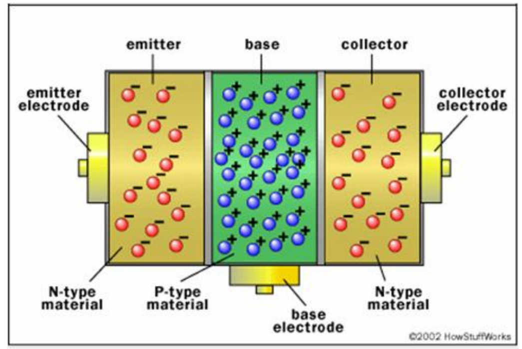
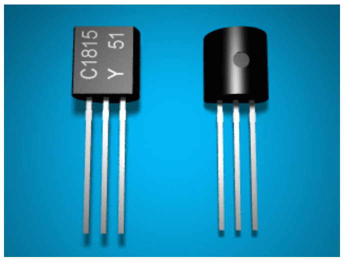
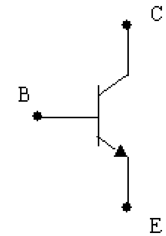
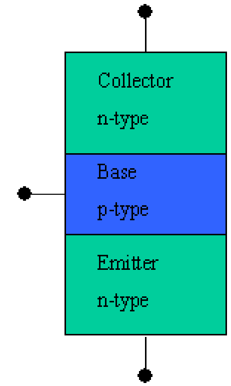


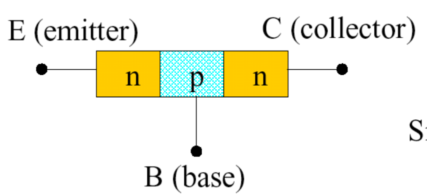


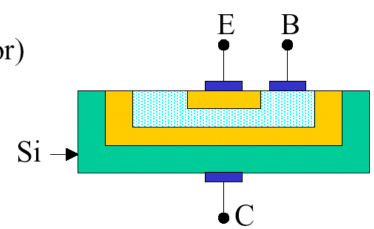
Transistors





Bardeen, Brattain and Shockley, while at Bell Laboratories, invented it in 1948 as part of a post-war effort to replace vacuum tubes with solid-state devices.





Why so called?

=> Transfer of Resistance

Transistor Types

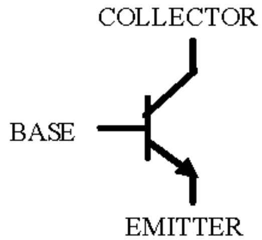
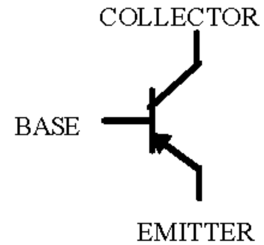
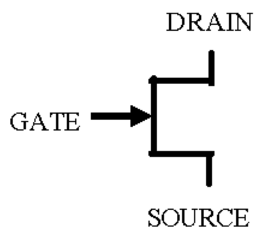
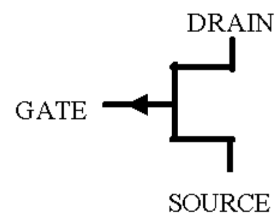
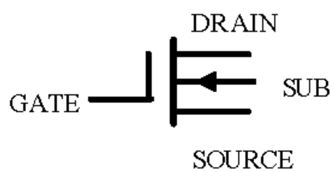
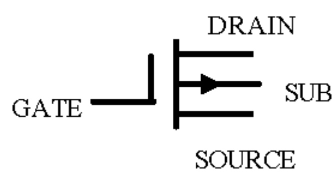
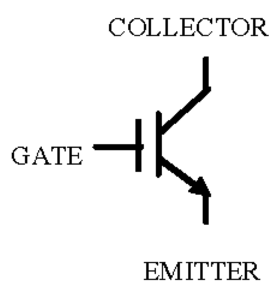
Introduction

There are three main classifications of transistors each with its own symbols, characteristics, design parameters, and applications. See below and the following pages for additional details and applications on each of these transistor types. Several special-function transistor types also exist which do not fall into the categories below, such as the unijunction (UJT) transistor that is used for SCR firing and time delay applications. These special-function devices are described separately.

- Bipolar transistors are considered *current driven* devices and have a relatively low input impedance. They are available as NPN or PNP types. The designation describes the polarity of the semiconductor material used to fabricate the transistor.

- Field Effect Transistors, FET's, are referred to as *voltage driven* devices which have a high input impedance. Field Effect Transistors are further subdivided into two classifications: 1) Junction Field Effect Transistors, or JFET's, and 2) Metal Oxide Semiconductor Field Effect Transistors or MOSFET's.

- Insulated Gate Bipolar Transistors, known as IGBT's, are the most recent transistor development. This hybrid device combines characteristics of both the Bipolar Transistor with the capacitive coupled, high impedance input, of the MOS device.

DEVICE NAME	SYMBOL		CHARACTERISTICS **And Applications**
	NPN	**PNP**	
Bipolar Transistor			A small input *current* signal flowing emitter-to-base in the transistor controls the transistor emitter-to-collector internal resistance. Used as amplifiers or switches in a wide variety of equipment ranging from small signal applications to high power output devices.
	N-CHANNEL	**P-CHANNEL**	
FET Junction Field Effect Transistor			Input *voltage* signal is applied to the gate-source junction in a reverse biased mode, resulting in a high input impedance. Input signal varies the source-to-drain internal resistance. Applications include high input impedance amplifier circuitry.
	N-CHANNEL	**P-CHANNEL**	
MOS Metal Oxide Semiconductor Field Effect Transistor			Similar to the JFET above except the input *voltage* is capacitive coupled to the transistor. The device is easily fabricated, inexpensive, and has a low power drain, but is easily damaged by static discharge. Computer chips utilize CMOS
IGBT Insulated Gate Bipolar Transistor			Similar to the Bipolar NPN above except the input *voltage* is capacitive coupled to the transistor as with the MOSFET devices. Main application is as a switch for the output section of small and medium size Variable Frequency Drives (VFD's).

Bipolar Junction Transistor

Definition ;Why so called?

Bipolar transistors are called *bi*polar because the main flow of electrons through them takes place in *two* types of semiconductor material: P and N, as the main current goes from emitter to collector (or vice versa). In other words, two types of charge carriers -- electrons and holes -- comprise this main current through the transistor.

A Bipolar Junction Transistor is a Current In/Current Out Device

- **A Transistor can be thought of as a device that is active in only One Direction:**
- **It can draw more or less current through its load resistor.**
- **It can either Sink Current or it can Source Current, it Cannot do Both.**

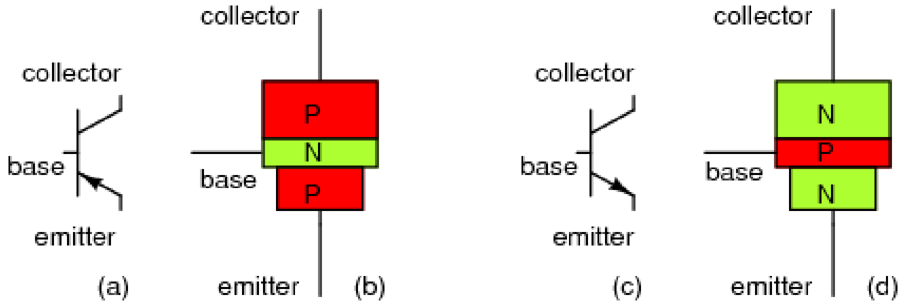
Bipolar Junction Transistor Construction

A bipolar transistor consists of a three-layer "sandwich" of doped (extrinsic) semiconductor materials, either P-N-P in Figure below (b) or N-P-N at (d).

Each layer forming the transistor has a specific name, and each layer is provided with a wire contact for connection to a circuit. The schematic symbols are shown in Figure below (a) and (c).

Construction

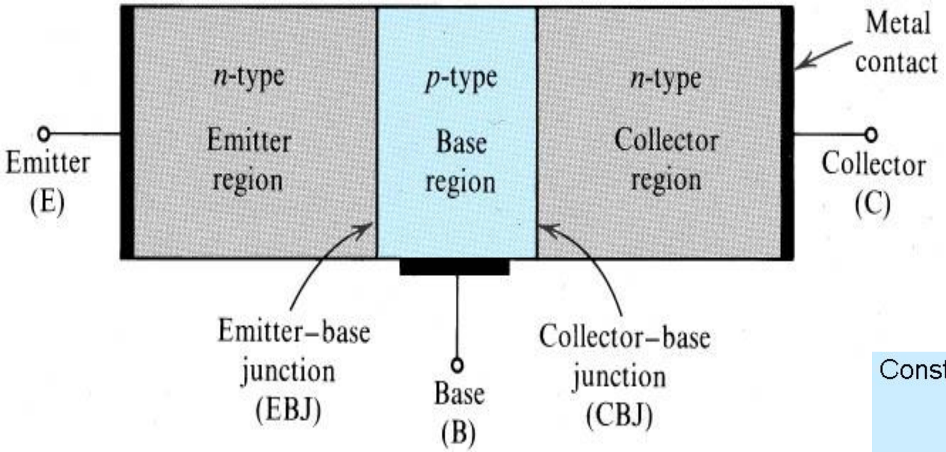
- The bipolar transistor is a three-layer semiconductor **device.**
- The base lead connects to the center semiconductor material of this three-layer device. The base region is dimensionally thin compared to the emitter and collector regions.
- Two PN (diode) junctions exist within a bipolar transistor. One PN junction exists between the emitter and the base region, a second exists between the collector and the base region. (See How to Test a Bipolar Transistor on Sheet 4.)

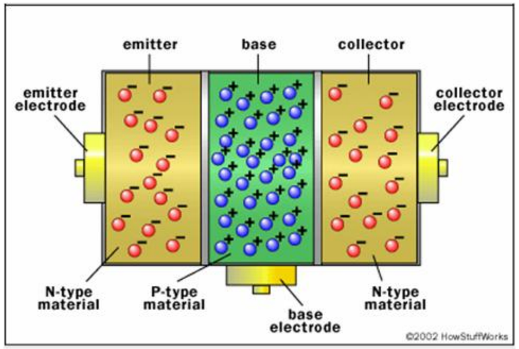


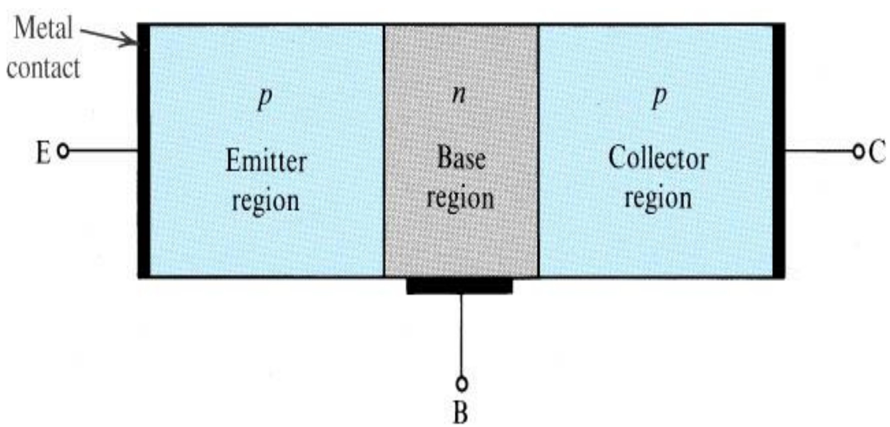
BJT transistor: (a) PNP schematic symbol, (b) construction (c) NPN symbol, (d) construction.

- **Emitter is heavily doped and has a moderate area as it has to provide the charge carriers for current conduction.**
- **Base is thin and very lightly doped to avoid recombination of charge carriers entering it from the emitter section.**
- **Collector is moderately doped as it has to help in providing the output current and has a large area so as to dissipate the heat developed due to the flow of a sufficiently large current.**

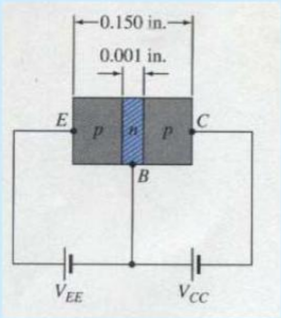
- The three leads or connecting terminals of a bipolar transistor are called the *Emitter*, *Base*, and *Collector*.
- Transistors function as current regulators by allowing a small current to *control* a larger current.
- The amount of current allowed between collector and emitter is primarily determined by the amount of current moving between base and emitter.



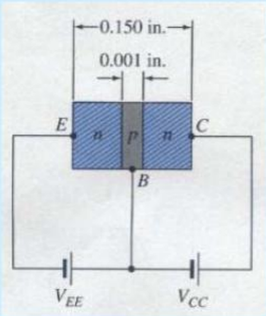




Construction of BJTs



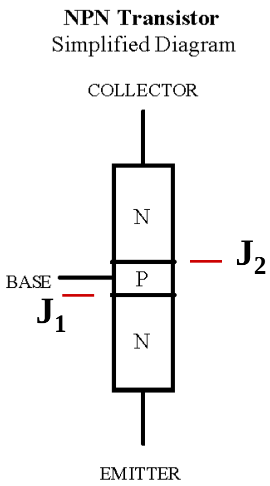
(a) pnp type and dc biasing

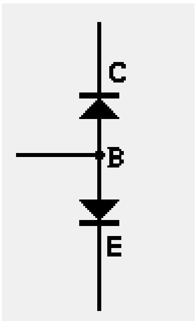


(b) npn type and dc biasing

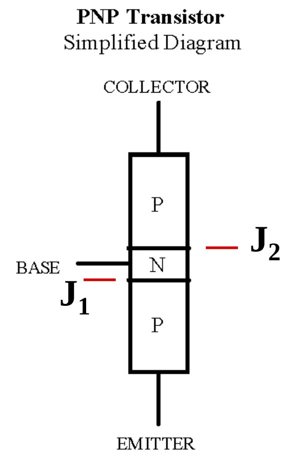
(i) Consists of three layers.
(ii) Dc biasing is necessary to establish proper region of operation for ac amplification.
(iii)The emitter layer is heavily doped, the base lightly doped and the collector only lightly doped.
(iv)The outer layers have widths much greater than the sandwiched p or n type material.
(v) E stands for Emitter, B for Base and C for Collector.
(vi) The terms bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material. (Unipolar: one carrier is employed (electron or hole , ex: diode)

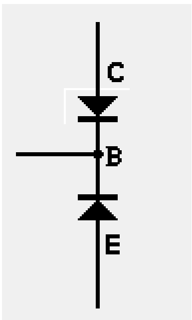
Thus, a BJT can be considered to be two PN-junctions or diodes connected back-to-back.





NPN BJT





PNP BJT

Transistor Biasing:

- **For proper BJT operation the two junctions or diodes must be biased appropriately depending upon the transistor application.**

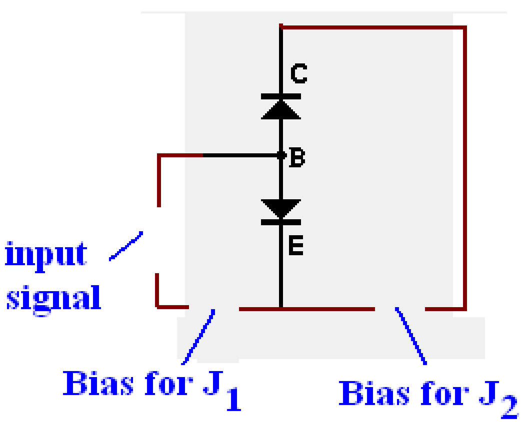
(It is necessary to bias that is apply power supply or external potential to overcome the barrier voltage) which is V_B=0.7V for Si and V_B=0.3V for Ge BJT.

- **Bias is to be applied across (1) the E-B jn or input junction (2) the C-B jn or output junction**
- **The two junctions are biased (according to BJT application) in a way that the junctions are either:**

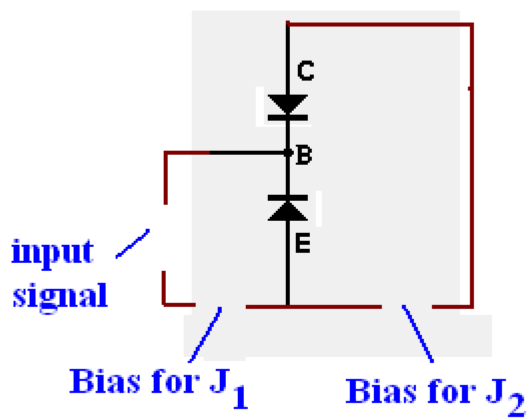
(1) forward biased and /or (2) reverse biased.

Biasing Arrangements according to BJT applications:

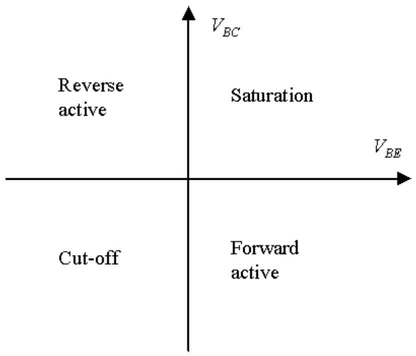
BJT Applications	Emitter-Base jn (input jn J_1)	Collector-Emitter jn (output jn J_2)	BJT Operating Mode/region
OFF-Switch	Reverse-Biased	Reverse-Biased	Cut-OFF (Input current I_B=0, Output Current I_C=0)
ON-Switch	Forward-Biased	Forward-Biased	Saturation (Input current I_B flows, Output Current I_C =maxm value)
Amplifier	Forward-Biased	Reverse-Biased	Active (Input current I_B flows, Output Current I_C flows proportional to input current)



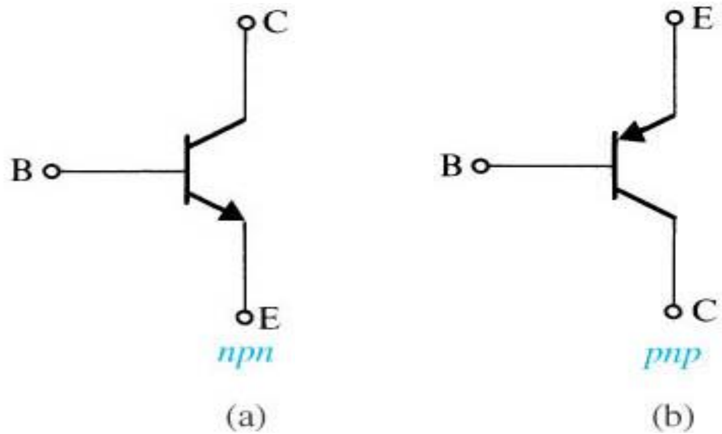
NPN BJT



PNP BJT



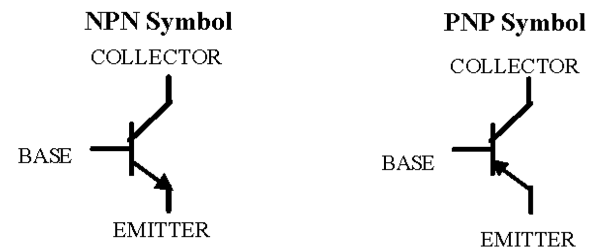
Circuit Symbols for BJTs



The emitter is distinguished by the arrowhead.

Bipolar Transistor Symbols

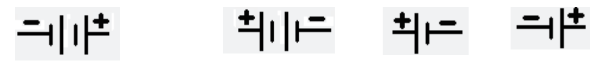
- The arrow is always on the emitter lead and points in the direction of *conventional* current flow (positive-to-negative). As with the diode, the nose of the arrow points to the negative, or N-Type semiconductor material, and the tail of the arrow is toward the P-Type material.
- The arrow on the NPN points away from the base. (Remember as NPN = Not Pointing iN.)
- The arrow on the PNP points toward the base. (Remember as PNP = Pointing iN Pointer.)



Arrows indicate the direction of conventional current flow.

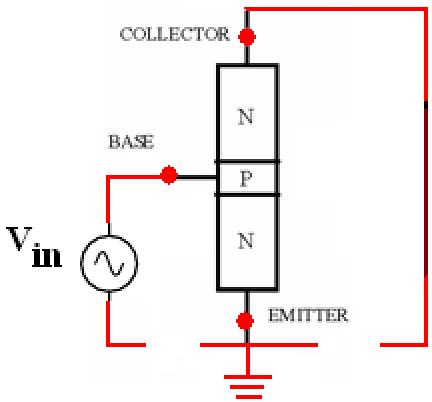
Conventional current direction is the same as direction of hole flow but opposite to the direction of electron flow.

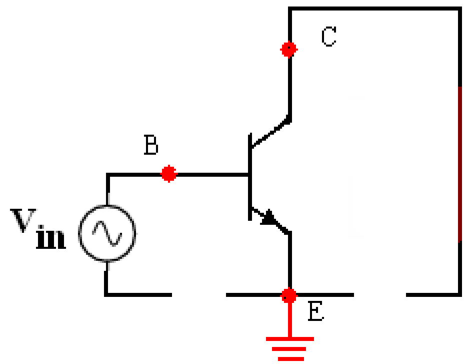
Draw the diagrams of various Biasing arrangements:

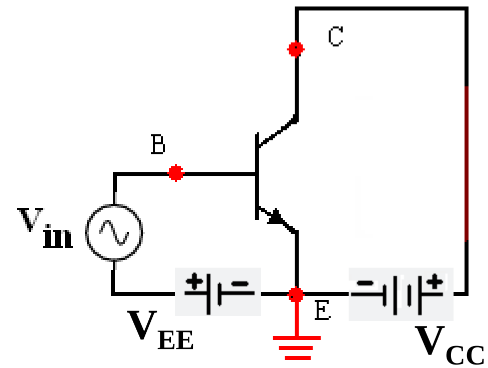


V_{CC}

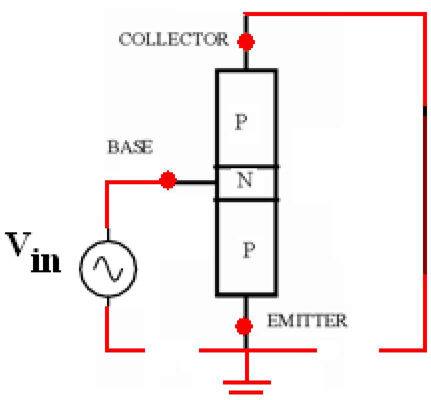
V_{EE}

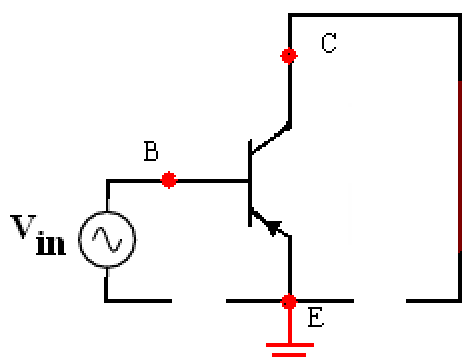


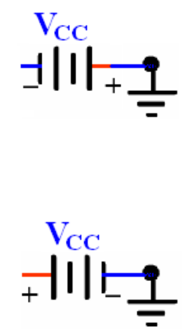




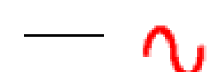
NPN BJT biased in Active mode





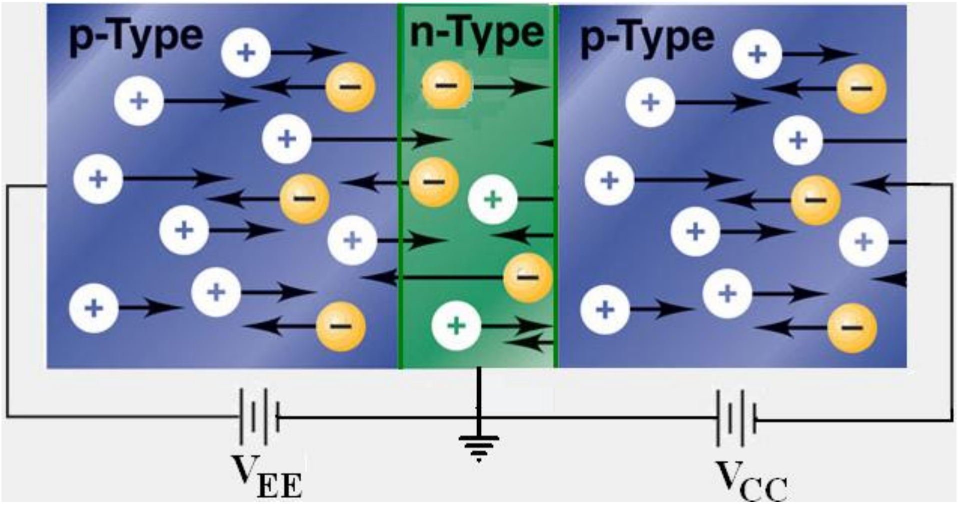


I_E

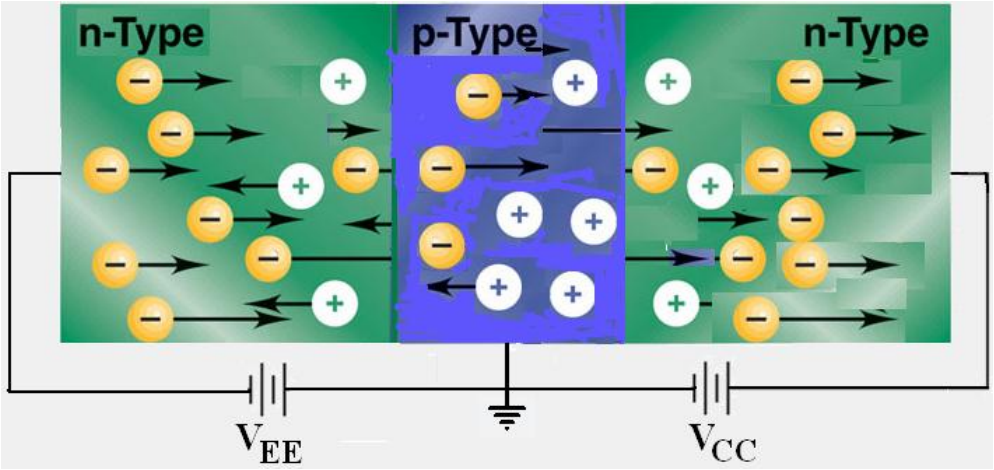


$V_{E\,B}$ =0.7V

Working or Operation of an NPN BJT

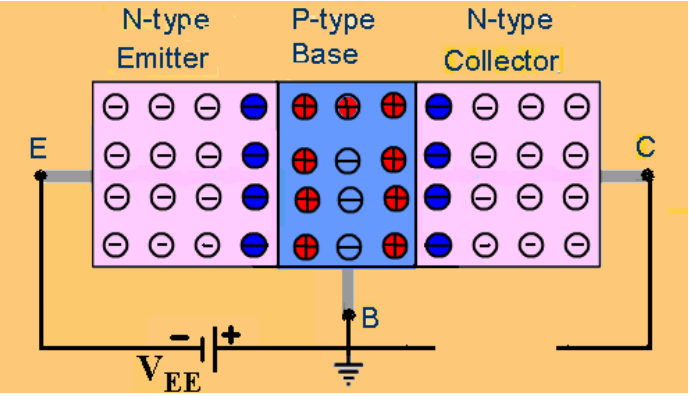


Working or Operation of an PNP BJT

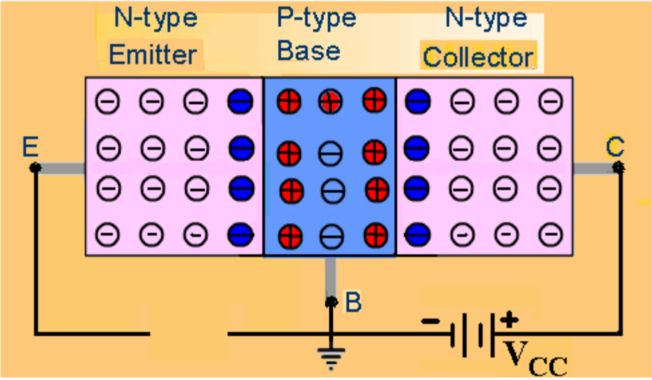


Working or Operation of an NPN BJT

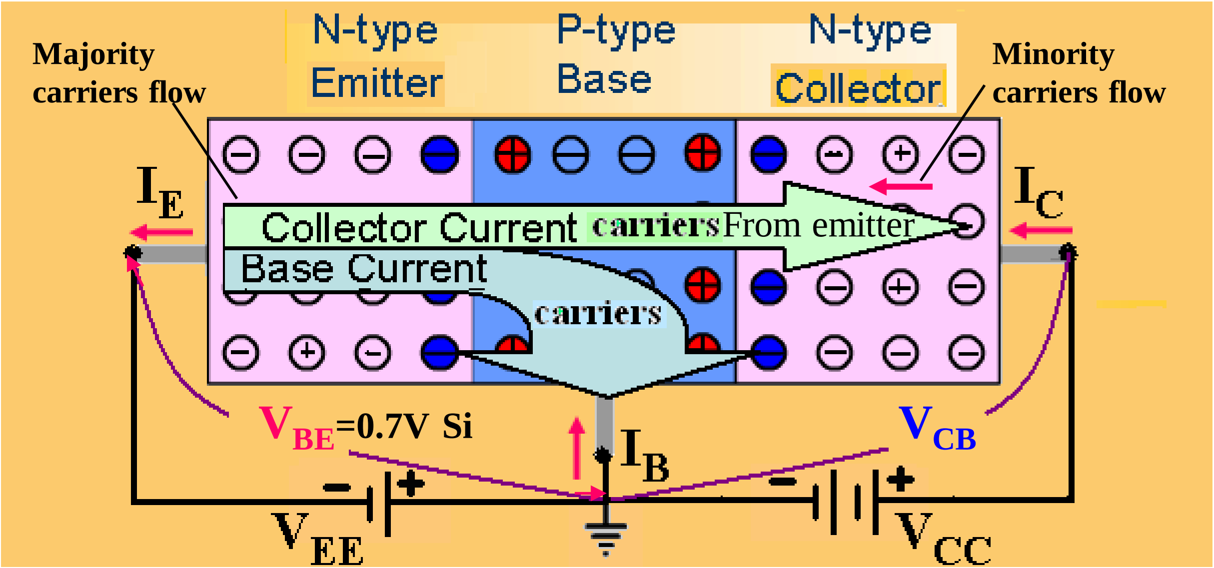
For a BJT (NPN or PNP) to function or operate or work properly the two diodes constituting the BJT must be biased appropriately. To understand the operation or working of a BJT it is always studied in the forward-active mode or as an Amplifier and hence biased accordingly.



→ Input diode F.B

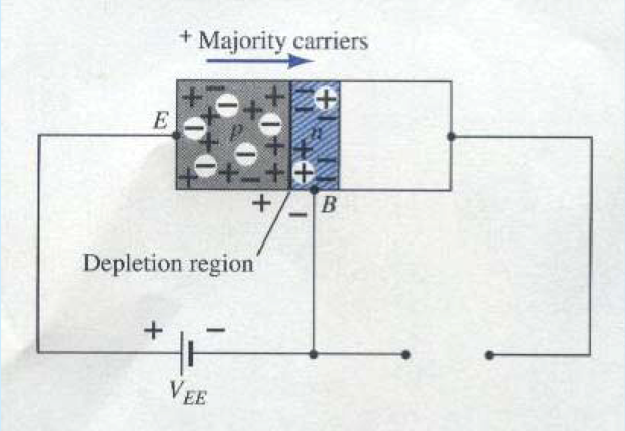


→ Output diode R.B.



NPN BJT biased to work as an Amplifier in Forward-Active mode.

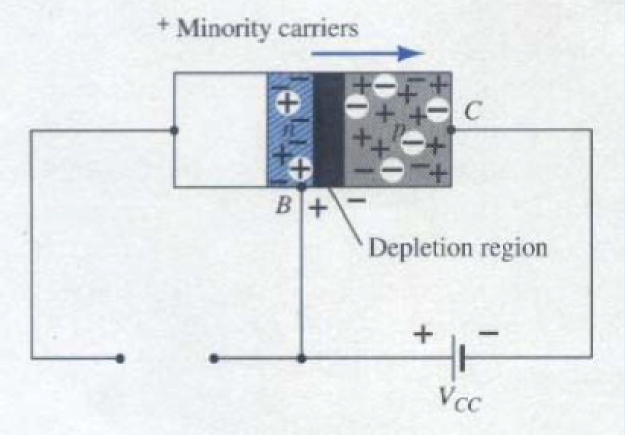
Operation of BJTs



Forward biased junction of a pnp transistor

The pnp transistor shown in this figure has been redrawn without the base-to-collector bias.

In this figure, the emitter-to-base is in the situation of forward-biased.
(p type is connected to +ve voltage terminal)
(n type is connected to –ve voltage terminal)
Here, the depletion region has been reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from the p- to the n-type material.



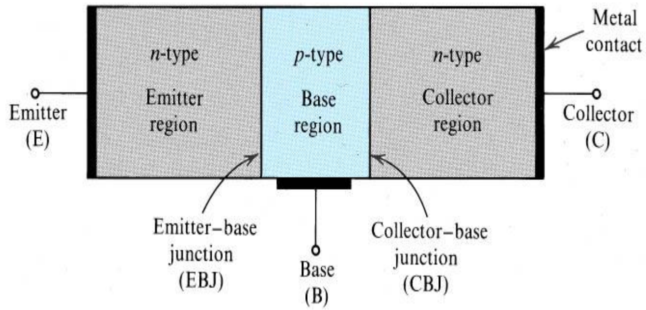
Reversed biased junction of a pnp transistor

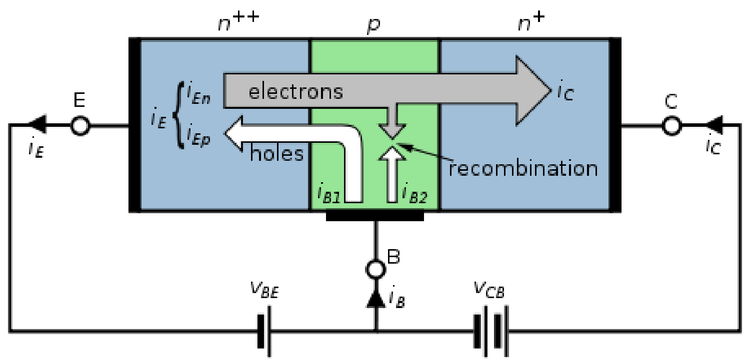
The pnp transistor shown in this figure has been redrawn without the emitter-to-base bias.

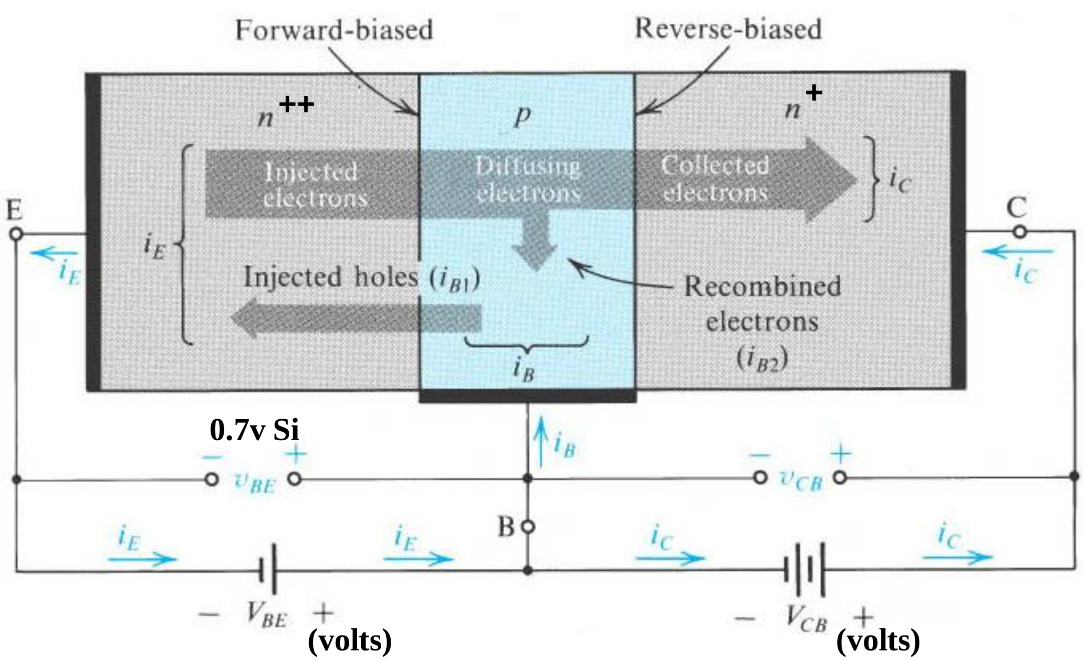
In this figure, the base-to-collector is in the situation of reversed biased.

Here, the flow of majority carriers is zero, Resulting in only a minority carrier flow.

Working or Operation of an NPN BJT







I_E is the Emitter Current due to the majority charge carriers (e-s in N-type Emitter) flowing from emitter towards collector through the base

I_E= 100% total current from emitter

I_B is the Base Current formed by the re-combination of the charge carriers entering the base from the emitter. Since the base is very lightly doped and is very thin , hence only a few re-combinations occur and the resultant base current is very small (µA) only about 2% of I_E.

I_C is the Collector Current formed by the fraction (98%) of majority charge carriers coming from the emitter plus some majority carriers present in the collector it self.

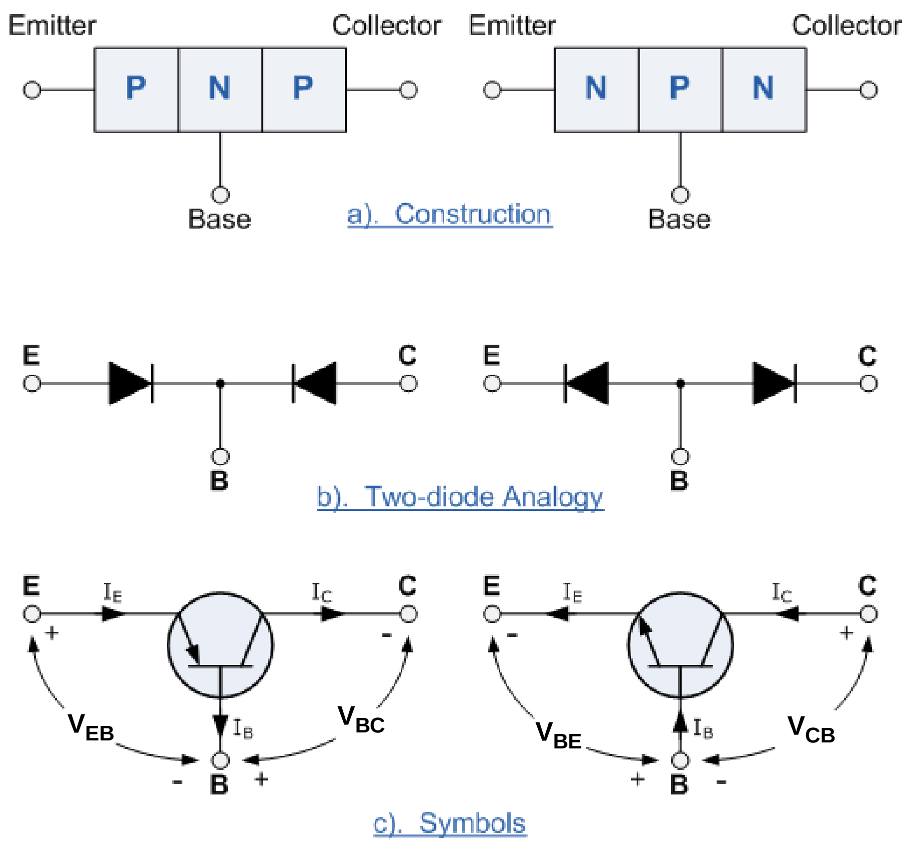
$$\underset{\text{mA}}{I_E} = \underset{\mu\text{A}}{I_B} + \underset{\text{mA}}{I_C}$$

$$100\% = 2\% \quad 98\%$$

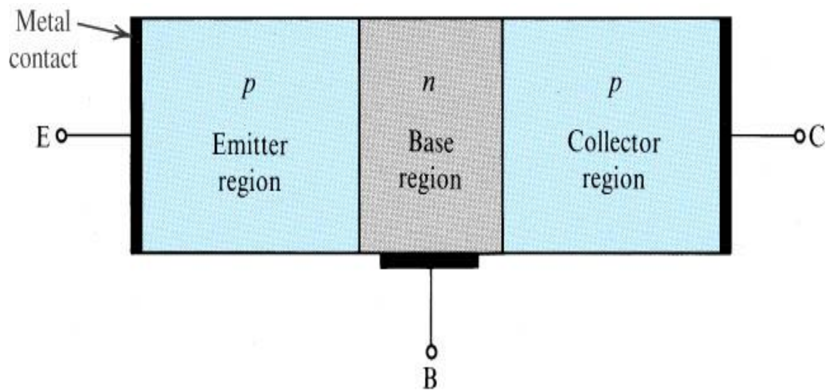
$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$

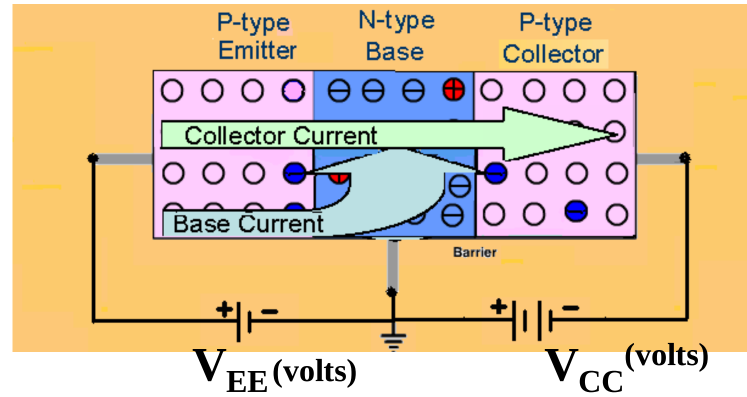
•I_{CO} = I_C **current with emitter terminal open and is called leakage current.**

Polarity and Method of naming the voltage drops across the input and output junctions of PNP and NPN transistors:

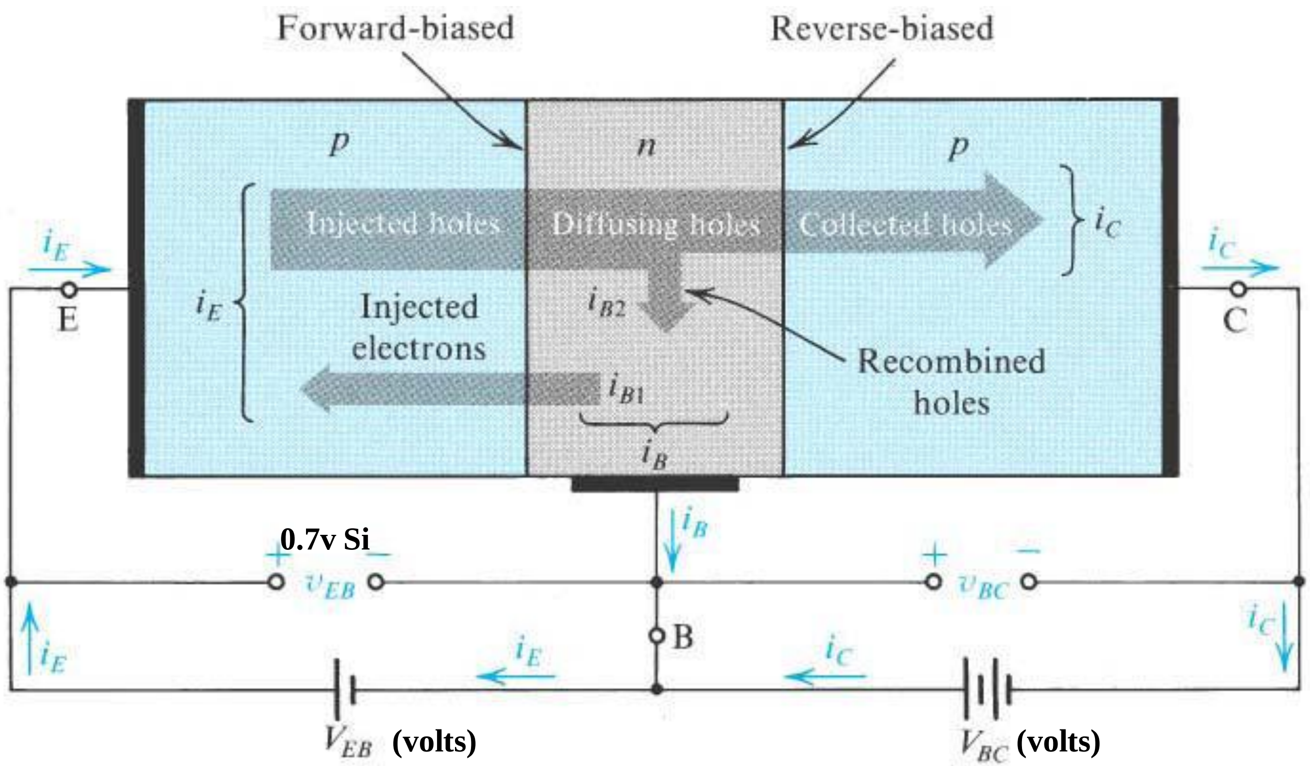


Working or Operation of an PNP BJT



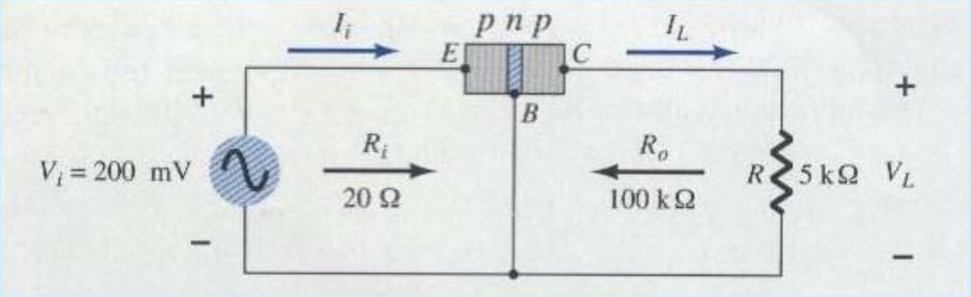


Ref: KFUPM



(volts)

Transistor Amplifying Action : Proof



$$I_i = \frac{V_i}{R_i} = \frac{200\text{ mV}}{20\ \Omega} = \mathbf{10\ mA}$$

Assume that

Also we know

$I_e = I_b + I_c$

$(I_c = I_e)$, Taking I_b= negligible

$$I_L = I_i = 10\text{ mA}$$

$$V_L = I_L R$$

$$= (10\text{ mA})(5\text{ k}\Omega)$$

$$= \mathbf{50\ V}$$

The voltage amplification is

$$A_v = \frac{V_L}{V_i} = \frac{50\text{ V}}{200\text{ mV}} = \mathbf{250}$$

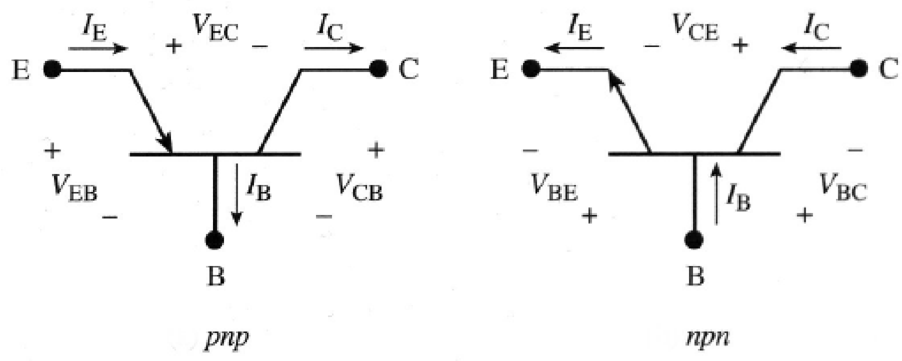
For the common-base configuration,
the ac input resistance can be determined from the input characteristics curve, while

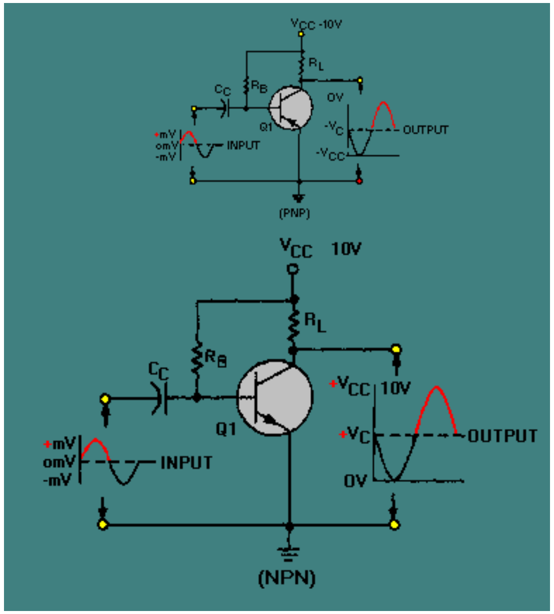
the ac output resistance can be determined from the output characteristics curve.

We will find that the input resistance is quite small typically varies from 10 to 100 Ohm (forward-biased), and

The output resistance is quite high typically varies from 50kiloOhm to 1 MegaOhm (reverse-biased).

Bipolar Junction Transistor Fundamentals





$$I_E = I_B + I_C$$

$$V_{EB} + V_{BC} + V_{CE} = 0$$

Transistor Configurations

There are 3 types of transistor connections or configuration in electric circuit:

a) CB (common base)
b) CE (common emitter)
c) CC (common collector)

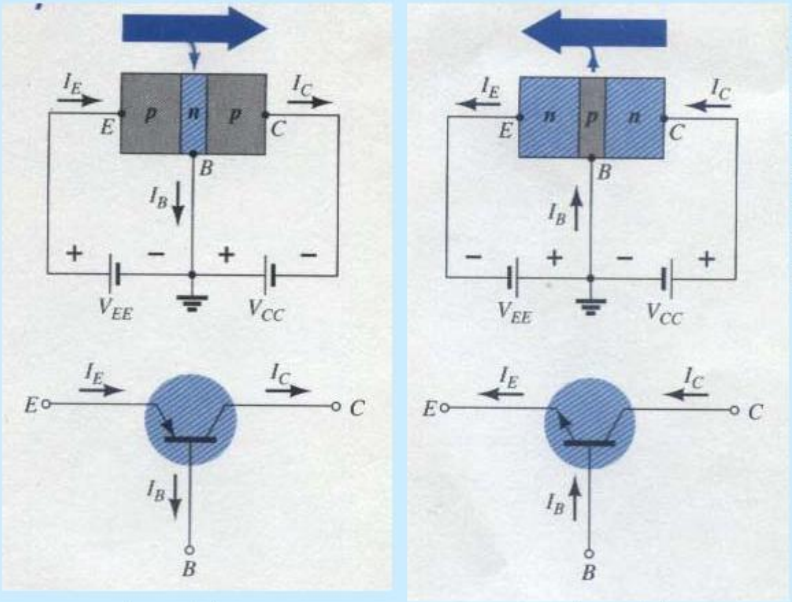
- **This configuration is based on which terminal is connected to the input signal and output signal.**
- **Table below shows the relationship between input signal and output signal with the transistor configuration.**

Configuration	Input terminal	Output terminal
CB	E	C
CE	B	C
CC	B	E

COMMON-BASE CONFIGURATION

Common-Base Configuration

COMMON-BASE CONFIGURATION



pnp transistor

npn transistor

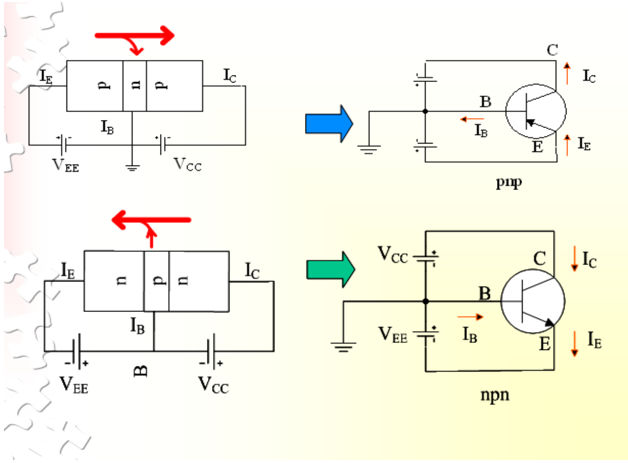
The common-base terminology is derived from the fact that the base is common to both input and output sides of the configuration. The base is the terminal closest to or at ground potential.

All current directions will refer to conventional (hole) flow rather than electron flow.

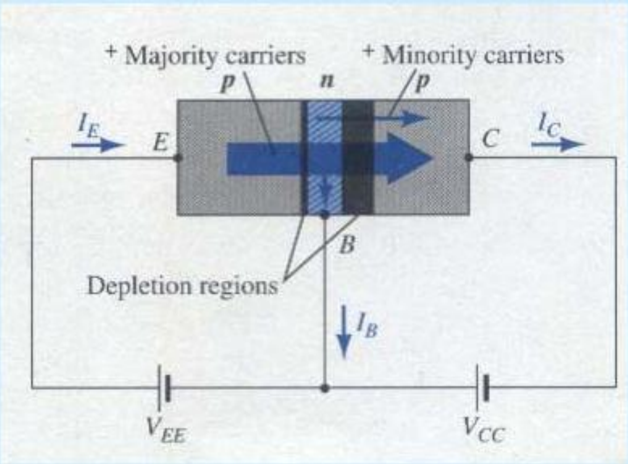
The arrow in the graphic symbol defines the direction of emitter current (conventional flow) through the device.

The direction of I_E is referred to the polarity of V_{EE} and the direction of I_C is referred to the polarity of V_{CC}.

- **Common-base terminology is derived from the fact that the :**
  - **- base is common to both input and output of the configuration.**
  - **- base is usually the terminal closest to or at ground potential.**
- **All current directions will refer to conventional (hole) flow and the arrows in all electronic symbols have a direction defined by this convention.**
- **Note that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.**



CBC: Collector Current Expression and Current Amplification Factor ‘α’



Applying KCL law, we obtain

$$\boxed{I_E = I_C + I_B}$$

The collector current is comprised of two components- the majority and minority carriers. The minority current component is called the leakage current, Ico (Ic current with emitter terminal open).

The collector current is determined in total by

$$\boxed{I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}}}$$

Current Amplification Factor

Alpha (α)

Also $$I_E = I_C + I_B$$

$$I_C \cong I_E$$

But the base current I_B is only about 2% to 5% of the emitter current I_E hence very small in comparison to I_E and collector current I_C, hence

We know that the collector current is expressed as

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$

Is the fraction 'α' of emitter current reaching the collector and the majority of carriers in collector

Leakage or minority carrier current and is vv small in comparison to the majority current hence can be neglected.

Thus, $\mathbf{I_C = \alpha I_E}$

$$\alpha = \frac{I_C}{I_E}$$ Is called the current amplification factor

In a dc mode, the levels of I_C and I_E due to the majority carriers are related by a quantity called alpha;

Is also called h_{FB} or large signal current gain for CB configuration

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

For $\boxed{I_C \cong I_E}$ alpha = 1

For practical devices the level of alpha typically extends from 0.90 to 0.998.

$$\boxed{I_C = \alpha I_E + I_{CBO}}$$

For ac mode where the points of operation moves on the characteristic curve, an ac alpha is defined by;

Change in collector current

$$\boxed{\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{constant}}}$$

Is also called h_{fb} or small signal ac current gain for CB configuration

Change in emitter current

For most situations, the magnitudes of dc alpha and ac alpha are quite close, Permitting the use of the magnitude of one for the other.

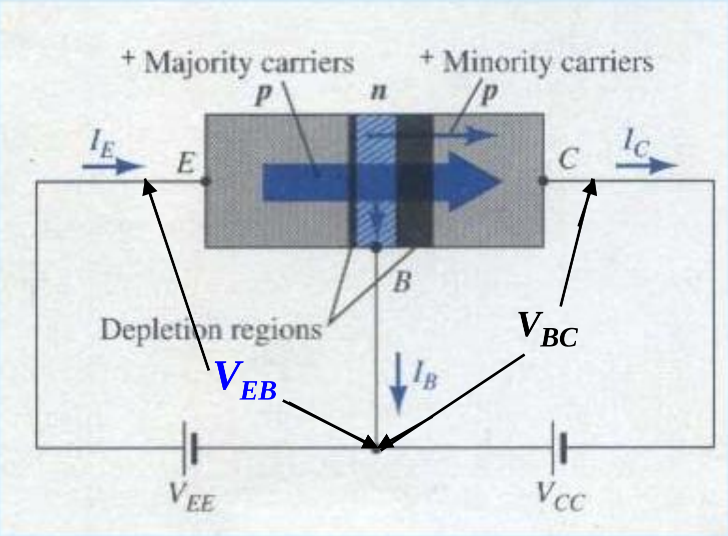
Common Base Voltage Gain

$$A_V = \frac{I_c \times R_L}{I_e \times R_{IN}} = \alpha \times \frac{R_L}{R_{IN}}$$

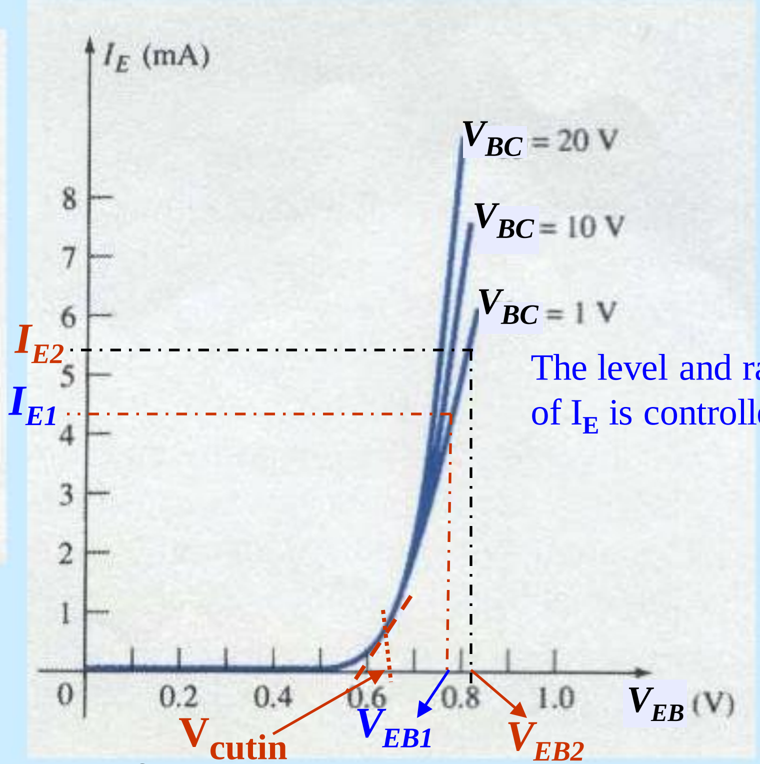
Characteristics of Common Base Configuration

Input Characteristics of CB Configuration

Input characteristics is the plot of I_E - vs - V_{EB} with output voltage V_{BC} remaining constant



Biasing pnp transistor (CB)



0.7V for Si

Input characteristics

The level and rate of change of I_E is controlled by V_{BC}

Conduction starts when V_{EB}=0.7V considering Si transistor as the input junction becomes FB at this voltage.

Hence the input characteristics is same as that of a Forward Biased PN-junction.

The transistor input resistance can be expressed as:

Static or dc input resistance

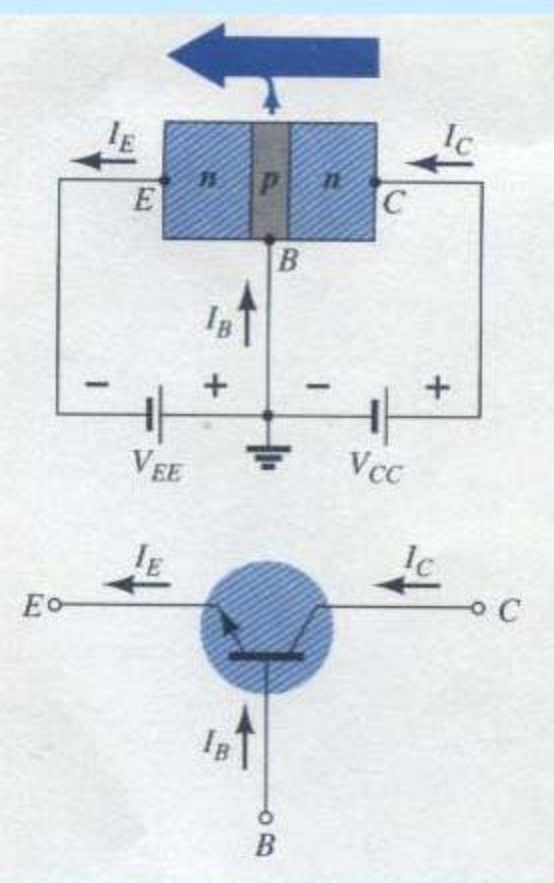
$$r_{idc} = \frac{V_{EB1}}{I_{E1}}\Bigg|_{V_{BC} = constant}$$

Dynamic or ac input resistance

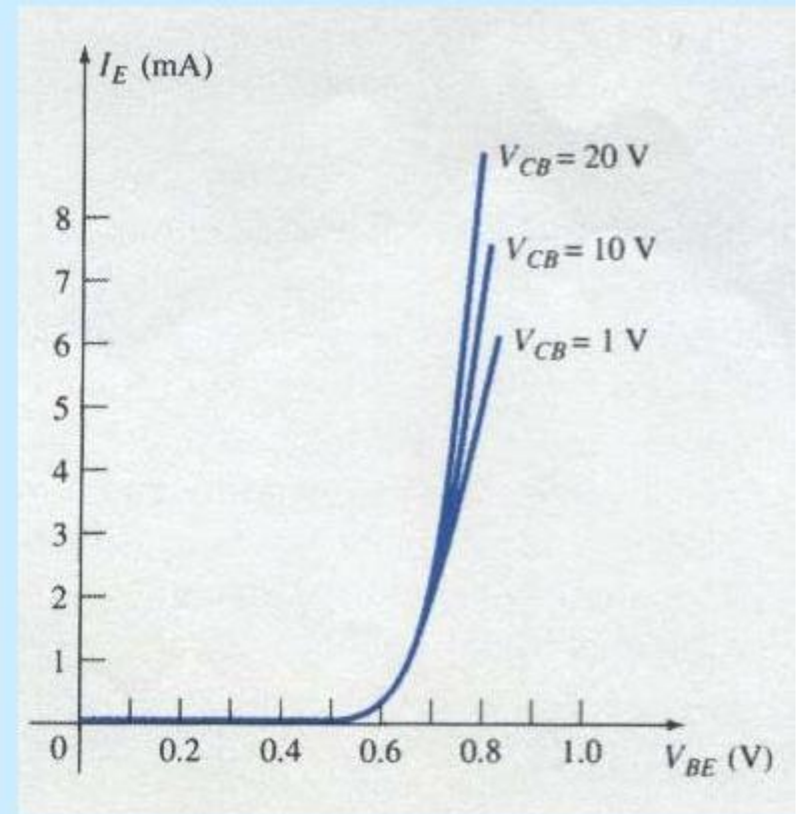
$$r_{iac} = \frac{\Delta V_{EB}}{\Delta I_E} \text{ or } r_{iac} = \frac{V_{EB2} - V_{EB1}}{I_{E2} - I_{E1}}\Bigg|_{V_{BC} = constant}$$

r_i is Only a few ohms, varies from about 10Ω to 100Ω. The input resistance r_i is small because input junction is FB.

NPN CB Configuration:



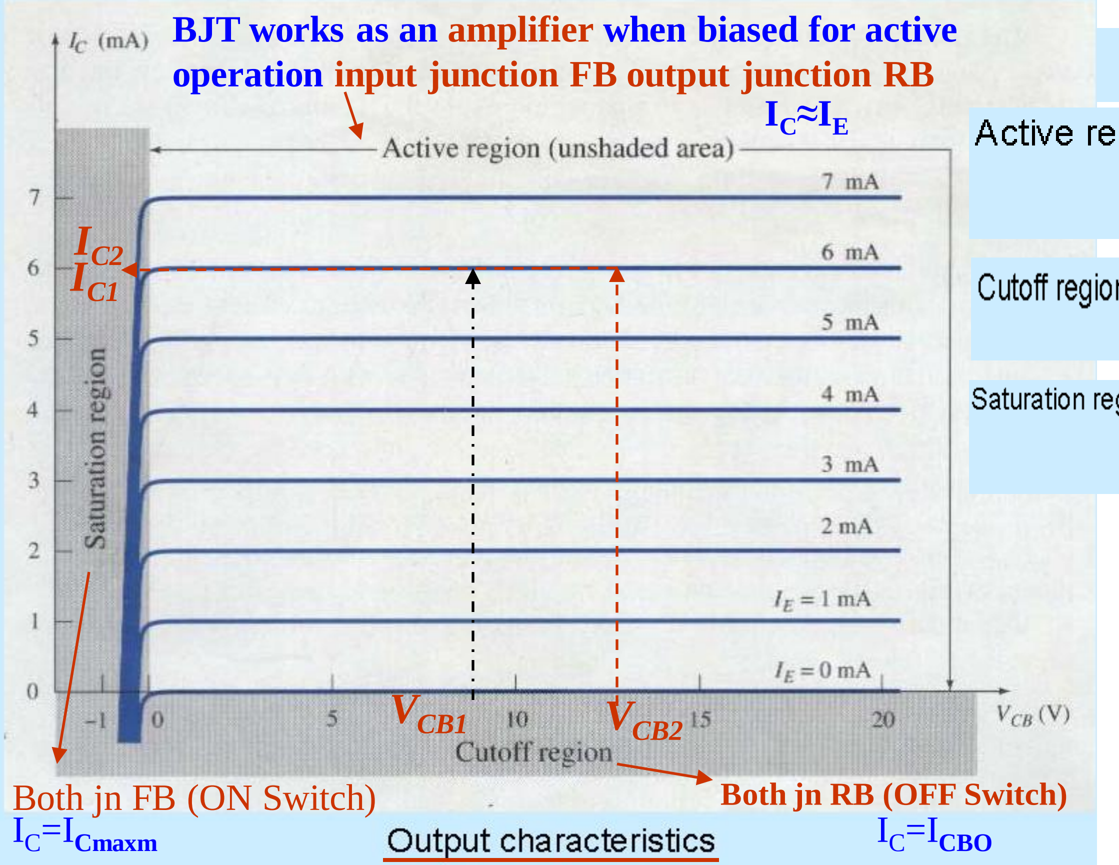
Biasing npn transistor (CB)



Input characteristics

Common Base Configuration: Output Characteristics

Output characteristics is the plot of I_C vs V_{CB} with input current I_E remaining constant



Output characteristics

$I_E = I_C + I_B$ The level of I_C will be controlled by I_E

3 Regions

Active region : the base-emitter junction is forward-biased, while the collector-base junction is reverse -biased. $I_C \approx I_E$

Cutoff region : the base-emitter junction and the collector-base junction are both reverse-biased. $I_C = I_{CBO}$

Saturation region : the region of the characteristics in the left of V_{CB} = 0V. The base-emitter junction and the collector-base junction are both forward-biased. $I_C = I_{Cmaxm}$

Output resistance r_o

The output resistance r_o is high because input junction is RB.

Also, from the curve it can be seen that the characteristic is absolutely flat indicating constant I_C.

This means that is there is no change in output current with variation in output voltage which indicates a very high resistance at the output.

r_o is very high, varies from about 1MΩ to about 10MΩ.

Static or dc output resistance

$$r_{odc} = \left. \frac{V_{CB1}}{I_{C1}} \right|_{I_E = \text{constant}}$$

Dynamic or ac output resistance

$$r_{oac} = \frac{\Delta V_{CB}}{\Delta I_C} \quad \text{or} \quad r_{oac} = \left. \frac{V_{CB2} - V_{CB1}}{I_{C2} - I_{C1}} \right|_{I_E = \text{constant}} \rightarrow \text{Very high}$$

CB Output Characteristics: Regions of Operation

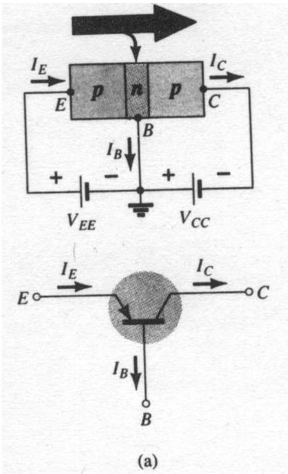
Active region	Saturation region	Cut-off region
• I_E increased, I_C increased • BE junction forward bias and CB junction reverse bias • Refer to the graf, $I_C \approx I_E$ • I_C not depends on V_{CB} • Suitable region for the transistor working as **voltage** amplifier	• BE and CB junction is forward 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}= 0 V.	• Region below the line of I_E=0 A • BE and CB is reverse bias • no current flow at collector, only leakage current

$I_E = I_B + I_C$

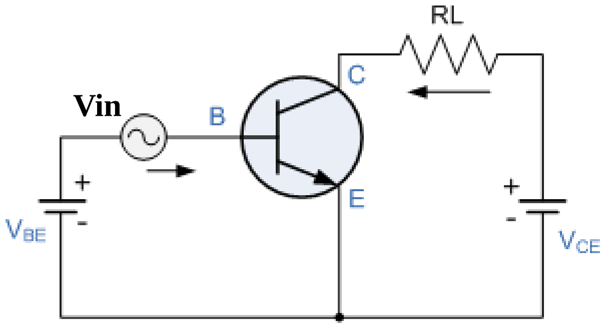
Current in base is negligible.
Current in emitter and collector is almost same.

Current gain less than unity

$\alpha = I_C/I_E$ (0.90 - 0.998)



COMMON-EMITTER CONFIGURATION



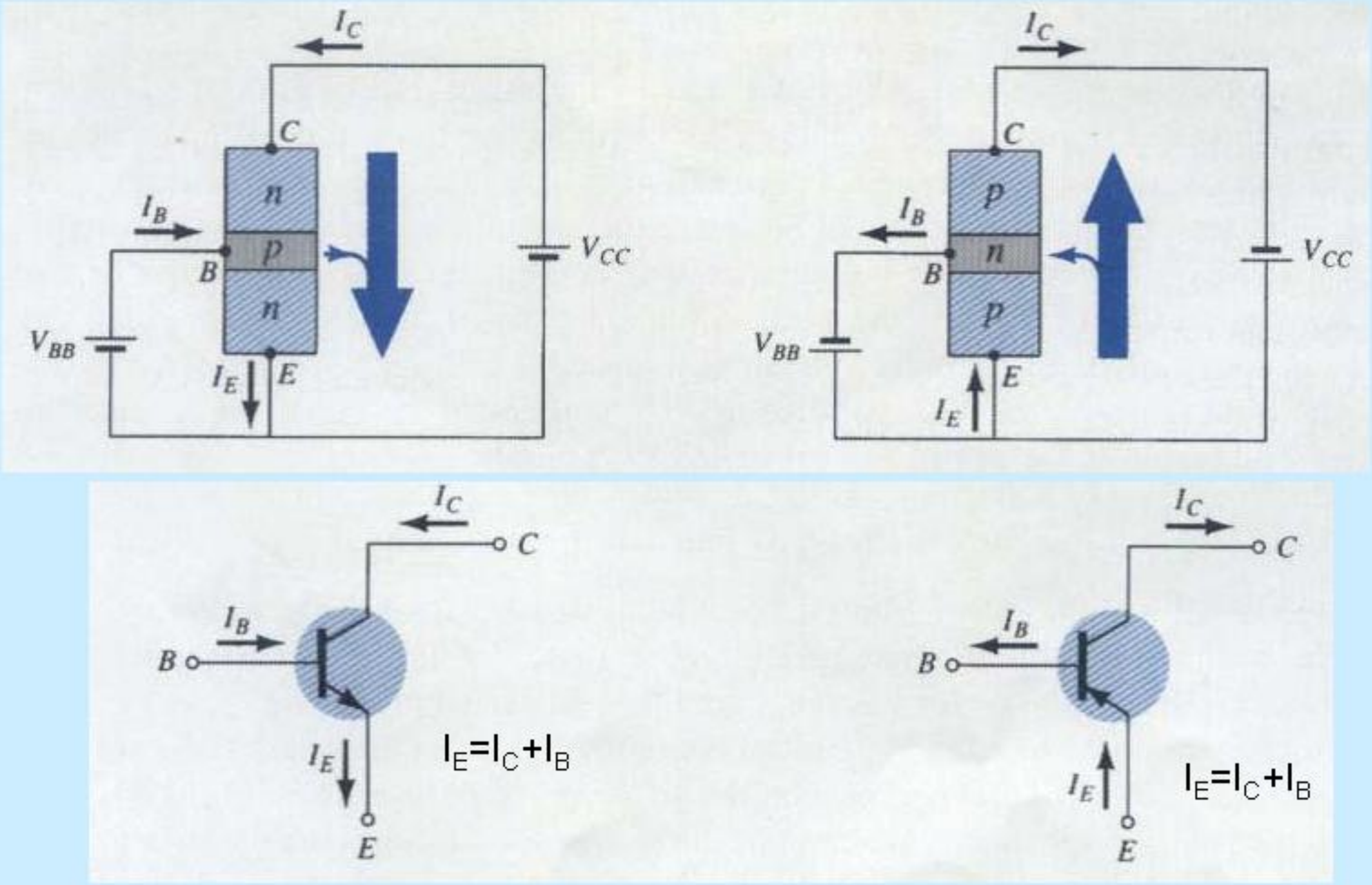
Common-emitter configuration (CE)

- It is called common-emitter configuration since :
  - emitter is common or reference to both i/p and o/p terminals.
  - emitter is usually the terminal closest to or at ground potential.

- Almost all amplifier design is using CE configuration due to the high gain for current and voltage.

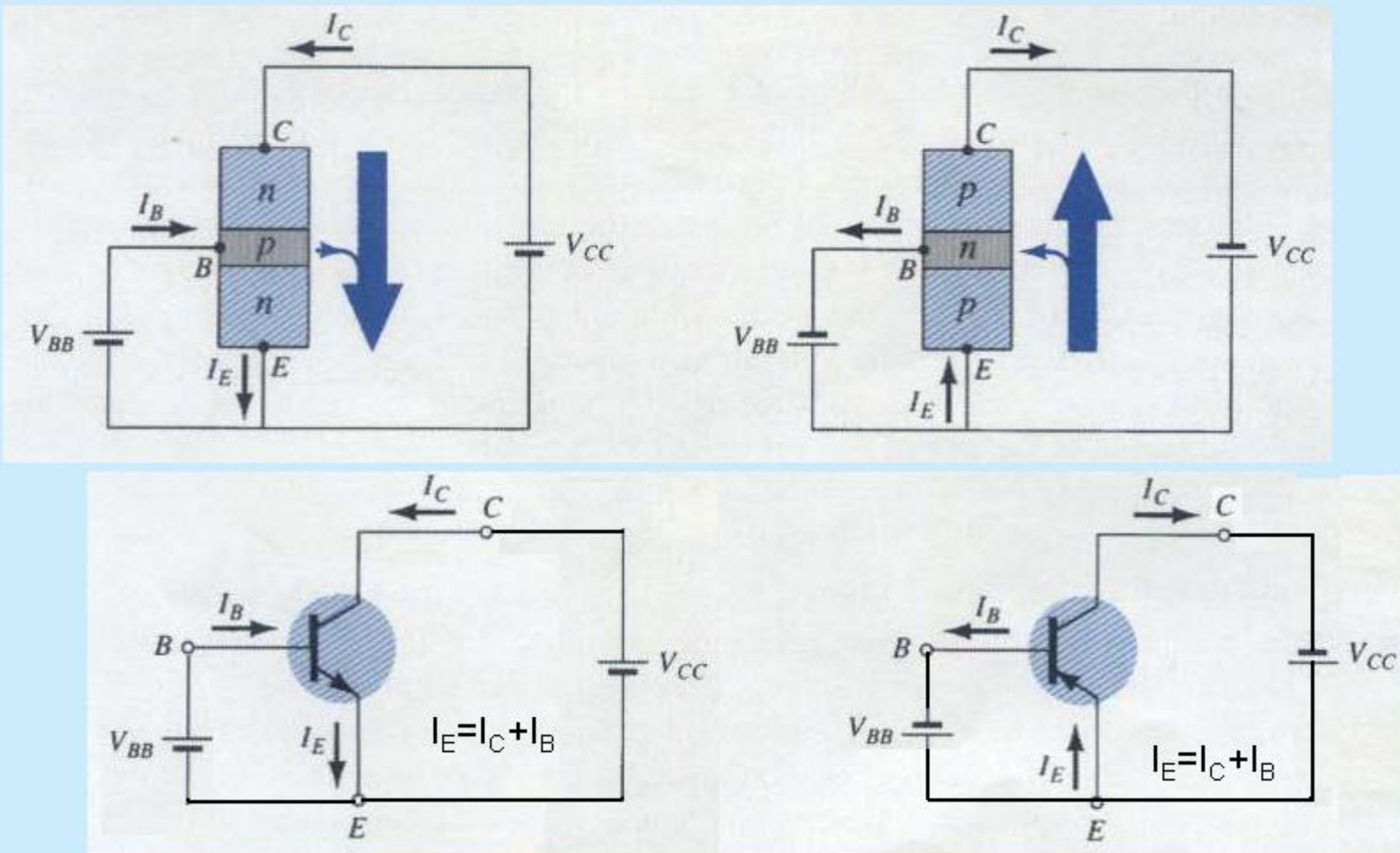
- Two set of characteristics are necessary to describe the behavior for CE ;input (base terminal) and output (collector terminal) parameters.

Common Emitter Configuration: Biasing arrangements



In this configuration, the emitter is common or reference to both the input and output Terminals. In this case, common to both the base and collector terminals.

Biasing in active mode with symbolic representations:

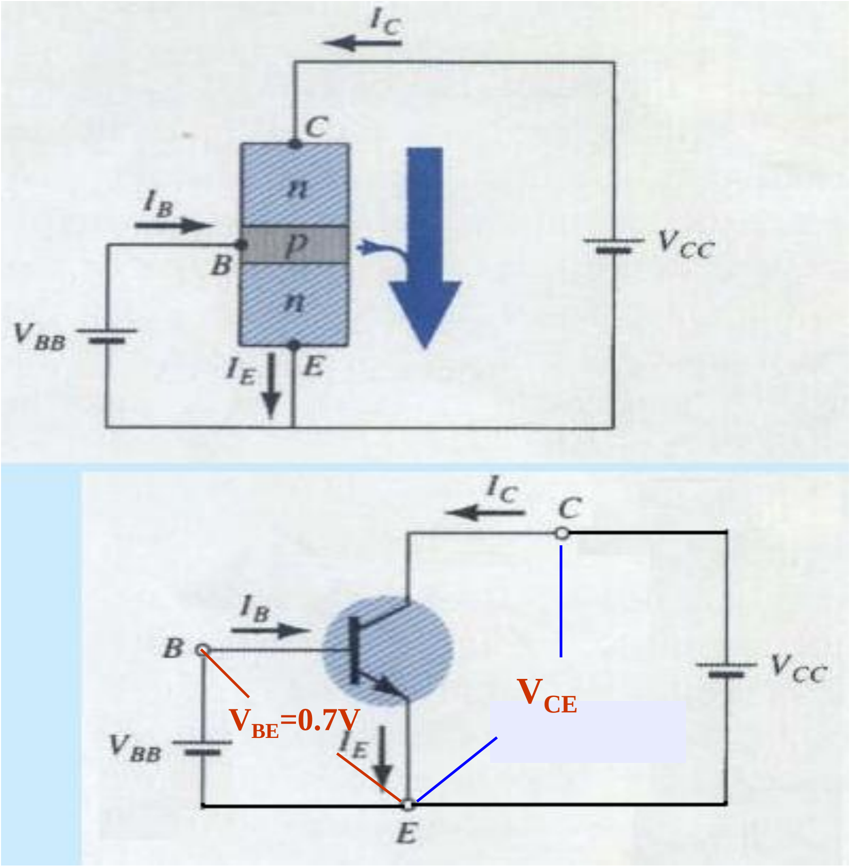


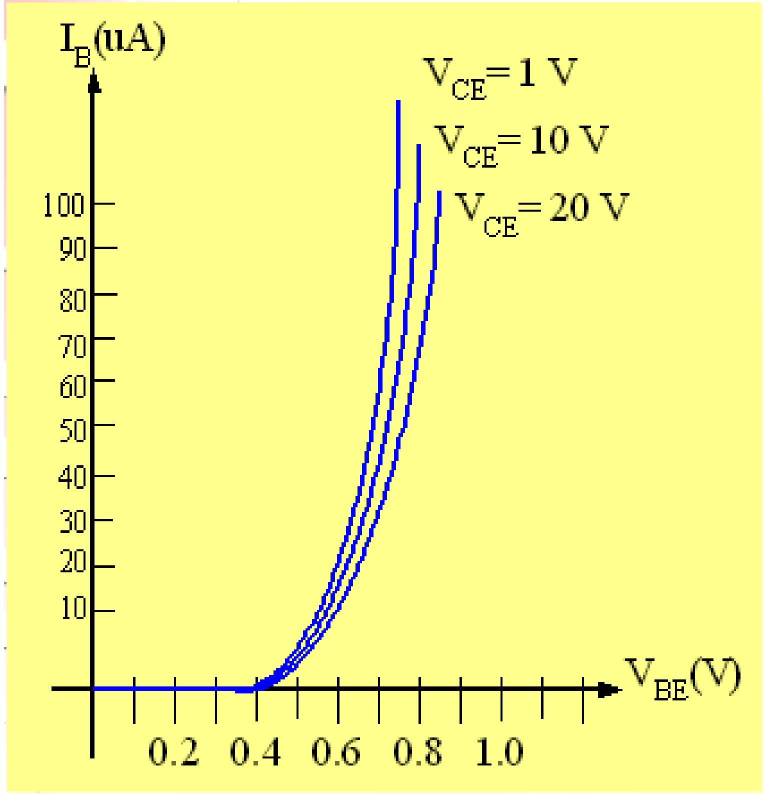
In this configuration, the emitter is common or reference to both the input and output Terminals. In this case, common to both the base and collector terminals.

Input /Output characteristics of CE Amplifier

- To describe the behavior of common-emitter amplifiers two sets of characteristics are required :
  - Input or driving point characteristics.
  - Output or collector characteristics
- The output characteristics has 3 basic regions depending on the biasing arrangements:
  - Active region –defined by the biasing arrangements (input jn FB –Output jn RB)
  - Cutoff region – region where the collector current is 0A (input jn RB –Output jn RB)
  - Saturation region- region of the characteristics to the left of V_{CB} = 0V (input jn FB – Output jn FB)

Input Characteristics of CE Configuration

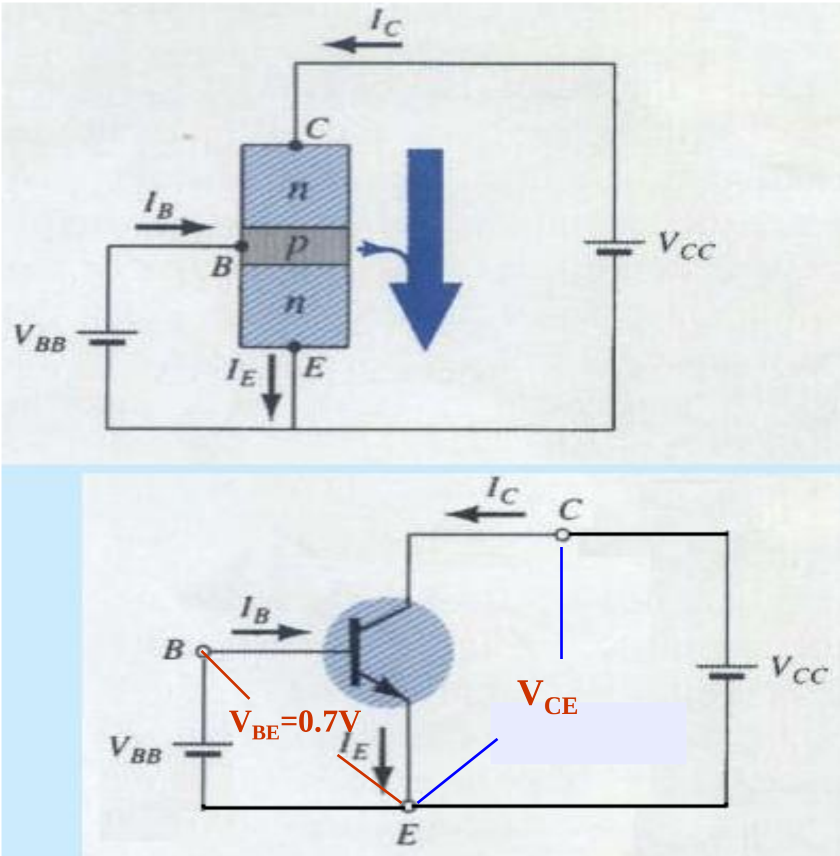


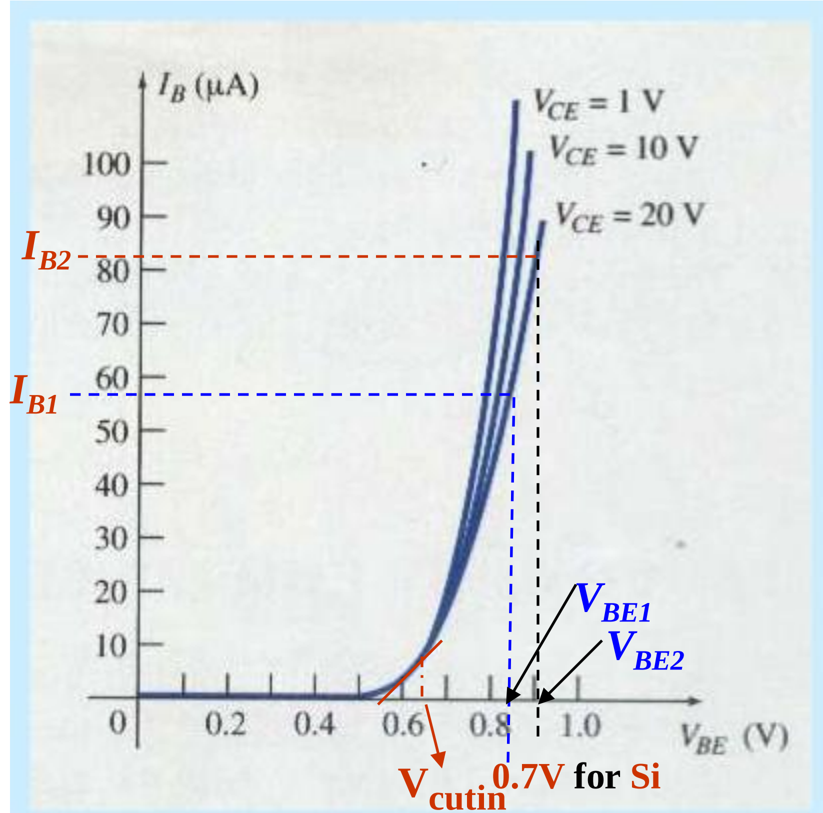


Input characteristics for a common-emitter NPN transistor

- **I_B is microamperes compared to milliamperes of I_C.**
- **I_B will flow when V_{BE} > 0.7V that is when the input jn or the base-emitter junction is forward biased for silicon and 0.3V for germanium**
- **Before this value I_B is very small and no I_B flows.**
- **Base-emitter junction is forward bias at V_{BE} > 0.7V and current conduction starts.**
- **The input characteristics is that of a FB PN-jn diode.**
- **Increasing V_{CE} will reduce I_B for different values.**

Input Characteristics of CE Configuration





CE Input characteristics
(base-emitter circuit)

Conduction starts when V_{BE}=0.7V considering Si transistor as the input junction becomes FB at this voltage.

Hence the input characteristics is same as that of a Forward Biased PN-junction.

The input resistance for CE configuration is moderately low. r_i is Only a few ohms, about to 1KΩ. The input resistance r_i has low value because input junction is FB

Static or dc input resistance

$$r_{idc} = \left.\frac{V_{BE1}}{I_{B1}}\right|_{V_{CE} = constant}$$

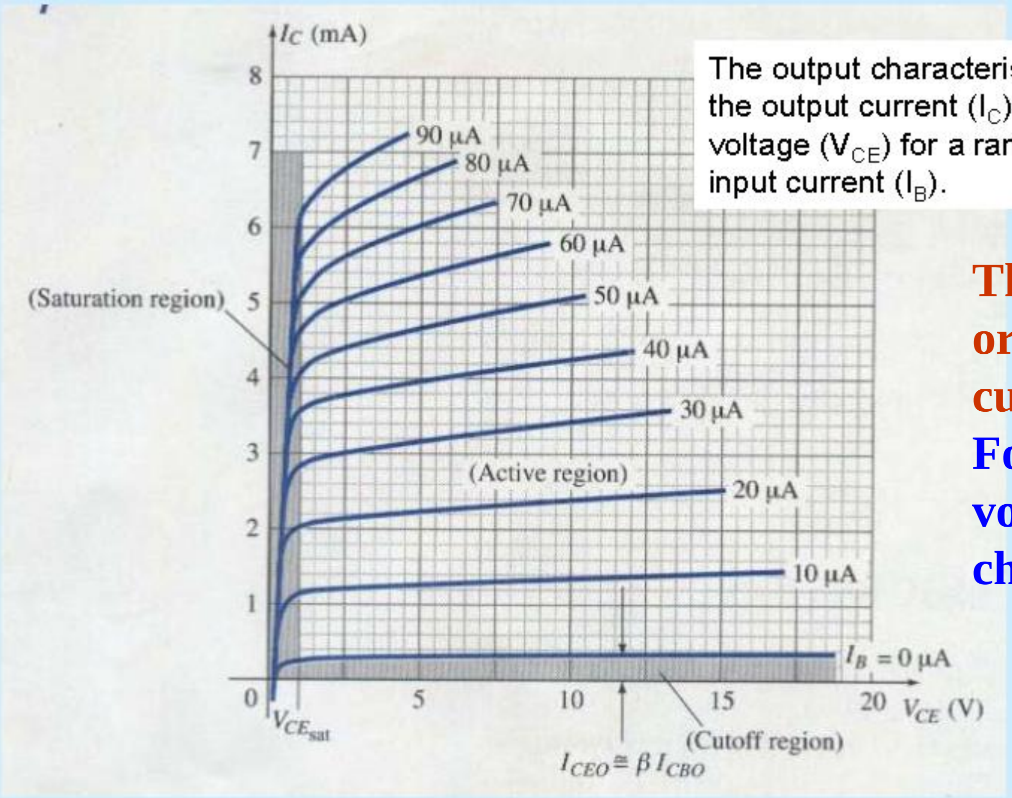
Dynamic or ac input resistance

$$r_{iac} = \frac{\Delta V_{BE}}{\Delta I_B} \text{ or } r_{iac} = \left.\frac{(V_{BE2} - V_{BE1})}{(I_{B2} - I_{B1})}\right|_{V_{CE} = constant}$$

volts

μ Amp

CE Configuration: Output Characteristics



The output characteristics are a plot of the output current (I_C) versus the output voltage (V_{CE}) for a range of values of input current (I_B).

Output characteristics (collector-emitter circuit)

The output characteristics is almost flat or constant for a particular value of input current I_B.

For a large variation in Collector emitter voltage V_{CE} there is only a very small change in collector current I_C.

This indicates that the collector current I_C is slightly controllable by variation in collector-emitter voltage V_{CE}

3 Regions

Active region : E-B itter junction is forward-biased, while C-E junction is reverse -biased. $I_C \approx I_E$

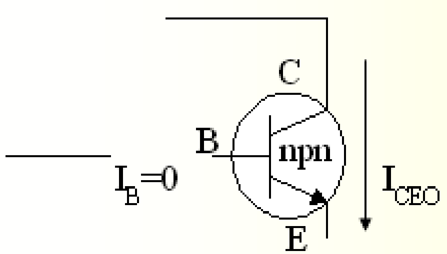
Cutoff region : E-B itter junction an C-E base junction are both reverse-biased. $I_C = I_{CEO}$ Or $I_C = \beta I_{CBO}$

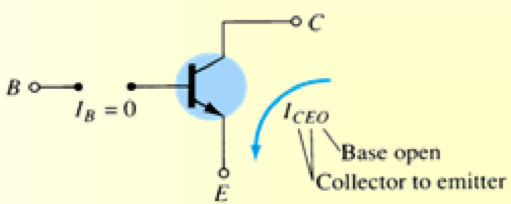
Saturation region : the region of the characteristics in **right of the V_{CE} charact** The base-emitter junction and the collector-base junction are both forward-biased. $I_C = I_{Cmaxm}$

CE Output Characteristics: Regions of Operation

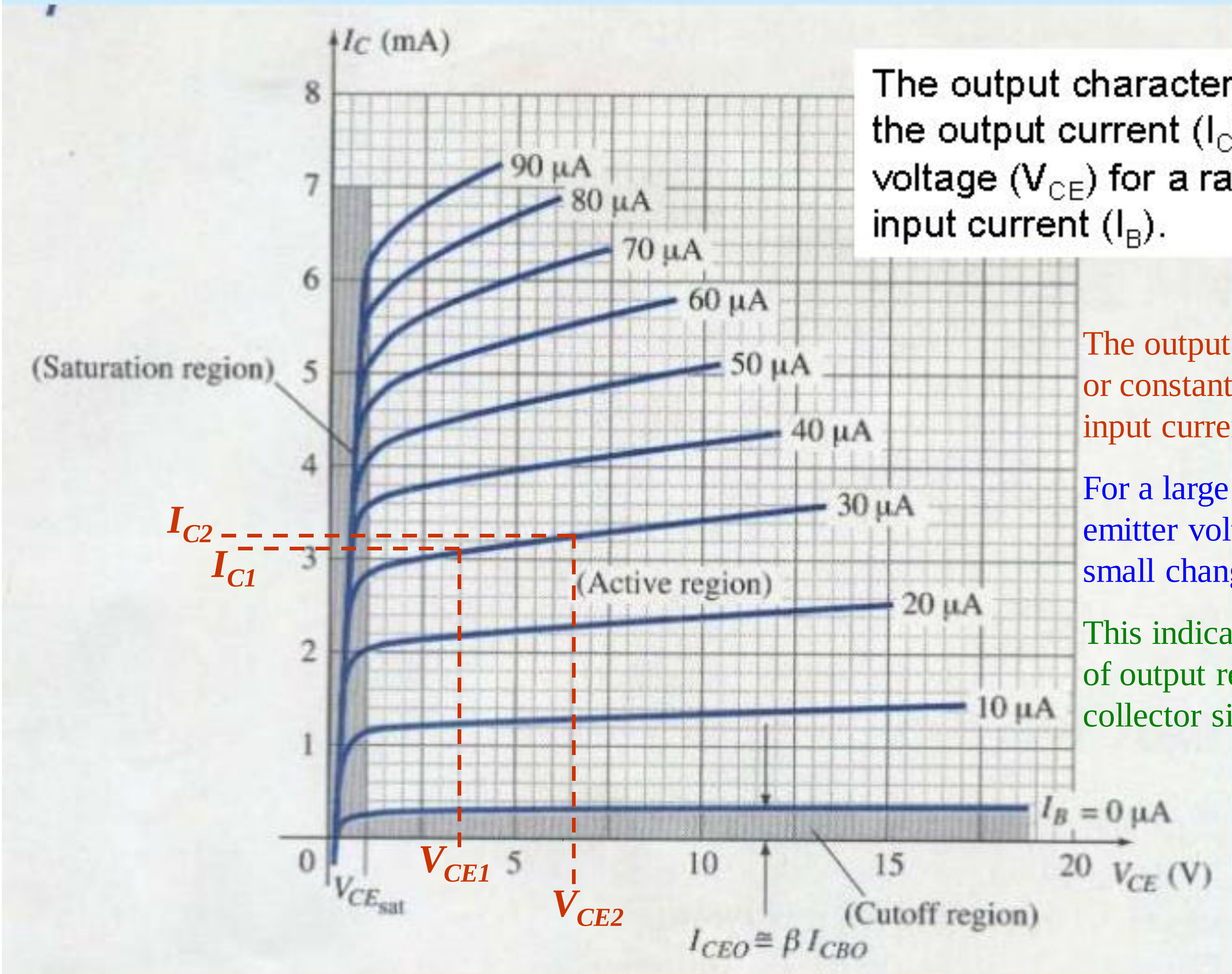
- **For small V_{CE} ($V_{CE} < V_{CESAT}$, I_C increase linearly with increasing of V_{CE}**
- **$V_{CE} > V_{CESAT}$ I_C not totally depends on V_{CE} → constant I_C**
- **I_B(μA) is very small compare to I_C (mA). Small increase in I_B cause big increase in I_C**
- **I_B=0 A → I_{CEO} flows.**
- **Noticing the value when I_C=0A. There is still some value of current flows.**

Active region	Saturation region	Cut-off region
• B-E junction is forward bias • C-B junction is reverse bias • can be employed for voltage, current and power amplification	• B-E and C-B junction is forward bias, thus the values of I_B and I_C is too big. • The value of V_{CE} is so small. • Suitable region when the transistor as a logic switch. • NOT and avoid this region when the transistor as an amplifier.	• region below I_B=0μA is to be avoided if an undistorted o/p signal is required • B-E junction and C-B junction is reverse bias • I_B=0, I_C not zero, during this condition I_C=I_{CEO} where is this current flow when B-E is reverse bias.





CE Configuration: Output Characteristics & Output Resistances



Output characteristics (collector-emitter circuit)

The output characteristics are a plot of the output current (I_C) versus the output voltage (V_{CE}) for a range of values of input current (I_B).

The output characteristics is almost flat or constant for a particular value of input current I_B.

For a large variation in Collector emitter voltage V_{CE} there is only a very small change in collector current I_C.

This indicates that there is a small value of output resistance offered by the collector side. **about to 10KΩ**

Static or dc output resistance

$$r_{odc} = \left.\frac{V_{CE1}}{I_{C1}}\right|_{I_B = \text{constant}}$$

Dynamic or ac output resistance

$$r_{oac} = \frac{\Delta V_{CE}}{\Delta I_C} \quad \text{or} \quad r_{oac} = \left.\frac{V_{CE2} - V_{CE1}}{I_{C2} - I_{C1}}\right|_{I_B = \text{constant}}$$

Moderately high

Collector current expression and Current Amplification Factor for CE Configuration:

Active region : the base-emitter junction is forward-biased, while the collector-base junction is reverse-biased.
The active region can be employed for voltage, current and power amplification.

Cutoff region : I_C is not equal to zero when I_B is zero.

For the common-base configuration, when the input current I_E was equal to zero, the collector current was equal only to the reverse saturation current I_{CO}.

Why?

$$I_C = \alpha I_E + I_{CBO}$$

$I_E = I_C + I_B$

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

Rearrange,

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

If I_B=0A, alpha=0.996

$$I_C = \frac{\alpha(0\text{ A})}{1-\alpha} + \frac{I_{CBO}}{1-0.996}$$
$$= \frac{I_{CBO}}{0.004} = 250 I_{CBO}$$

If I_B=0A & I_{CBO}= 1microampere

I_C = 250(1microAmpere)=0.25mA

$$\boxed{I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B = 0\,\mu\text{A}}}$$

Using an equivalence of

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

We find that

$$I_{CEO} = (\beta + 1) I_{CBO}$$

$$\boxed{I_{CEO} \cong \beta I_{CBO}}$$

Comparing current amplification factors for CB and CE configurations

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

$$\boxed{\mathbf{I_C = \beta I_B + I_{CEO}}}$$

Beta

In a dc mode, the levels of I_C and I_B are related by aquantity called beta;

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

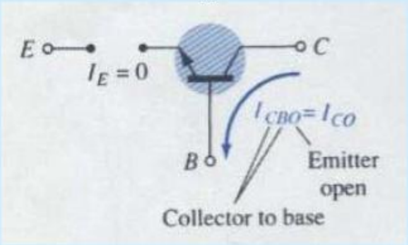
For $\boxed{I_C \cong I_E}$ alpha = 1

For practical devices the level of beta typically extends from 50 to 400.

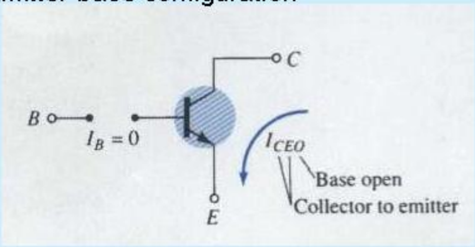
For ac mode where the points of operation moves on the characteristic curve, an ac beta is defined by;

$$\boxed{\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE} = \text{constant}}}$$

Common-base configuration



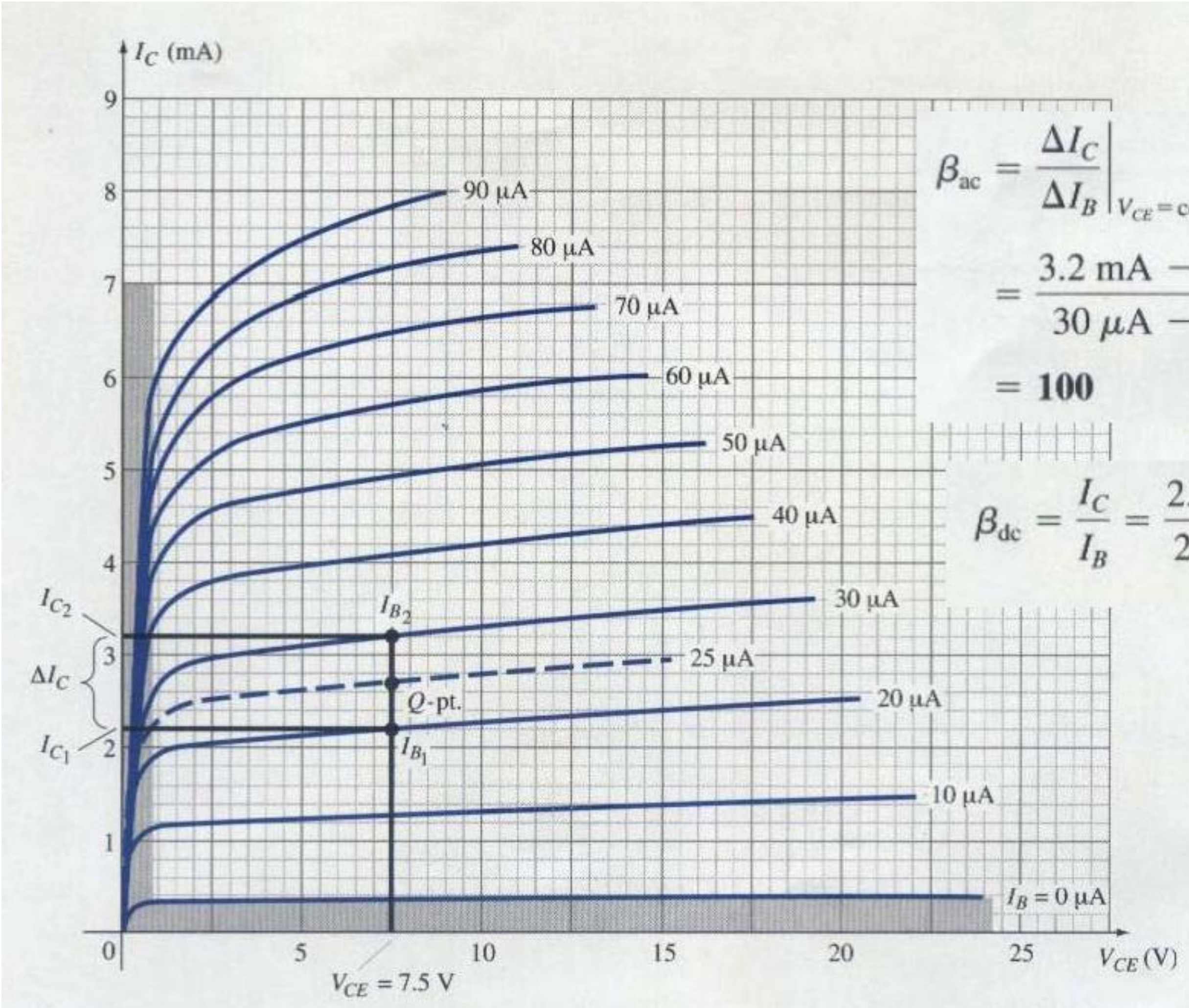
Emitter-base configuration



$$\boxed{I_C \cong I_E}$$

$$I_E = I_C + I_B$$

But the base current I_B is only about 2% to 5% of the emitter current I_E hence very small in comparison to I_E and collector current I_C, hence



$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=\text{constant}} = \frac{I_{C_2} - I_{C_1}}{I_{B_2} - I_{B_1}}$$

$$= \frac{3.2\text{ mA} - 2.2\text{ mA}}{30\ \mu\text{A} - 20\ \mu\text{A}} = \frac{1\text{ mA}}{10\ \mu\text{A}}$$

$$= \mathbf{100}$$

$$\beta_{dc} = \frac{I_C}{I_B} = \frac{2.7\text{ mA}}{25\ \mu\text{A}} = \mathbf{108}$$

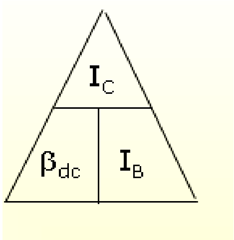
Note that;
Value of beta ac
is close
to beta dc.

Beta (β) or amplification factor

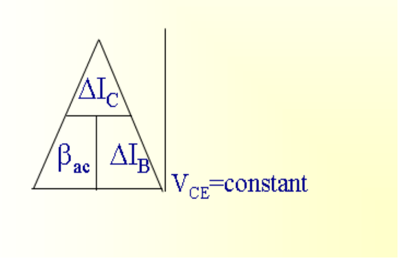
- **The ratio of dc collector current (IC) to the dc base current (IB) is dc beta (βdc) which is dc current gain where IC and IB are determined at a particular operating point, Q-point (quiescent point).**
- **It's define by the following equation:**

  $30 < \beta dc < 300 \rightarrow$ 2N3904

- **On data sheet, β_{dc}=h_{FE} with *h* is derived from ac hybrid equivalent circuit. h_{FE} are derived from forward-current amplification and common-emitter configuration respectively.**



- **For ac conditions an ac beta has been defined as the changes of collector current (I_C) compared to the changes of base current (I_B) where I_C and I_B are determined at operating point.**
- **On data sheet, β_{ac}=h_{fe}**
- **It can defined by the following equation:**



Relationship between Beta and Alpha

$$\beta = I_C/I_B$$
$$I_B = I_C/\beta,$$

$$\alpha = I_C/I_E$$
$$I_E = I_C/\alpha.$$

$$I_E = I_C + I_B$$
$$\frac{I_C}{\alpha} = I_C + \frac{I_C}{\beta}$$

Dividing both sides by I_C,

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$
$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$
$$\boxed{\alpha = \frac{\beta}{\beta + 1}}$$
$$\boxed{\beta = \frac{\alpha}{1 - \alpha}}$$

In addition, recall that

$$I_{CEO} = \frac{I_{CBO}}{1 - \alpha}$$

Using an equivalence of

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

We find that

$$I_{CEO} = (\beta + 1)I_{CBO}$$
$$\boxed{I_{CEO} \cong \beta I_{CBO}}$$

Beta is particularly important parameter because it provides a direct link between current levels of the input and output circuits for a common-emitter configuration. That is, $\boxed{I_C = \beta I_B}$

Since,

$$I_E = I_C + I_B$$
$$= \beta I_B + I_B$$

Finally,we have

$$\boxed{I_E = (\beta + 1)I_B}$$

COMMON-COLLECTOR CONFIGURATION

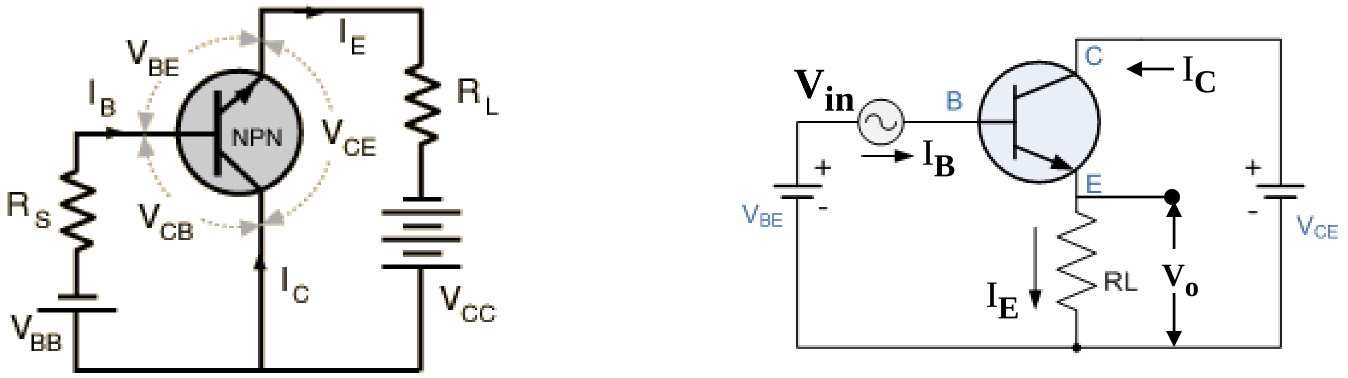
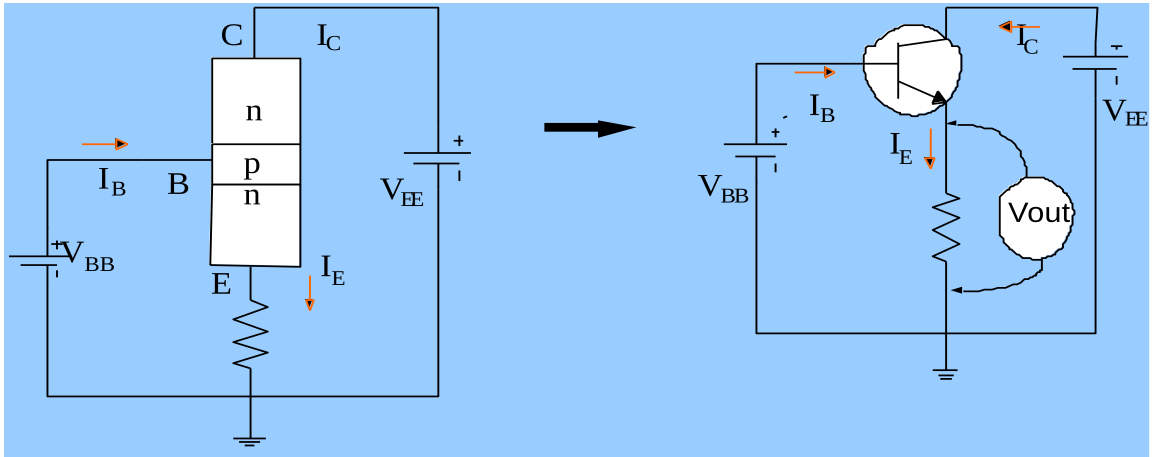
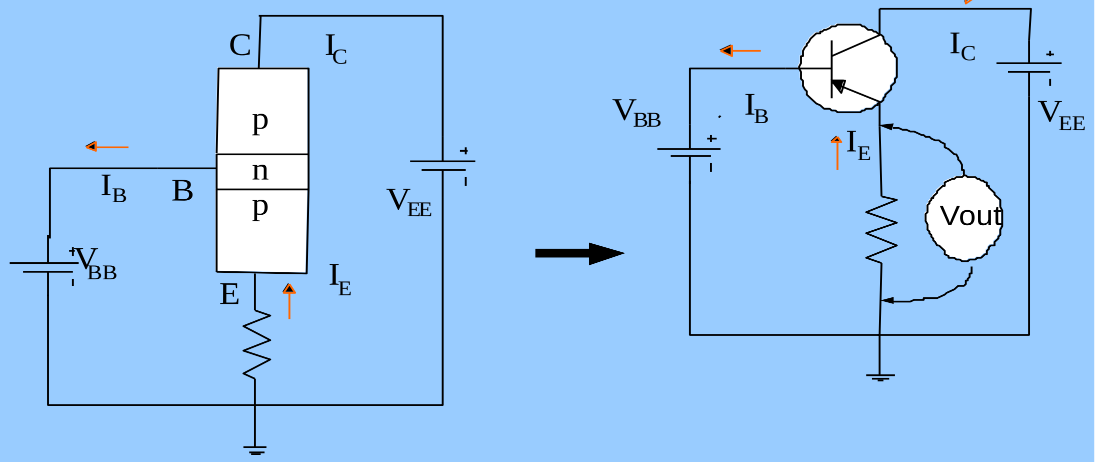


Figure- Two ways of showing Common Collector Configuration



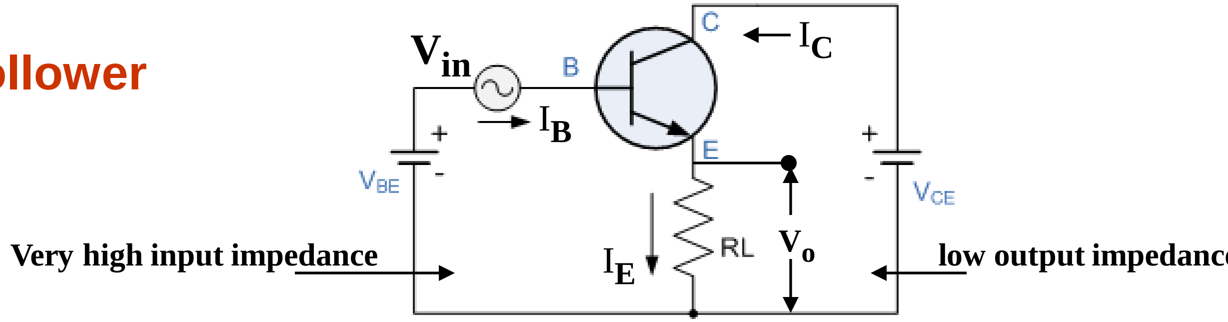
(a) npn transistor configuration



(b) pnp transistor configuration

Common-collector configuration

Emitter Follower



In the Common Collector or Grounded Collector configuration, the collector is now common and the input signal is connected to the Base, while the output is taken from the Emitter load as shown. This type of configuration is commonly known as a Voltage Follower or Emitter Follower circuit. The common collector amplifier, often called an emitter follower since its output is taken from the emitter resistor

Applying KVL to input or base loop:

$$V_o = V_{in} - 0.7$$

$$V_o \leq V_{in}$$

Output voltage follows the input voltage, hence the name.

Application:

The Emitter follower configuration is very useful for impedance matching applications because of the very high input impedance, in the region of hundreds of thousands of Ohms, and it has relatively low output impedance.

Its input impedance is much higher than its output impedance.

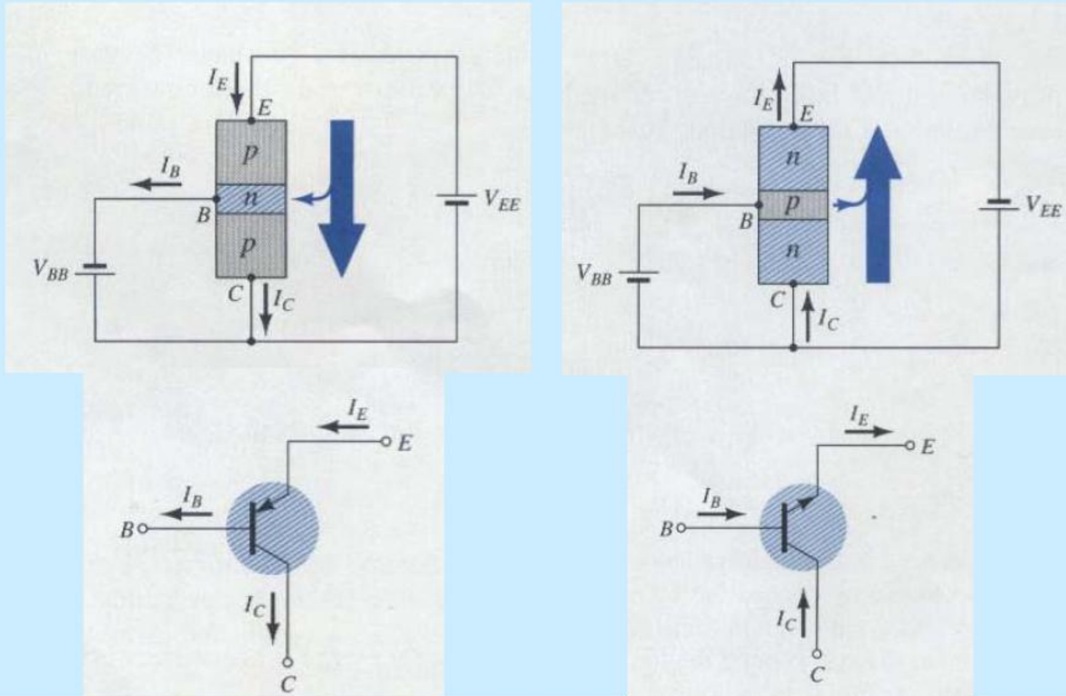
It is also termed a "buffer" for this reason and is used in digital circuits with basic gates.

Common – Collector Configuration

- Also called emitter-follower (EF).
- It is called common-collector configuration since both the signal source and the load share the collector terminal as a common connection point.
- The output voltage is obtained at emitter terminal.
- The input characteristic of common-collector configuration is similar with common-emitter configuration.
- Common-collector circuit configuration is provided with the load resistor connected from emitter to ground.
- It is used primarily for impedance-matching purpose since it has high input impedance and low output impedance.

COMMON-COLLECTOR CONFIGURATION

The common-collector configuration is used primarily for impedance-matching purposes since it has a high input impedance and low output impedance, opposite to that of the common-base and common-emitter configurations.



For all practical purposes, the output characteristics of the common-collector configuration are the same as for the common-emitter configuration.

For the common-collector configuration, the output characteristics are a plot of I_E versus V_{CE} for a range of values of I_B.

There is an almost unnoticeable change in the vertical scale of I_C of the common-emitter characteristics if I_C is replaced by I_E for the common-collector characteristics since alpha =1.

Current Amplification Factor of CC Configuration

$$I_E = I_C + I_B$$

$$\gamma = \quad A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1$$

$$\therefore A_i = \beta + 1$$

the **emitter follower** which is a current amplifier but has no voltage gain,

- For the common-collector configuration, the output characteristics are a plot of I_E vs V_{CE} for a range of values of I_B.

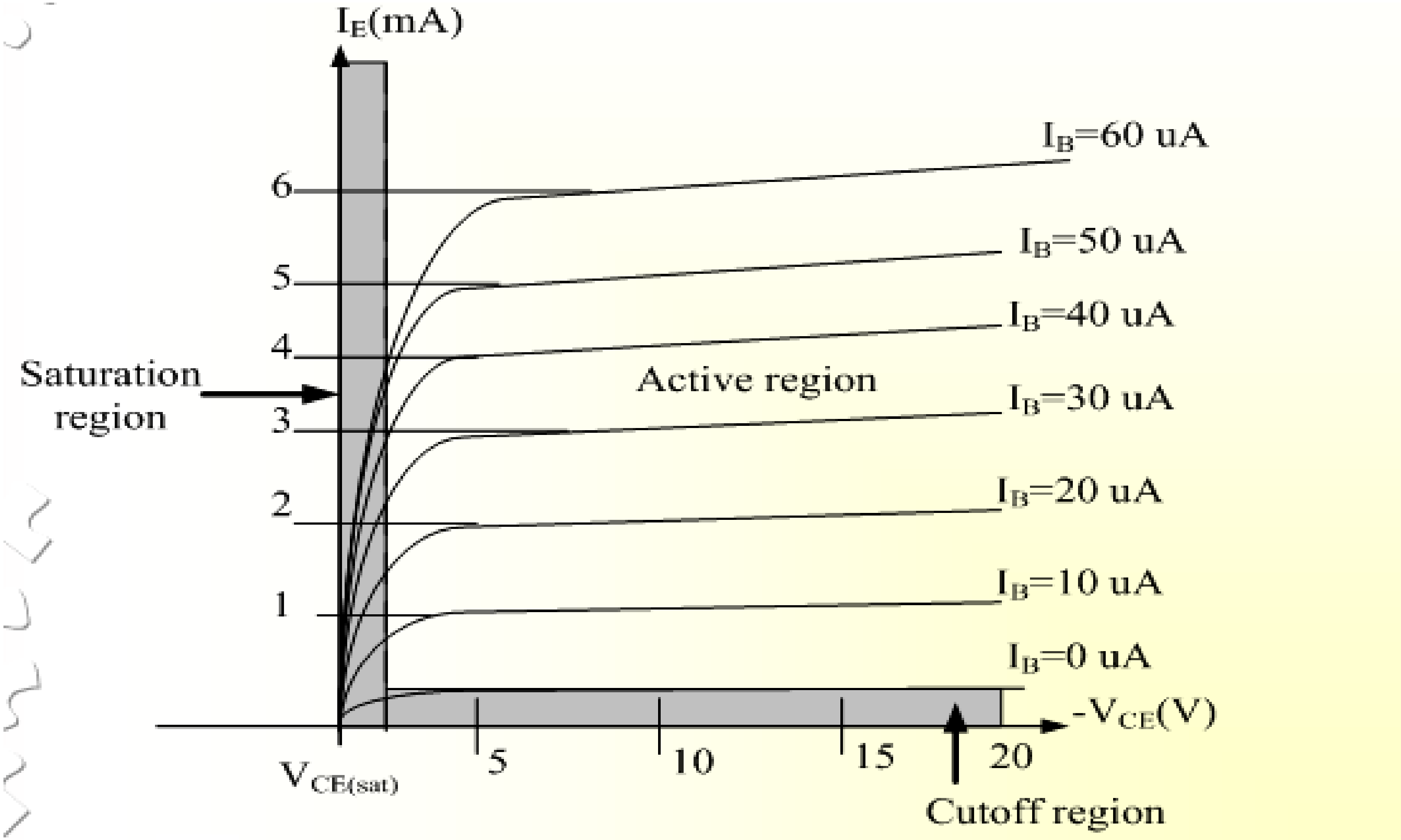


Fig : Output characteristic in CC configuration for npn transistor

Comparison between CB, CE and CC Configurations

Characteristic	Common Base	Common Emitter	Common Collector
Input impedance	Low	Medium	High
Output impedance	Very High	High	Low
Phase Angle	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

SUMMARY

$$I_E = I_C + I_B$$

$$I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}}$$

$$V_{BE} = 0.7\ \text{V}$$

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

$$\alpha_{\text{ac}} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=\text{constant}}$$

$$I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B=0\ \mu\text{A}}$$

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

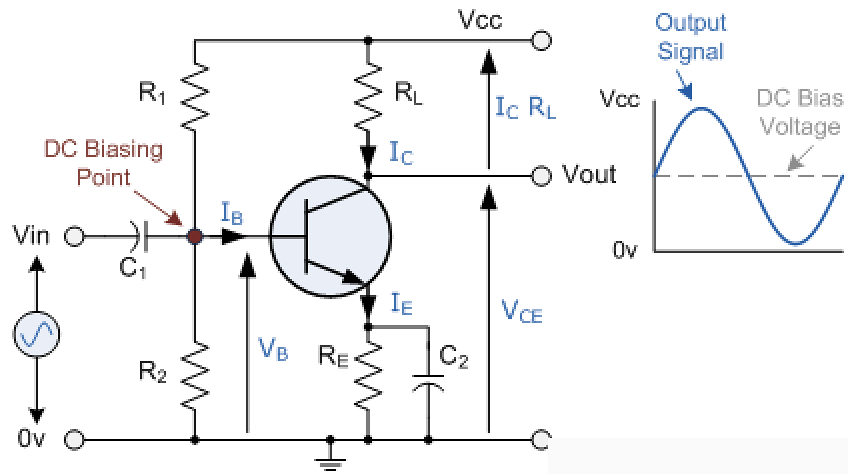
$$\beta_{\text{ac}} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=\text{constant}}$$

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

$$I_C = \beta I_B$$

$$I_E = (\beta + 1) I_B$$

$$P_{C_{\max}} = V_{CE} I_C$$



180° phase reversal

1. Common Base Configuration - has Voltage Gain but no Current Gain.

2. Common Emitter Configuration - has both Current and Voltage Gain.

3. Common Collector Configuration - has Current Gain but no Voltage Gain.

$$\text{Collector Current, } I_C = \frac{V_{CC} - V_{CE}}{R_L}$$

Example No1.

An NPN Transistor has a DC current gain, (Beta) value of 200. Calculate the base current Ib required to switch a resistive load of 4mA.

$$I_B = \frac{I_C}{\beta} = \frac{4\times10^{-3}}{200} = 20uA$$

Therefore, β = 200, Ic = 4mA and Ib = 20µA.

Example No2.

An NPN Transistor has a DC base bias voltage, Vb of 10v and an input base resistor, Rb of 100kΩ. What will be the value of the base current into the transistor.

Formula:

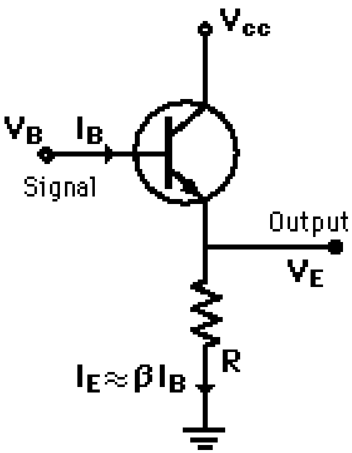
$$I_B = \frac{V_B - V_{BE}}{R_B}$$

Where: Ib is the base current, Vb is the base bias voltage, Vbe is the base-emitter volt drop (0.7v) and Rb is the base input resistor.

$$I_B = \frac{V_B - V_{BE}}{R_B} = \frac{10 - 0.7}{100k\Omega} = 93\mu A$$

Therefore, Ib = 93µA.

Emitter Follower Discussion



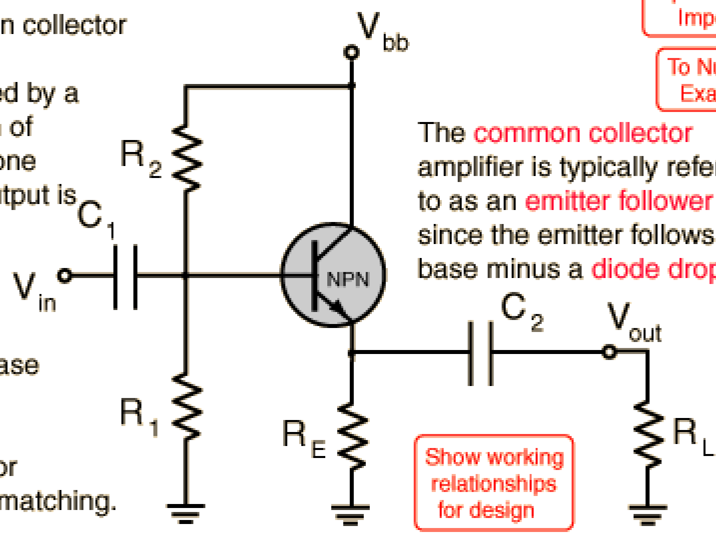
- The common collector junction transistor amplifier is commonly called an emitter follower.
- The voltage gain of an emitter follower is just a little less than one since the emitter voltage is constrained at the diode drop of about 0.6 volts below the base .
- Its function is not voltage gain but current or power gain and impedance matching.
- It's input impedance is much higher than its output impedance so that a signal source does not have to work so hard.
- This can be seen from the fact that the base current in on the order of 100 times less that the emitter current.
- The low output impedance of the emitter follower matches a low impedance load and buffers the signal source from that low impedance.

NPN Common Collector Amplifier

Input and Output Impedances

To Numerical Example

The common collector amplifier is characterized by a voltage gain of essentially one since the output is constrained at a voltage about 0.6 volts below the base which is the signal input. It is useful for impedance matching.



The common collector amplifier is typically referred to as an emitter follower since the emitter follows the base minus a diode drop.

Show working relationships for design

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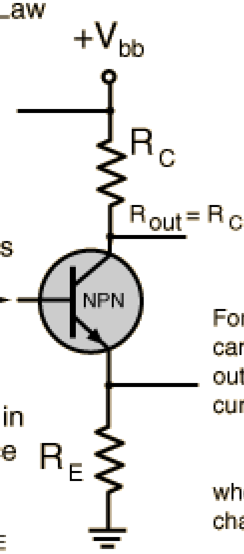
Junction Transistor Amplifiers

Common Emitter Impedances

Using a straight DC Ohm's Law approach to the input resistance would give

$$R_{in} = \frac{V_B}{I_B} = \frac{V_{BE} + I_E R_E}{I_B}$$



But the base-emitter diode is not ohmic and the forward voltage $V_{BE} = 0.6\text{v}$ is essentially constant after it is turned on. For changes in signal voltage, the resistance is effectively

$$R_{in} = \frac{V_B}{I_B}$$

$$R_{in} = \frac{I_E R_E}{I_B} \approx \beta R_E$$

using $I_C = \beta I_B$ and $I_C \approx I_E$

Looking directly into the transistor

$$R_{input} = \beta R_E$$

$$R_{output} = R_C$$

but the biasing circuit should be included.

For signal purposes, the supply V_{bb} can be considered a ground a nd the out put voltage changes follow the current changes in R_C according to

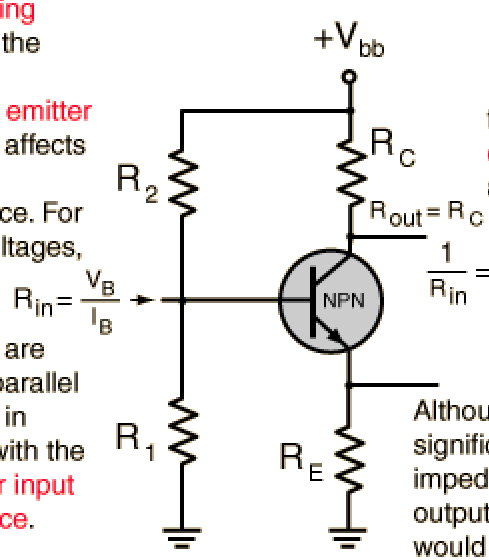
$$v_C = i_C R_C$$

where the small letters indicate changes. So $R_{out} = R_C$.

Common Emitter Amplifier

Common Emitter Impedance

The biasing circuit in the practical common emitter amplifier affects the input impedance. For signal voltages, the biasing resistors are seen in parallel and also in parallel with the transistor input impedance.



$$\frac{1}{R_{in}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{\beta R_E}$$

for the common emitter example, the resistances are:

$$\frac{1}{R_{in}} = \frac{1}{68.25K} + \frac{1}{6.75K} + \frac{1}{(100)(.375K)}$$

$$R_{in} = 5.28\ \text{k}\Omega$$

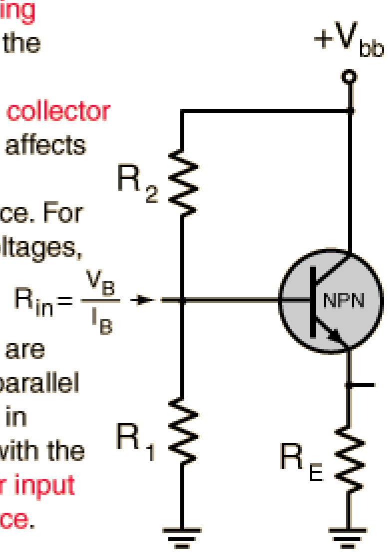
$$R_{out} = 3.75\ \text{k}\Omega$$

Although the example amplifier gave significant voltage gain, its input impedance is rather low and its output impedance is higher than would be desirable.

Common Emitter Amplifier

Common Collector Impedance

The biasing circuit in the practical common collector amplifier affects the input impedance. For signal voltages, the biasing resistors are seen in parallel and also in parallel with the transistor input impedance.



$$\frac{1}{R_{in}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{\beta R_E}$$

for the common emitter example, the resistances are:

$$\frac{1}{R_{in}} = \frac{1}{34.5\text{ K}} + \frac{1}{40.5\text{ K}} + \frac{1}{(100)(.375\text{K})}$$

$$R_{in} = 17.7\text{ k}\Omega$$

Because of negative feedback the effective output impedance is

$$R_{out} \approx R_{source}/\beta$$

Although the gain of this amplifier is one, it has a high input impedance and low output impedance. It provides current and power gain and helps match impedances with load.

Common Collector Amplifier

MOSFET as an Amplifier