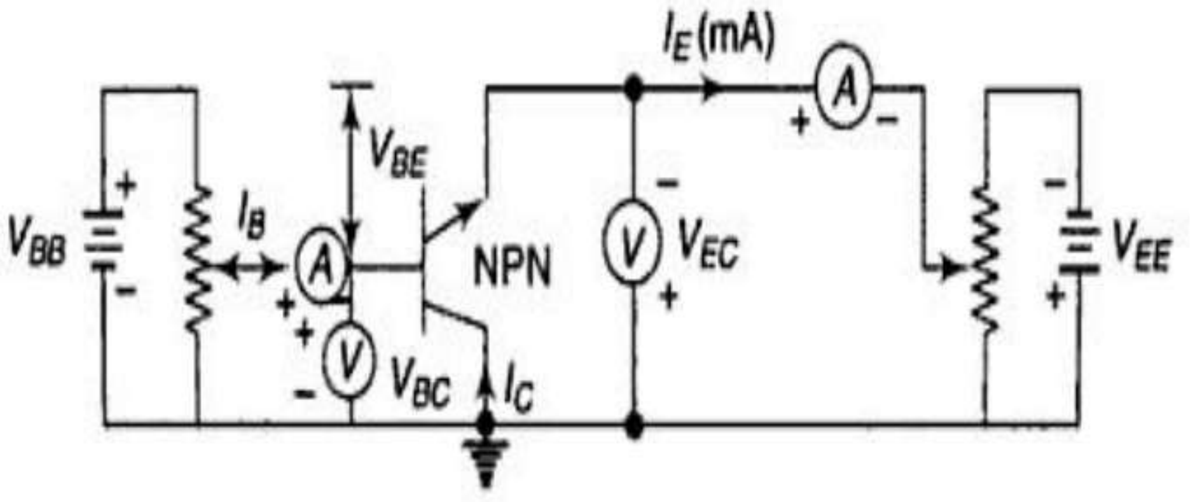


Figure 2.16 Circuits to determine CC static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the emitter base voltage VEB is kept constant at zero and base current IB is increased from zero by increasing VBC. This is repeated for higher fixed values of VCE.A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown in figure2.17.

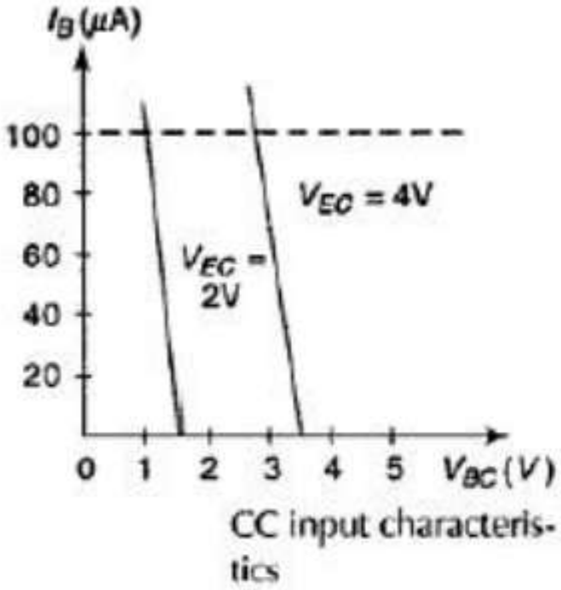


Figure 2.17 CC input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current IB is kept constant at zero and emitter current IE is increased from zero by increasing VEC. This is repeated for higher fixed values of IB.

From the characteristic it is seen that for a constant value of IB, IE is independent of VEB and the curves are parallel to the axis of VEC.

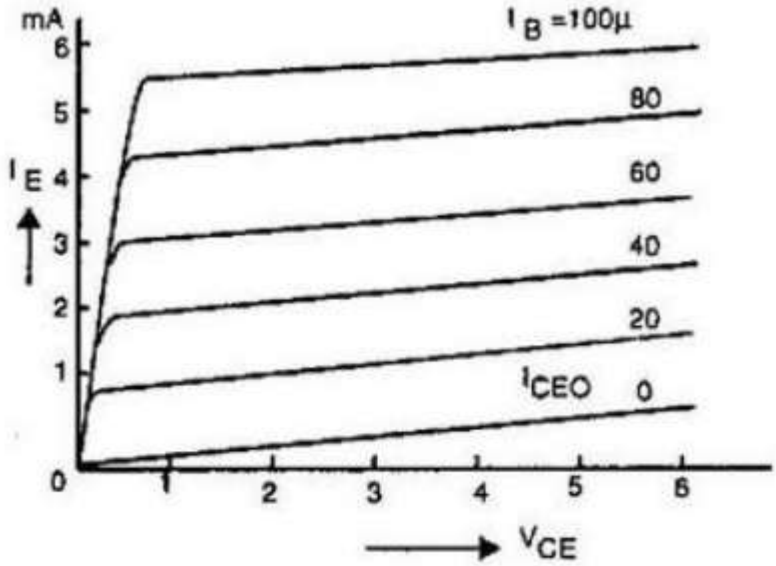


Figure 2.18 CC output characteristics

A comparison of CB, CE and CC Configurations

Property	*CB*	*CE*	*CC*
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (about 750 kΩ)
Output resistance	High (about 450 kΩ)	Moderate (about 45 kΩ)	Low (about 25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500	Less than 1
Phase shift between input & output voltages	0 or 360°	180°	0 or 360°
Applications	for high frequency circuits	for audio frequency circuits	for impedance matching

h-PARAMETER BJT MODEL

A transistor can be treated as a two-port network. The terminal behavior of any two-port network can be specified by the terminal voltage Vi and Vo at port 1 and port 2 respectively and currents Ii and Io, entering ports 1 and 2 respectively. As shown in figure 2.20.

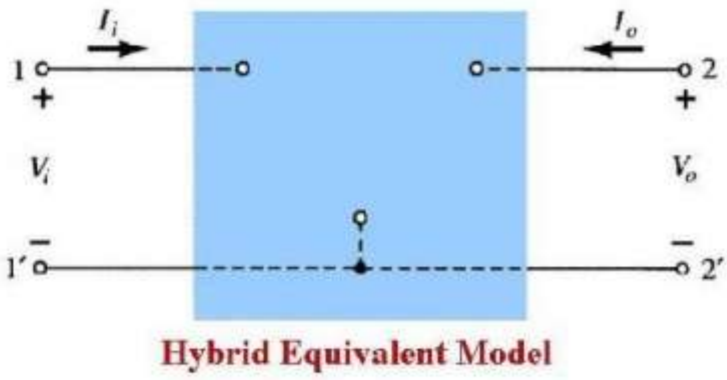


Figure 2.21 two port network

Of these four variables, Vi , Vo ,Ii and Io two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two port parameters out of which the following are very important.

i. h-parameters or hybrid parameters
ii. Z-parameters or impedance parameters
iii. Y-parameters or admittance parameters

The h-parameter model is typically suited to transistor circuit modeling. Hence, both short-circuit and open-circuit terminal conditions are used.

If the input current and the output voltage are taken as independent variables, the input voltage and output current can be written as

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

$$V_1 = h_{11}I_1 + h_{12}V_2$$

$$I_2 = h_{21}I_1 + h_{22}V_2$$

The four hybrid parameters h_{11}, h_{12}, h_{21} and h_{22} are defined as follows:

When $V_1 = 0$ i.e., with output port short circuited,

$$h_{11} = \left[\frac{V_1}{I_1}\right] with\, V_2 = 0$$

= input impedance

$$h_{21} = \left[\frac{I_2}{I_1}\right] with\, V_2 = 0$$

= forward current gain or forward transfer ratio

When $I_1 = 0$ i.e., with input port open circuited,

$$h_{21} = \left[\frac{I_2}{V_2}\right] with\, I_1 = 0$$

= output admittance

$$h_{11} = \left[\frac{V_1}{V_2}\right] with\, I_1 = 0$$

= reverse voltage gain or reverse transfer ratio

The equivalent circuit of the h-parameter representation is shown in figure 2. Here h12V2 is the controlled voltage source and h21I2 is the controlled current source.

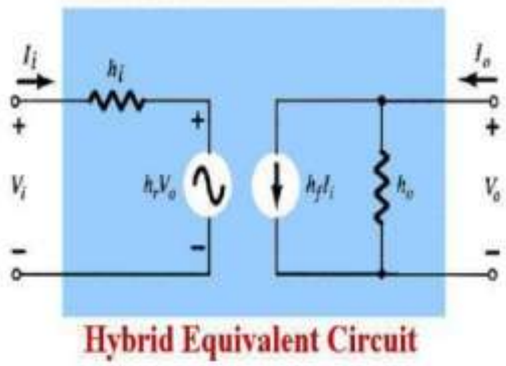


Figure 2.22 Equivalent circuit of h-parameter model

When h-parameters are applied to transistors, it is a common practice to add a second subscript to designate the type of configuration. Considered –e for common emitter, b for common base and c for common collector. Thus, for a common emitter (CE) configuration,

Ebers-Moll Model

The Ebers-Moll model, or equivalent circuit, is one of the classic models of the bipolar transistor. This particular model is based on the interacting diode junctions and applicable in any of the transistor operating modes.

The general expression for collector current IC of a transistor for any voltage across collector junction VC and emitter current IE is

$$I_C = -\alpha_N I_E - I_{CO}\left(e^{\frac{V_C}{V_T}} - 1\right)$$

Where α_N is the current gain in normal operation and I_{CO} is the collector junction reverse saturation current.

In the inverted mode of operation, the above equation can be written as

$$I_E = -\alpha_I I_C - I_{EO}\left(e^{\frac{V_E}{V_T}} - 1\right)$$

Where α_I is the inverted common-base current gain and I_{EO} is the emitter junction reverse saturation current.

The above four parameters are related by the condition

$$\alpha_I I_{CO} = \alpha_N I_{EO}$$

For many transistors I_{EO} lies in the range 0.5 I_{CO} to I_{CO}

In above figure, two separate ideal diodes are connected back to back with saturation currents-and - and there are two dependent current-controlled sources shunting the ideal diodes. The current

sources account for the minority carrier transport across the base. An application of kirchhoff's current law to the collector node of the above figure gives

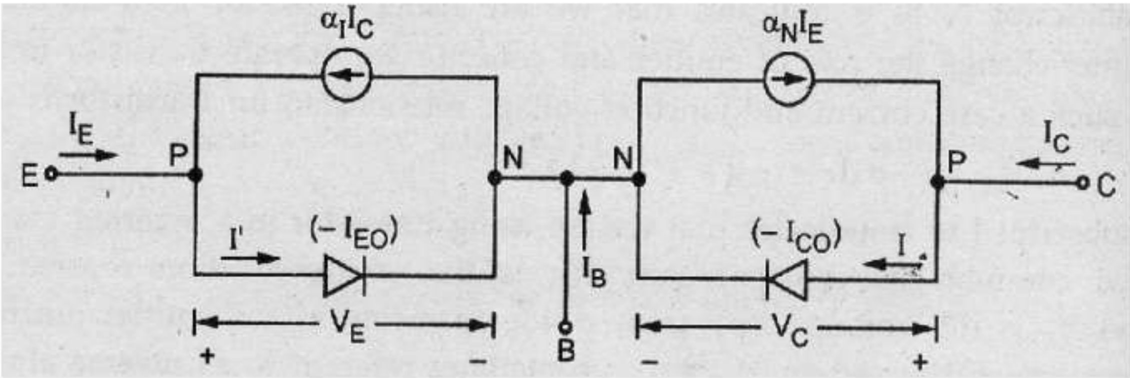


Figure 2.24 Ebers-moll models for a PNP transistor

INTRODUCTION

A Bipolar Junction Transistor (BJT) is a three – terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name bipolar.

BJT is analogous to a vacuum diode and its comparatively smaller in size. It is used in amplifier and oscillator circuits.

Applications

Computers

Satellites

Modern Communication systems

CONSTRUCTION

BJT consists of a silicon crystal in which a thin layer of N – type silicon is sandwiched between two layers of P – type silicon. This transistor is referred to as PNP. Alternatively, in a NPN transistor, a layer of P – type material is sandwiched between two layers of N – type material.

Three portions of the transistor are Emitter, Base and Collector. The arrow on the emitter specifies the direction of current flow when the EB junction is forward biased.

Emitter – Heavily doped so that it can inject a large number of charge carriers from the emitter to the base.

Base – Lightly doped and very thin

Collector – moderately doped.

Transistor Biasing

Usually the emitter – base junction is forward biased, and collector base junction is reverse biased. Due to forward bias on the emitter – base junction an emitter current flow through the base into the collector. Through the, collector base junction is reverse biased, almost entire current flows through the collector circuit.

OPERATION OF AN NPN TRANSISTOR

The forward bias applied to the emitter base junction of an NPN transistor causes a lot of electrons from the emitter region to crossover to the base region. As, the base is lightly doped with P – type impurity, the number of holes in the base region is very small and hence the number of electrons that combine with holes in the P – type base region is also very small. Hence a few electrons combine with holes to constitute a base current I_B. The remaining electrons crossover the junction to constitute a collector current I_C. Thus the base and Collector current is summed up gives the emitter current,

$$I_E = -(I_B + I_C)$$

In the external circuit of the NPN bipolar junction transistor, the magnitudes of the emitter current I_E, Base current I_B and the collector current I_C are related by

$$I_E = (I_B + I_C)$$

OPERATION OF PNP TRANSISTOR

The forward bias applied to the emitter – base junction of a PNP transistor causes a lot of holes from the emitter region to cross over to the base region as the base is lightly doped with N – type impurities. The number of electrons in the base is very small and hence the number of holes combined wit electrons in the N – type base region is also very small. Hence, a few holes combined with electrons to constitute a base current I_B. The remaining holes crossover the junction to constitute a collector current I_C. Thus, the base and Collector current is summed up gives the emitter current,

$$I_E = -(I_B + I_C)$$

In the external circuit of the PNP bipolar junction transistor, the magnitudes of the emitter current I_E, Base current I_B and the collector current I_C are related by

$$I_E = (I_B + I_C)$$

There are current amplification factors α and β in common base and common emitter transistor configuration respectively for the static (DC) currents, and for small changes in the currents.

Large – signal current gain (α)

The large signal current gain of a common base transistor is defined as the ratio of negative of the collector current increment to the emitter – current change from cut – off to I_E. i.e.,

$$\alpha = -\frac{I_C - I_{CBO}}{I_E - 0}$$

$I\_CBO - reverse\ saturation\ current\ flowing\ through\ the\ reverse\ biased\ collector - base\ junction\ i.e., the\ collector\ to\ base\ leakage\ current\ with\ emitter\ terminal\ open.$

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

$I\_C\ and\ I\_E$ are flowing on opposite direction, α is always positive. Typical values of α ranges from 0.90 to 0.955.

General transistor Equation

BIPOLAR JUNCTION TRANSISTOR (BJT)

The BJT is constructed with three doped semiconductor regions separated by two PN junctions, as shown in the epitaxial planar structure in Figure. The three regions are called emitter, base, and collector. Physical representations of the two types of BJTs are shown in Figure. 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 current carriers in the transistor structure.

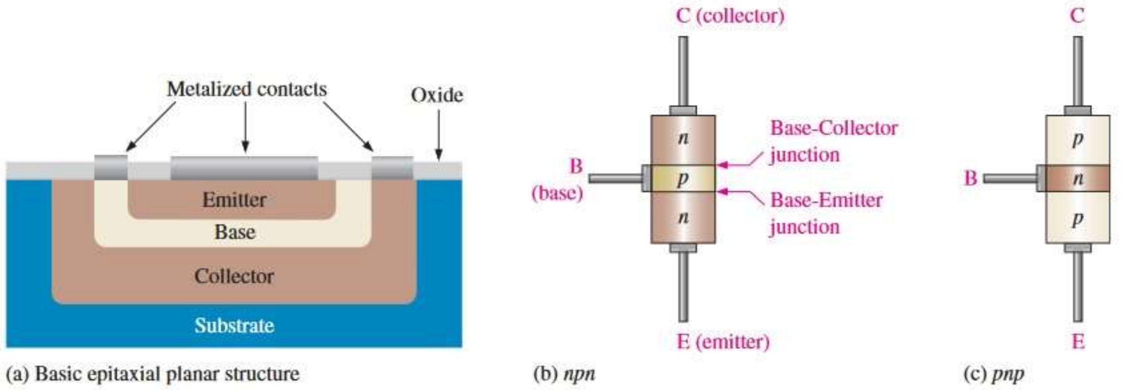
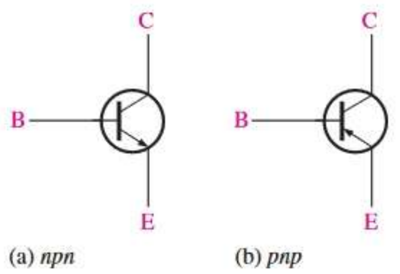


Fig: Basic BJT construction

The pn junction joining the base region and the emitter region is called the base-emitter junction. The pn unction joining the base region and the collector region is called the base-collector junction, as indicated in Figure. A wire lead connects to each of the three regions, as shown. These leads are labeled E, B, and C for emitter, base, and collector, respectively. The base region is lightly doped and very thin compared to the heavily doped emitter and the moderately doped collector regions.



Following Figure shows the schematic symbols for the npn and pnp bipolar junction transistors.

BASIC BJT OPERATION

In order for a BJT to operate properly as an amplifier, the two *pn* junctions must be correctly biased with external dc voltages. In this section, we mainly use the *npn* transistor for illustration. The operation of the *pnp* is the same as for the *npn* except that the roles of the electrons and holes, the bias voltage polarities, and the current directions are all reversed.

Biasing

Figure below shows a bias arrangement for both *npn* and *pnp* BJTs for operation as an **amplifier.** Notice that in both cases the base-emitter (BE) junction is forward-biased and the base-collector (BC) junction is reverse-biased. This condition is called *forward-reverse bias.*

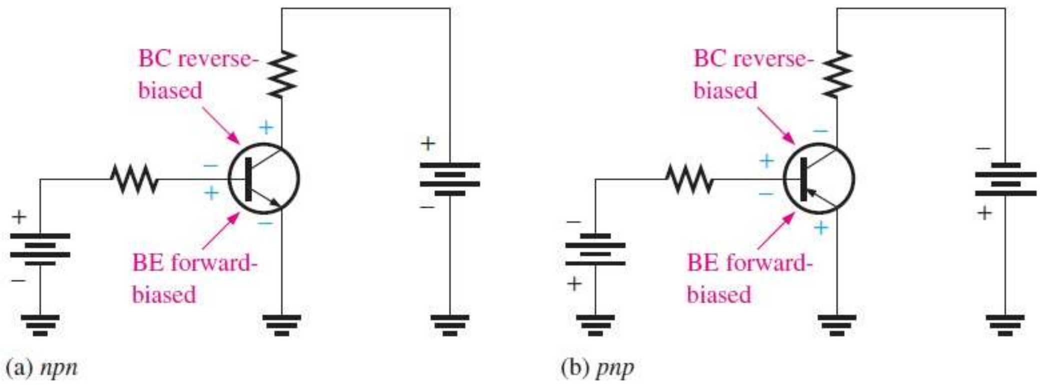


Fig: Forward-reverse bias of a BJT.

Operation

To understand how a transistor operates, let's examine what happens inside the *npn* structure. The heavily doped *n*-type emitter region has a very high density of conduction-band (free) electrons, as indicated in Figure. These free electrons easily diffuse through the forward - based BE junction into the lightly doped and very thin *p*-type base region, as indicated by the wide arrow. The base has a low density of holes, which are the majority carriers, as represented by the white circles. A small percentage of the total number of free electrons injected into the base region recombine with holes and move as valence electrons through the base region and into the emitter region as hole current, indicated by the red arrows.

When the electrons that have recombined with holes as valence electrons leave the crystalline structure of the base, they become free electrons in the metallic base lead and produce the external base current. Most of the free electrons that have entered the base do not recombine with holes because the base is very thin. As the free electrons move toward the reverse-biased BC junction, they are swept across into the collector region by the attraction of the positive collector supply voltage. The free electrons move through the collector region, into the external circuit, and then return into the emitter region along with the base current, as indicated. The emitter current is slightly greater than the collector current because of the small base current that splits off from the total current injected into the base region from the emitter.

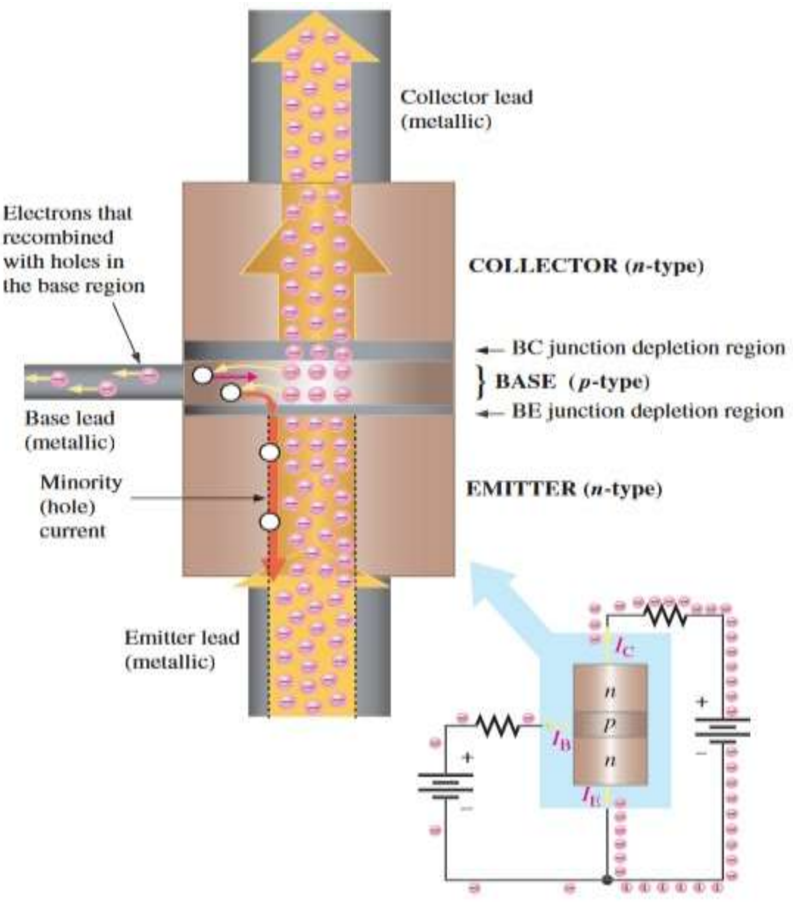


Fig: BJT operation showing electron flow

Transistor Currents

The directions of the currents in an npn transistor and its schematic symbol are as shown in Figure; those for a pnp transistor are shown in Figure. Notice that the arrow on the emitter inside the transistor symbols points in the direction of conventional current. These diagrams show that the emitter current (IE) is the sum of the collector current (IC)and the base current (IB), expressed as follows.

$$I_E = I_C + I_B$$

As mentioned before, I_B is very small compared to I_E or I_C.

h – Parameter Model

A transistor can be treated as a two – port network. The terminal behaviour of any two – port network can be specified by the terminal voltages V_1 and V_2 at port 1 and 2 respectively, and currents I_1 and I_2 entering ports 1 and 2, respectively. Of these four variables V_1, V_2, I_1 and I_2 two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables.

i. h – parameters or Hybrid parameters
ii. Z – parameters or Impedance Parameters
iii. Y – parameters or Admittance Parameters

The h – parameter representation is widely used in modelling of transistors. Hence, both short – circuit and open – circuit conditions are used. Input current I_1 and Output Voltage V_2 are taken as independent variables.