Subject Name: **Electronic Devices & Circuits**

Subject Code: **EC-3004**

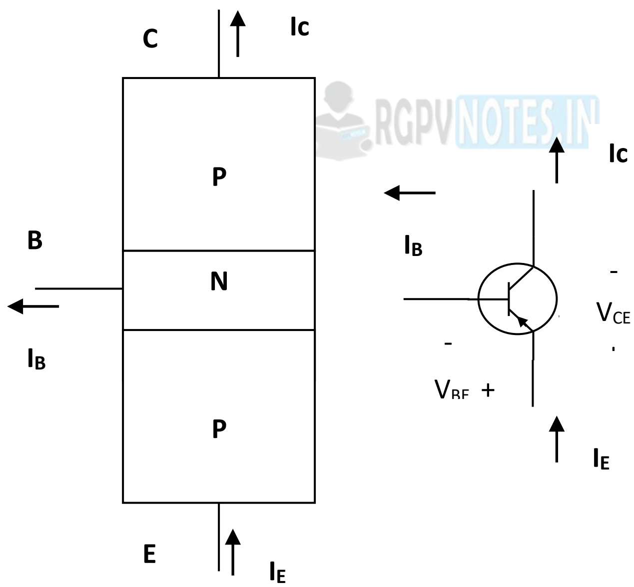
Semester: **3rd**

UNIT 2

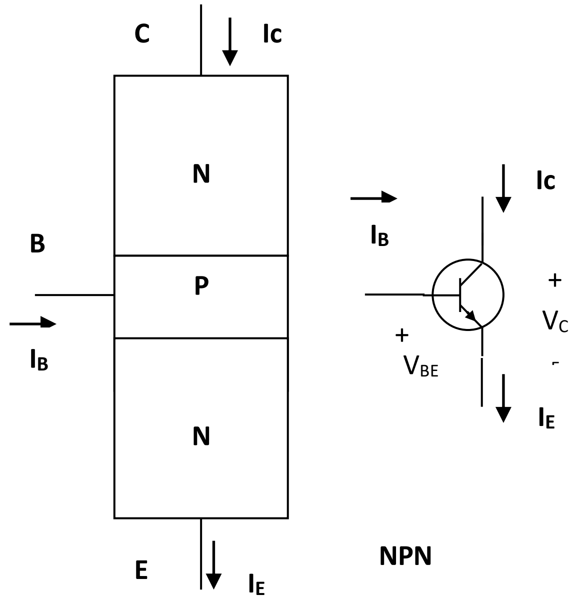
Syllabus : Bipolar junction transistor - Construction, basic operation, current components and equations, CB, CE and CC configuration, input and output characteristics, Early effect, Region of operations: active, cut-off and saturation region. BJT as an amplifier. Ebers-Moll model, Power dissipation in transistor (Pd, max rating), Photo transistor.

BIPOLAR JUNCTION TRANSISTOR:

A transistor is an electronic device which is be used as a amplifier or a switch. It is consist of three layer sandwich of extrinsic semi-conductor material; either a p-type is sandwich between two n types (NPN) or a n type is sandwich between p type (PNP). These layers have different names. They are different from each other, why? Because their physical size and the doping levels. The side which supplies charges called as emitter, other side which collects this charges is called collector. The middle section is called the base.



PNP Transistor



EMITTER: the left part of the transistor is emitter. It supplies majority charge carriers to base. Electrons are majority carriers for NPN and holes are majority carriers for PNP. Here Doping level of emitter is very heavy and it is forward biased as compared to base.

COLLECTOR: the right part section is collector and it collects the majority carriers. It is reverse biased with respect to base. It is moderately doped.

BASE: The middle region is the base. It is the thinnest of all. It is lightly doped.

There are two junctions, emitter and collector junction, both have their own barrier potential. The emitter junction provides low resistance for majority charge carriers to pass easily. The resistance of the CB junction is large, therefore large reverse bias voltage is to be applied to the junction.

In this three region, the collector region is large. The emitter region is a small and the base region is the very small.

The current direction is shown by arrowhead.

The transistors are current controlled device. The voltage power and current at the output end are controlled by the input current. There are two types of charge carriers: majority and minority hence it is called as Bi-Polar. As the speed of the fan can be controlled manually with the help of regulator, in the same terms if electrical controlled is used to regulate the current then it is called Transistor.

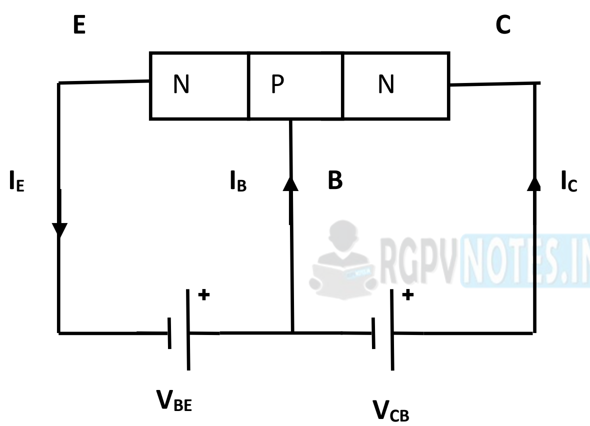
Advantages of BJT:

As compared told traditional controls such as vacuum tube, it is small in size, small weight, rugged construction.

It has medium to towering voltage range. It is having low voltage drop. Applications:

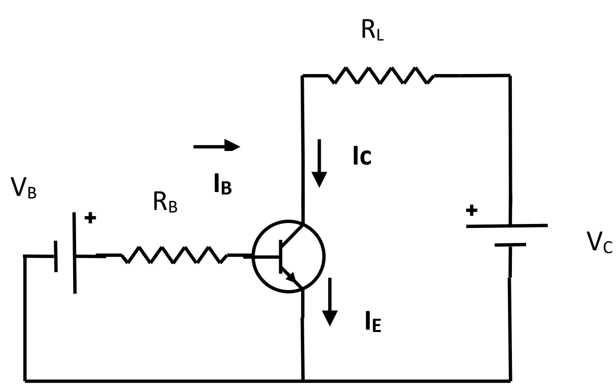
NPN Transistor working:

In NPN transistor there is separation of p type semiconductor between two n type. In NPN majority carriers are electrons. The flow of these electrons is from emitter to collector. The NPN transistor consists three terminals – emitter, base and collector.



NPN Transistor Circuit:

The above figure shows the NPN transistor circuit with supply voltages and resistive loads. Here the collector terminal always connected to the positive voltage, the emitter terminal connected to the negative supply and the base terminal controls the ON/OFF states of transistor depending on the voltage applied to it.



In the above circuit connections, supply voltage VB is applied to the base terminal through the load resistance. Vcc is connected to the collector terminal through the load Resistance. Here R_B and R_L can limit the current by the particular terminals. Here the base terminal and collector terminals are always positive voltages with respect to emitter.

If the base voltage equals emitter voltage then the transistor is in OFF mode. If the base voltage is more than emitter voltage then the transistor becomes switched until it is in ON state. If the enough positive voltage is applied to the base terminal i.e. ON state, then electrons flow generated and the current (IC) flows from emitter to the collector. Here the base is acting as input and the collector-emitter region acting as output.

To allow current flow between emitter and collector properly, it is essential that the collector voltage must be positive and more than the emitter voltage. Little amount of voltage drop is in between base and emitter, like 0.7V. So the base voltage must be greater 0.7V otherwise the transistor will not be operated. The equation of base current for a bipolar NPN transistor is given by,

$$I_B = (V_B - V_{BE})/R_B$$

Where,

IB is Base current

VB is Base bias voltage

VBE is Input Base-emitter voltage = 0.7V

RB is Base resistance

The output collector current in common emitter NPN transistor is calculated by applying KVL.

The equation for V_{CC} is given as

$$V_{CC} = I_C R_L + V_{CE} \text{ ………… } (1)$$

From the above equation the collector current for CE is given as

$$I_C = (V_{CC} - V_{CE})/R_L$$

In a common emitter the relation between I_C and I_B is given as

$$I_C = \beta\, I_B$$

In active region the NPN transistor is acting as a amplifier. In CE total current flow through the transistor is defined IC/IB. This ratio is called as "DC current gain" and it is unit less. This ratio is represented with β and the maximum value of β is about to be 200. In common base NPN transistor the total current gain is expressed as IC/IE. This ratio is represented with α and this value is equal to 1.

α, β and γ Relationship:

The relationship between α and β.

α is DC current gain for CB = Output current/Input current

In CB output current is (IC) and is emitter current (IE).

$$\alpha = I_C/I_E \text{ ....(2)}$$

This current gain (α) value is very near about unity but somewhat less than the unity.

$$I_E = I_C + I_B$$

$$I_B = I_E - I_C$$

from equation 2, the collector

$$I_C = \alpha I_E$$

$$I_B = I_E - \alpha I_E$$

$$I_B = I_E (1-\alpha)$$

β = DC current gain for common emitter circuit = Output current/Input current

Here output current is collector current and input current is base current.

$$\beta = I_C/I_B$$

$$\beta = I_C/I_E (1-\alpha)$$

$$\beta = \alpha/(1-\alpha)$$

From the above equations the

$$\alpha = \beta (1-\alpha) = \beta/(\beta+1)$$

$$\beta = \alpha (1+\beta) = \alpha/ (1-\alpha)$$

The relationship between α, β and γ factors.

In CC the current gain is defined as the ratio emitter current IE to base current IB. This current gain is represented with γ.

$$\gamma = I_E/I_B$$

We know that emitter current

$$I_E = I_C + I_B$$

$$\gamma = (I_C + I_B)/I_B$$

$$\gamma = (I_C/I_B) + 1$$

$$\gamma = \beta + 1$$

The relationships between α, β and γ are given as below

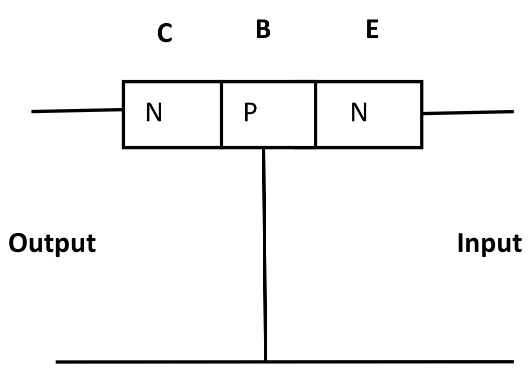
$$\alpha = \beta / (\beta+1), \qquad \beta = \alpha / (1-\alpha), \qquad \gamma = \beta + 1$$

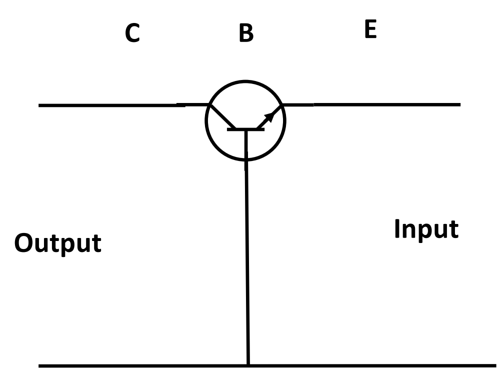
Different configurations of transistor:

The transistor consists of three terminals – emitter, base and collector. But in the circuit we require four terminals, 2 terminals for I/P and 2 terminals for O/P. For these problems we use one terminal as common for both input and output actions. Using this property we make the circuits and are called transistor configurations. Generally the transistor configurations are three types they are common base configuration, common collector configuration and common emitter configuration.

1. Common Base Configuration (CB)
2. Common Collector (CC) Configuration
3. Common Emitter (CE) Configuration

Common Base (CB) Configuration:





In this configuration we use base as common for both input and output signals. The configuration name itself indicates the common terminal. Here the input is applied between the base and emitter terminals and the corresponding output signal is taken between the base and collector terminals with the base terminal grounded. Here the input parameters are VEB and IE and the output parameters are VCB and IC. The input current flowing into the emitter terminal must be higher than the base current and collector current to operate the transistor, therefore the output collector current is less than the input emitter current.

The current gain should be equal to or less than 1 for this configuration. The amplifier circuit of this type is called as non-inverting amplifier circuit. The construction of this connection circuit is complex because this type has very high voltage gain values.

This type of connection has high resistance. The voltage gain for this connection is given below.

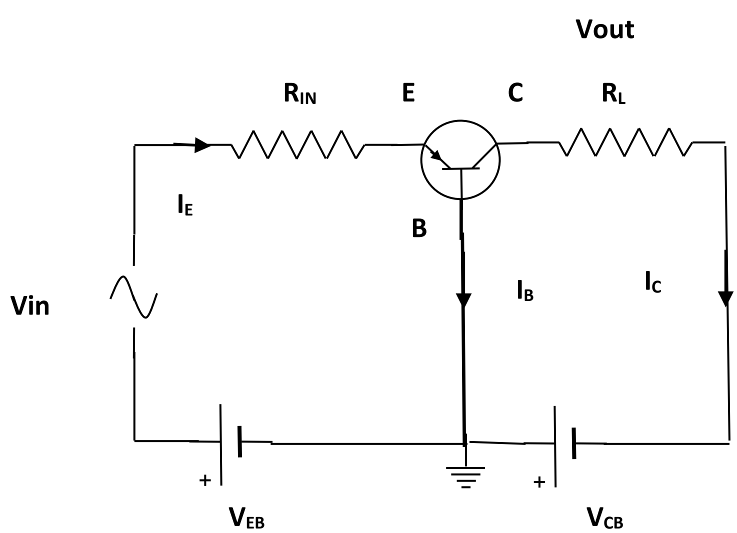
A_V = Vout/Vin = (IC*RL) / (IE*Rin)

Current gain in CB connection is given as

α = Output current/Input current

α = I_C/I_E

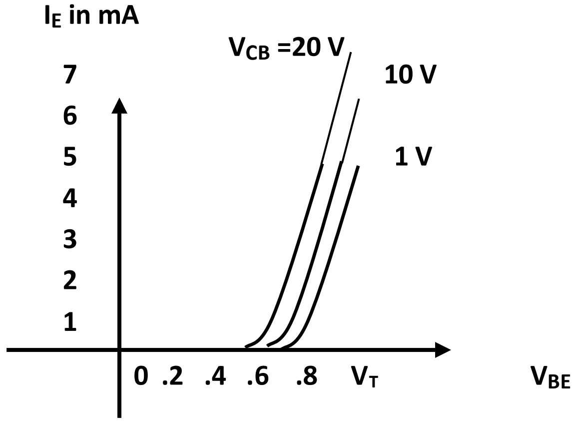
The CB circuit is mainly used in single stage amplifier circuits. The CB circuit is given below.



Input Characteristics:

Input characteristics implies characteristics of I_{in} vs V_{in} keeping contant V_O. First keep contant V_O, VCB constant and then VEB is varied for different values then at each value record the input current IE value. Repeat the same process at different V_O levels. Now for these values plot the graph between IE and VEB. The below figure show the input characteristics of CB connection. The equation for input resistance Rin is.

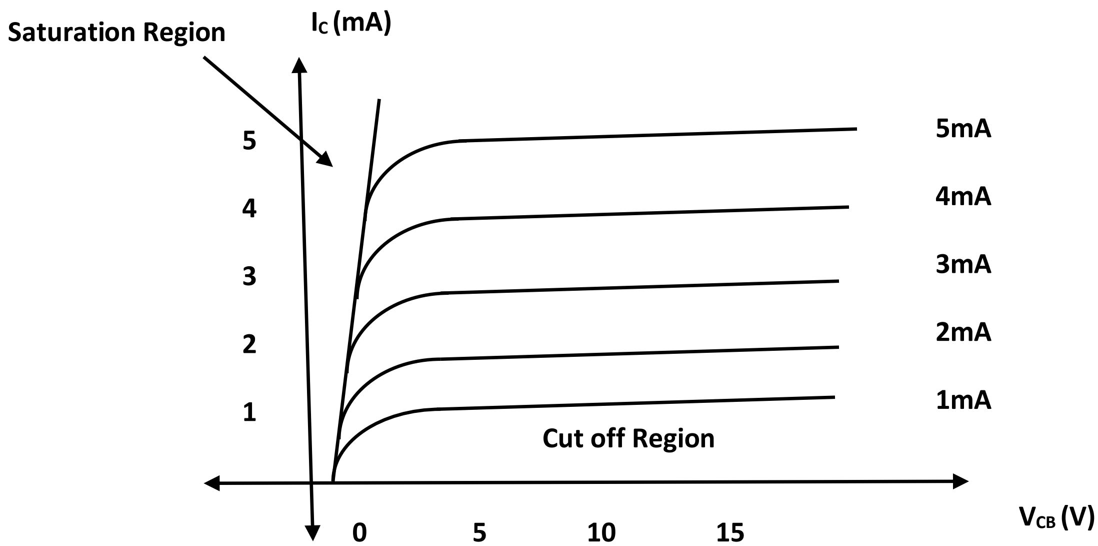
$$R_{in} = V_{EB} / I_E \text{ (when } V_{CB} \text{ is constant)}$$



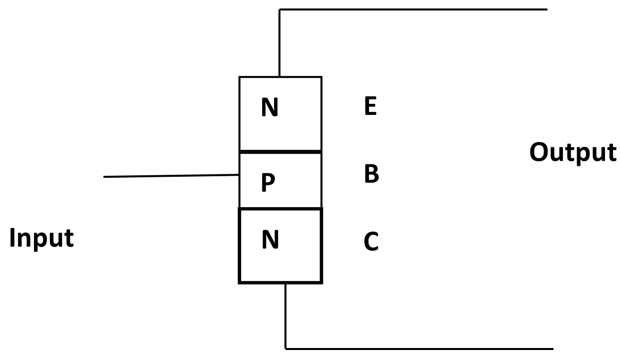
Output Characteristics:

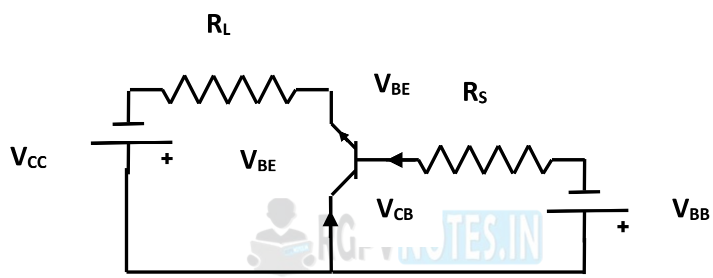
The output characteristics of CB connection is the characteristics between I_{out} and V_{out} keeping constant I_{in}. I'st keep the I_E constant and vary the V_{CB}, now record the IC values at every point. Repeat the process at different values. Finally draw the plot VCB vs IC at constant IE. The below figure show the output characteristics of common base configuration. The equation for the output resistance value is.

Rout = V_{CB} / I_C (when I_E is constant)



Common Collector Configuration:





In this configuration collector terminal is common both input and output. This connection is known as emitter follower connection. This configuration is mostly for buffering. This connection is widely used in impedance matching.

In this connection the input signal is applied to the base-collector and the output is taken from the emitter-collector. Here the inputs are VBC and IB and the outputs are VEC and IE. The common collector connection has high input impedance and low output impedance. Here the emitter current is equal to the addition of collector current and the base current.

Current gain,

Ai = Output current/Input current

Ai = IE/IB

Ai = (IC + IB)/IB

Ai = (IC/IB) + 1

$$A_i = \beta + 1$$

The CC transistor circuit is shown above. The voltage gain for this circuit is less than 1 but it has large current gain because the R_L in this circuit receives the collector and base currents.

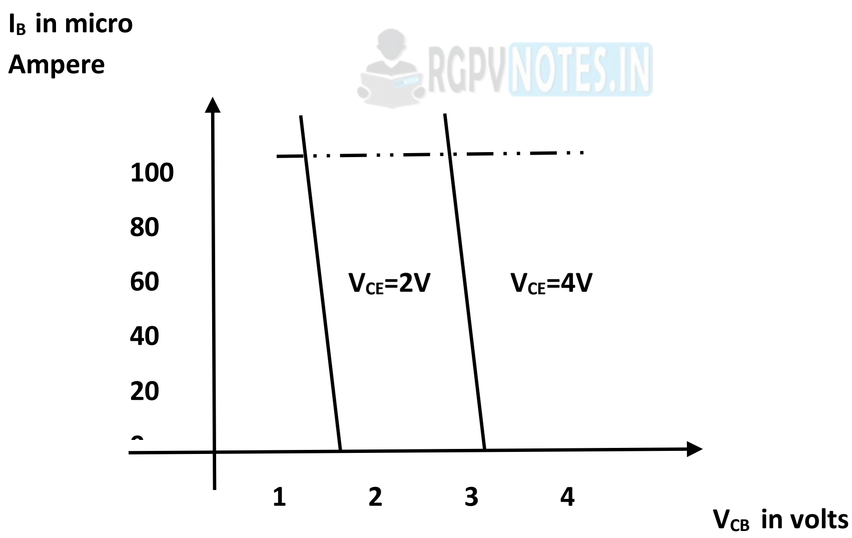
Input Characteristics of common collector configuration:

The input characteristic of CC configuration is different from the CB and CE configurations because the input voltage VBC is determined by VEC level. Here,

VEC = VEB + VBC

VEB = VEC – VBC

The input characteristic of a common-collector configuration is obtained between inputs current IB and the input voltage VCB for constant output voltage VEC. Make the output voltage VEC constant and vary the input voltage VBC for different values and record the IB values. Now using these values draw a graph between the parameters of VBC and IB at constant VEC.

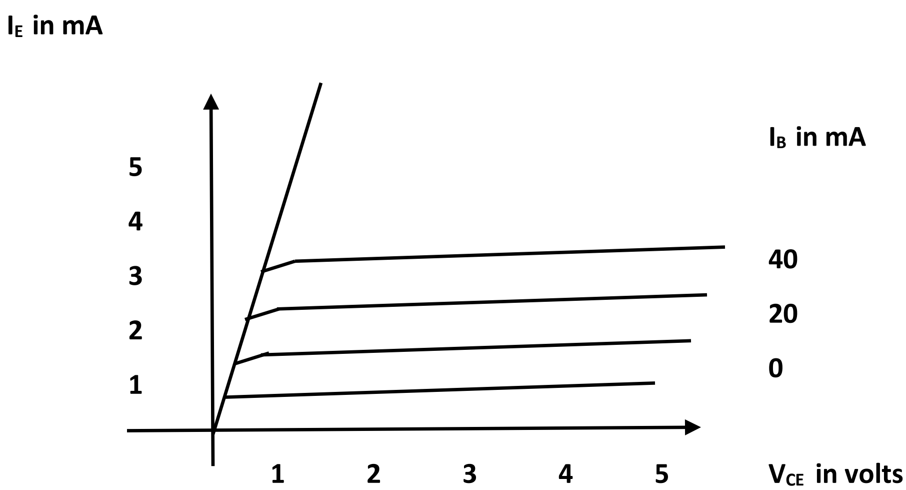


Output Characteristics of common collector configuration:

The output characteristic of a CC is obtained between the output voltage VEC and output current IE for constant input current IB. In the operation of CC circuit if the base current is equal to zero then the emitter current becomes zero. As a result no current flows through the transistor.

If the base current increased then the transistor is operated in active region and reaches to saturation region. To plot the graph first we make the IB at constant value & vary

VEC for various points, now record the value of IE. Repeat the process for different IB. Now using these values plot the graph between IE and VCE at constant IB. The below figure show the output curves of common collector.



Early Effect:

As you increase collector to base voltage in CB connection ie. if more reverse bias base collector junction the depletion region width increases as depletion region width is proportional to reverse bias voltage.

This depletion layer protrude more in the base than collector because base is not heavily doped as compared to collector. As depletion region is a region of not covered charge carriers due to protection of charge total charge in base is equal to the total charge in collector. Total uncovered charge in base is equal to product of base depletion layer amount and doping concentration, likewise in collector. Hence

WB*NB*AB=WC*NC*AC

as side area is same for base and collector so

WB*NB=WC*NC

Since NC>NB, WB>WC where W stands for depletion layer widths, A stands for areas, N stands for doping concentrations of respective regions B for base, C for collector.

Operation of BJT

BJT have two junctions BE junction, BC junction. therefore there are four different regions of operation in which either of the two junctions are forward biased reverse biased or both. But the BJT can be successfully operated in there different modes depending to the external bias voltage applied at each junction. The other part of operation of BJT is called as not active region.

Transistor in active region

Active region is one in which BE junction is forward biased and BC junction is reverse biased in a transistor. In NPN transistor when biasing is in active region the currents flowing through it will be

The currents flowing through the three terminals of BJT are:

Emitter current: A current flows from E into B having of electrons and hole current flowing from B to E.

Base current: A recombination current flows from the B which in the circuit appears as I_B supplied by power supply which is equal to the rate at which charge carriers (holes) are nowhere to be found in base due to recombination. This current will be small as base is lightly doped and numbers of charge carriers are fewer. Also a reverse saturation electron current flows B to C as BC junction is reverse biased.

Collector current: The collector current consists of two current

a) Reverse saturation current through reverse biased BC junction. The BC junction can be thought of as reverse biased diode. Then the current through the BC junction from the diode current equation is given as

Irev,c = Ico (1-exp (Vbc/Vt)) in case of transistor as reverse current flows from the B to C and Vbc is negative for a reverse biased PN junction.

where Ico is reverse saturation current,Vt is voltage equivalent of temperature = k*T/e = 26 mV at 300 Deg C, k is Boltzmann's constant =1.38*10-23 Joule/Kelvin, T is absolute temperature in kelvin,e is electronic charge = 1.6*10-19 C .

b) The I_E left after recombination I_B flows into collector. The fraction of I_E is quantify in terms of a parameter termed as alpha.Alpha(α) is the large signal current gain which is defined as ratio of collector current to emitter current. In cut off IE = 0 amps and Ic = Ico.

α = (Ic -Ico) / (IE-0)

Adding up, the I_C is given as

$I_c = -\alpha * I_E + I_{co} (1-e^{V_c/V_t})$

If we don't consider reverse saturation current Ico then β can be represented in terms of α, $\beta = \alpha / (1-\alpha)$ and $\alpha = \beta/(1+\beta)$.

putting the value of α in terms of β in the equation for I_C and assuming the reverse current is ~Ico

$I_c = -\beta * I_E/(1+\beta) - I_{co}$

since $I_C+I_B+I_E = 0$ we will get $I_c = \beta*(I_C+I_B)/(1+\beta) + I_{co}$

rearranging the terms $I_c = (\beta * I_B) + I_{co}*(1+\beta)$

By neglecting the Ico term there exists a linear relationship between Ic and I_B in a CE transistor described by a parameter β also called as large signal current gain in CE configuration as in CE configuration input current is I_B and output current is Ic.

Transistor in Saturation region:

Saturation region is one in which both EB and BC junctions of the transistor are forward biased. In this region high current flows through the transistor, as both the junctions of the transistor are forward biased and high resistance offered is very much less. Transistor in saturation region is consider as ON state in digital logic.

A transistor is said to be in saturation if

$\beta > I_c/I_b$

There will be extra component of electron current flowing from C to B. Small variation in C to B forward voltage leads to large variations in collector currents .

Transistor in Cutoff region:

In this both junctions are reverse biased. Hence transistor which is in cut off does not conduct currents expect for small reverse saturation currents. In cutoff condition I_E is zero and the I_C consists of small reverse saturation currents. The transistor when used as switch is operated in cutoff on condition and saturation regions which corresponds to switch off and on condition in that order.

Introduction to Ebers moll model of transistor

Ebers Moll model is a simple method of representing the transistor as a circuit model. The Ebers Moll model of transistor holds for all regions of operation of transistor. This model is based on assumption that base spreading resistance can be avoided. It will be clear that why two diodes connected back to back cannot function as a transistor as dependent current source will be missing which is dependable for all the properties of transistor.

Transistor in inverting mode of operation

The inverted mode of operation corresponds to the use of collector as source of I_E.

For a diode with voltage applied between the terminals, the current flowing through the junction in terms of applied voltage between its terminals is given by

$$I=I_O *(e^{V/V_t}-1)$$

Where I_O is rev. saturation current of the transistor.

The I_c in a BJT when operated in normal mode is

$$I_c= -\alpha_N*I_E + I_{co} *(1-e^{V_{CB}}/V_t)$$

In inverted mode of operation the I_c can be found by replacing α_N by α_I, I_{CO} by I_{EO}, V_{BC} by V_{BE}

$$I_E= -\alpha_I*I_C+I_{EO}(1-e^{V_{BE}}/V_t)$$

Explanation of Ebers-moll model

This model of transistor is known as Ebers Moll model of transistor. Applying Kirchhoff's current law at the collector node,

$$I_C= -\alpha_N*I_E + I_{CO} *(1 – e^{V_{CB}}/V_t)$$

Where α_N is the current gain of CB transistor mention above in normal mode of operation, V_{BC} is the B to C voltage, I_{co} is the reverse saturation current of BC junction. In the same way at E & B node by applying Kirchhoff's current law

$$I_E= -\alpha_I*I_C+I_{EO}(1 – e^{V_{BE}}/V_t),\ I_E+I_B+I_C = 0$$

Where α_I is the inverted current gain of CB transistor with roles of C & E are interchanged, V_{BE} is the B to E voltage, I_{co} is the reverse saturation current of BE junction. αI and αI are related through the reverse saturation currents of the diode as

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

The above equations are resulting based on the assumption of low stage minority carrier injection, in such a case E or C currents are mainly dominated by diffusion currents, drift current is negligible as compared to drift currents.

BJT Ratings: important maximum ratings of BJT

Maximum collector current ($I_{C(max)}$)

Maximum power dissipation ($P_{D(max)}$)

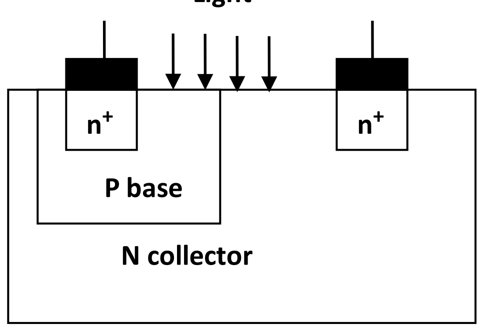
Maximum output voltage.

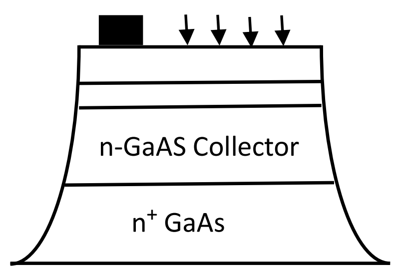
$P_{D(max)} = V_{CE} \cdot I_{C(max)}$

$= V_{CE(max)} \cdot I_C$

Photo Transistor:

Phototransistors are either three terminal (emitter, base and collector) or two terminal (emitter and collector) semiconductor device which have a light-sensitive base region. Even if all transistors show light-sensitive nature, these are specially designed and optimized for applications. These are made of diffusion and have much large collector and base regions in comparison with the normal transistors. These devices can be either homo junction structured or hetero junction structured, as shown by Fig. 1a and 1b. In homo junction phototransistors, the complete device will be made of a single material type; either silicon or germanium. However to raise their efficiency, the phototransistors can be made of non-identical materials (like GaAs) on either side of the pn junction leading to hetero junction devices. but, homo junction devices are more often used in comparison with the hetero junction devices as they are cheaper.





The behavior of phototransistors is same as to that of normal transistors except that here the affect brought about by the base voltage will be practiced due to the incident light. This can be made clear by analyzing the points below

1. The curves of phototransistors are same to those of normal transistors except that they have I_B replaced by light intensity. This means that this device have three operating regions viz., cut-off, active and saturation. This further implies that the phototransistors can be used for either switching applications or for amplification just like simple transistors.

2. The phototransistors can be configured in two different configurations namely, CC and CE, depending on the terminal which is common between the I/P & O/P terminals, same as normal transistors.

3. A small reverse saturation current, flows through the phototransistor even in the no light whose value increases with an increase in the value of temperature, a property identical to that exhibited by the ordinary transistors.

4. Phototransistors are level to permanent break due to breakdown if the voltage applied across the collector-emitter junction increases beyond its breakdown voltage, just as in the case of normal transistors.

In the case of phototransistor, the collector terminal is connected to the supply voltage and the output is obtain at the E terminal while the B terminal is be left not connected. Under this conditions, if light is made to fall on the B region of the phototransistor, then it results in the generation of electron-hole pairs which give rise to I_B. This further result in the flow of I_E through the device. This is why, here, the extent of the photo-current developed will be proportional to the luminance and is amplified by the gain of the transistor leads to a larger I_C. The output of the photo transistor depends factors like

- Wavelength of the incident light
- Area of the light-exposed CB junction
- DC current gain of the transistor.

The characteristic of a particular phototransistor can be expressed in terms of

- Luminous sensitivity defined as the ratio of photoelectric current to the incident luminous flux
- Spectral response which decides the longest wavelength which can be used as the sensitivity of the phototransistors is a function of wavelength

- **Photoelectric gain which indicates its efficiency of converting light into an amplified electrical signal**
- **Time constant which influences its response time.**

Advantages of Phototransistor

1. **compact , Simple and no much expensive.**
2. **High current.**
3. **Sensitive to a wide range of wavelengths ranging from UV to IR through visible radiation.**
4. **Reliable and stable.**

Disadvantages of Phototransistor

1. **Cannot handle high voltages.**
2. **Affected by electromagnetic energy.**
3. **Do not permit the easy flow of electrons.**
4. **Poor high frequency response.**

Applications of Phototransistor

1. **Object detection**
2. **Encoder sensing**
3. **Security systems**
4. **Relays**