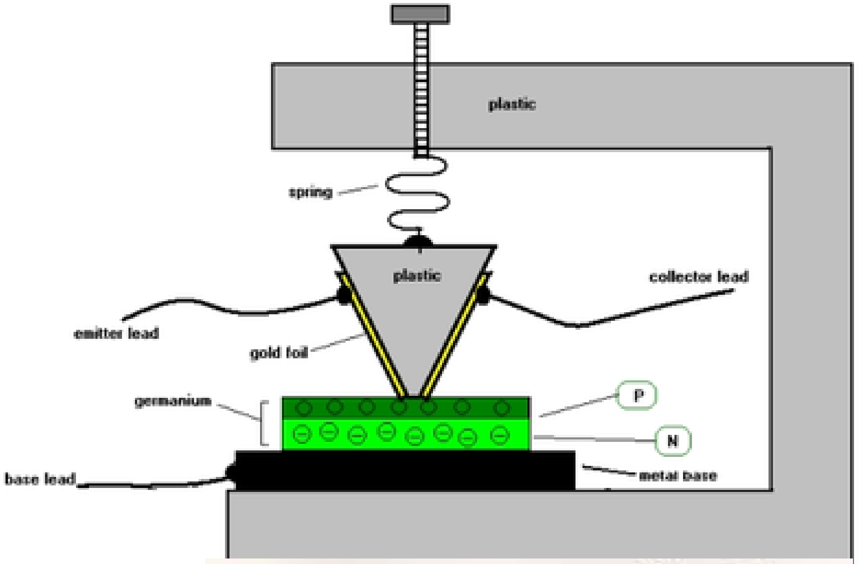
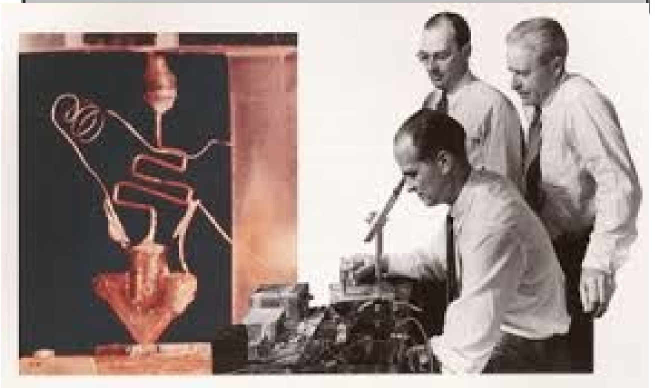
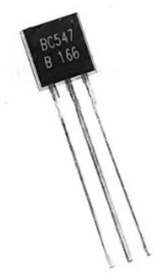
Bipolar Junction Transistor (BJT)

History

- Invented in 1947 by Shockley, Bardeen, and Brattain at Bell Laboratories.
- Awarded with the Nobel Prize
- Transistors were originally manufactured using Germanium.
- Today's Silicon-based transistors were adopted because Germanium breaks down at 180 degrees F
- It's a three terminal device.
- The name transistor is derived from the term transfer resistance. Transistor – Trans-Resistor
- The current (voltage) through two of the terminals is controlled by the current (voltage) through another pair of terminals.
- Transistor can act as a switch.
- Transistor has the ability to amplify a signal between one pair of terminals by using an input signal at another pair of terminals. Thus, a transistor can also act as an amplifier

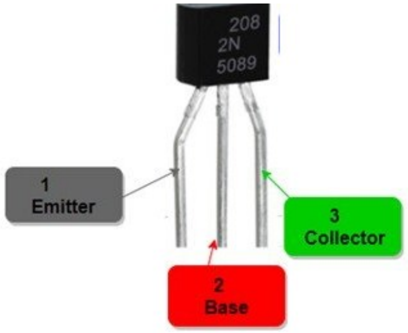




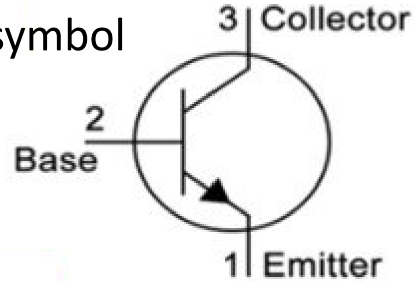


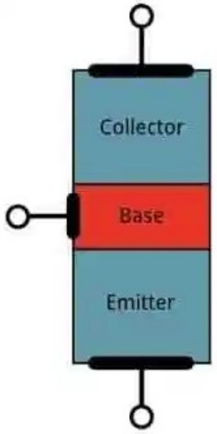
Construction

- The BJT is a three terminal device and has two junctions
- The N and P regions are different both geometrically and in terms of the doping concentration of the regions
  - **Emitter region** - this is usually a heavily doped region (P/N). The emitter 'emits' the carriers into the base.
  - **Base region** - this is a lightly doped region. The base region is also physically thin so that carriers can pass through with minimal recombination.
  - **Collector region** - this is a lightly doped region. The collector region has a larger width that the other two regions since charge is accumulated here from the base.



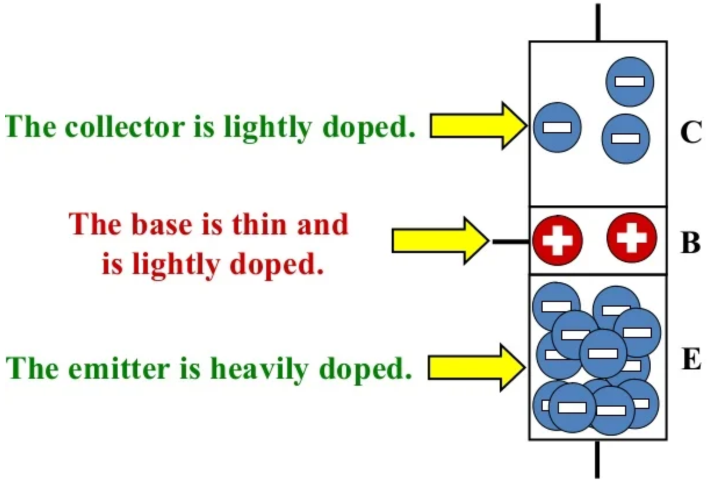
symbol





The doping concentrations in the collector, base and emitter are not the same

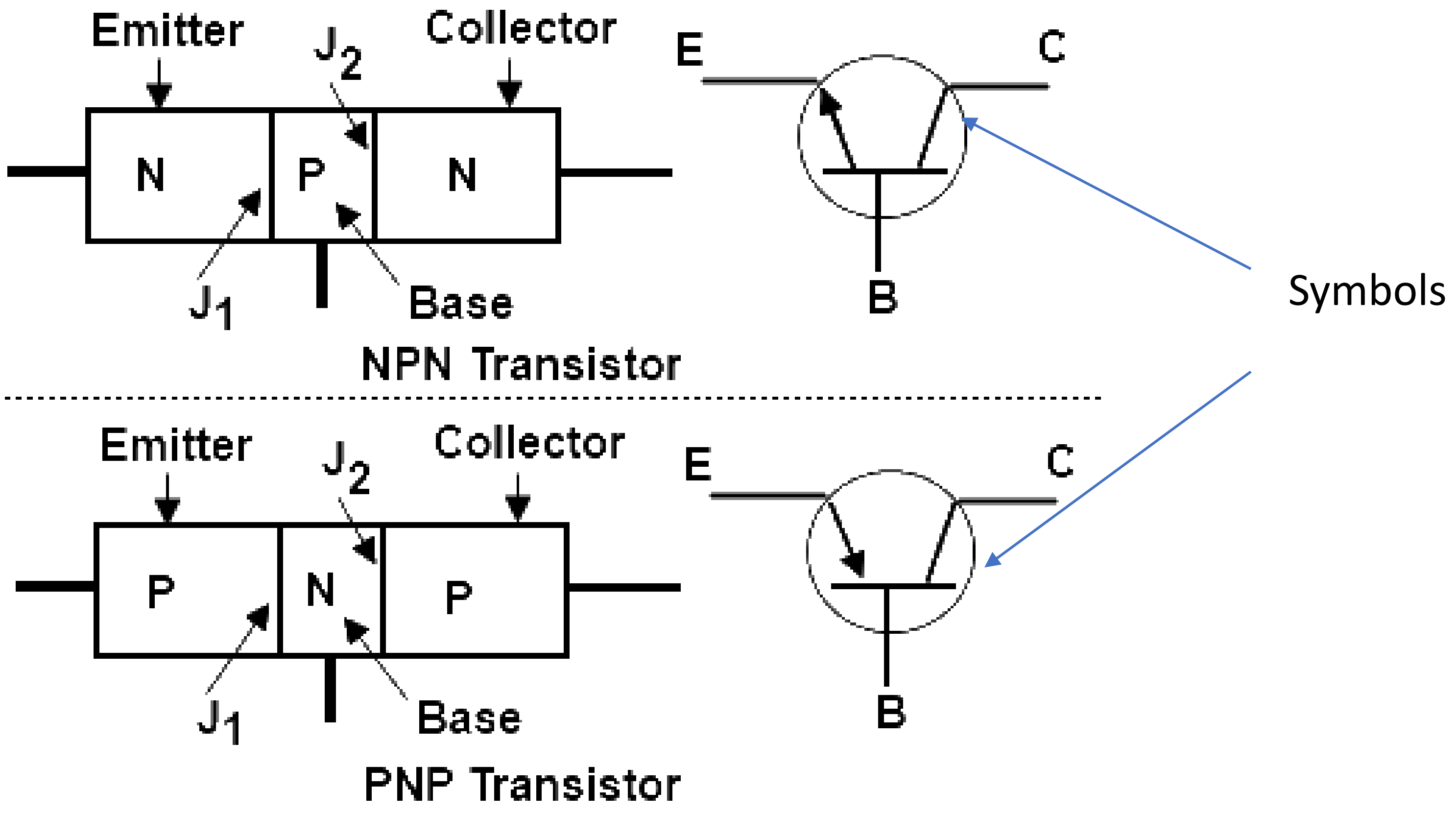
- Collector doping is usually ~ **10^6**
- Base doping is slightly higher ~ **10^7 – 10^8**
- Emitter doping is much higher ~ **10^{15}**



Types of Transistors

Therefore the behavior of the device is not electrically and geometrically symmetric and the terminals cannot be cannot be interchanged

Common Base (CB)
Common Emitter (CE)
Common Collector



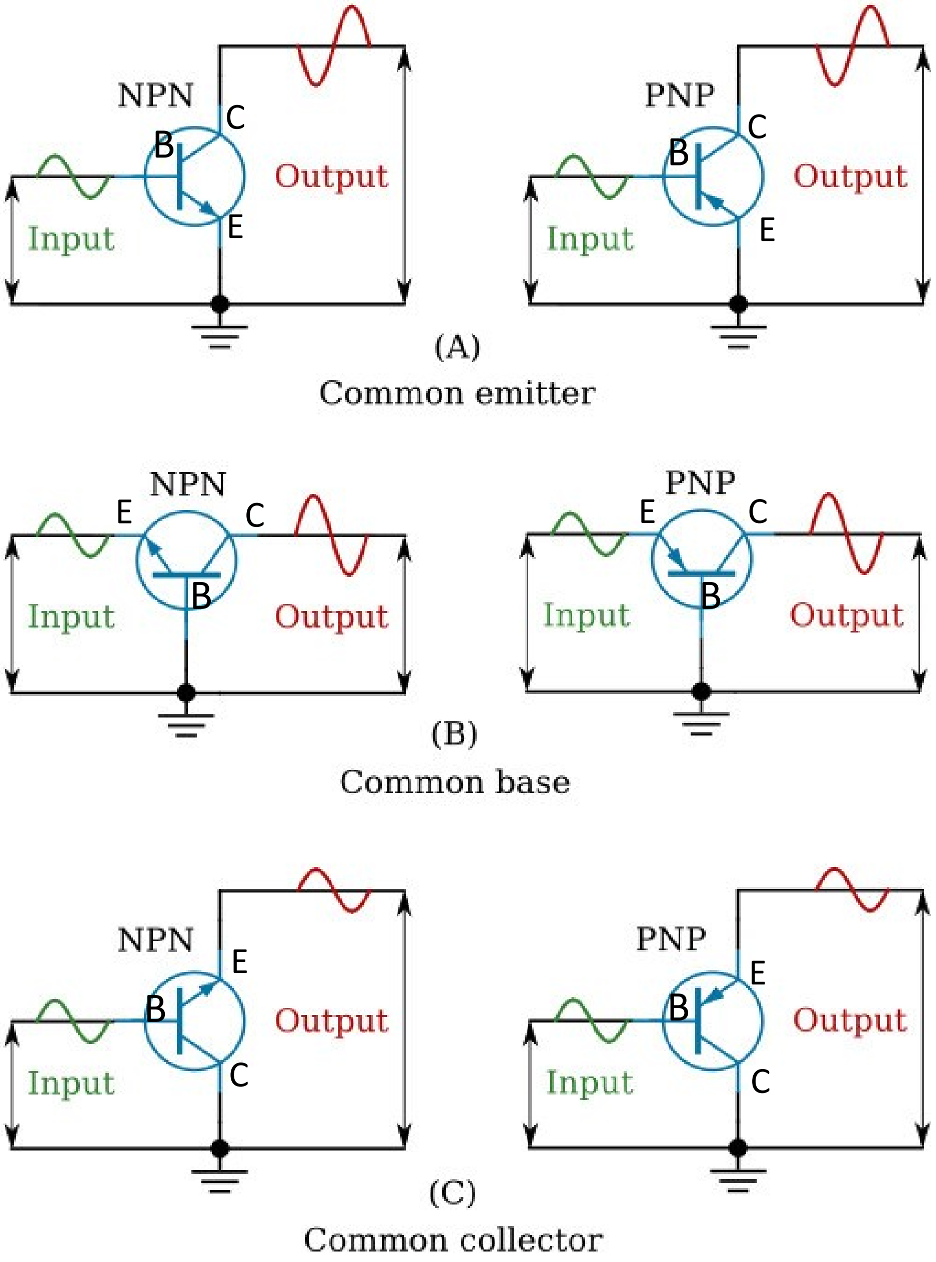
Note: NPN type is most commonly used Transistor. The majority charge carriers in an [NPN transistor]() are electrons and the majority carriers in a PNP transistor are holes. The electrons have better mobility than holes and helps in better conduction.

Modes of Operation

- Active
  - Most important mode of operation
  - offer amplifier operation, The region where current curves are practically flat
- Saturation
  - Barrier potential of the junctions cancel out each other causing a virtual short-closed switch
- Cut-Off
  - Current reduced to zero, Ideal transistor behaves like an open switch

Region of operation	Base Emitter Junction	Collector Base Junction	Application
Cut off	Reverse biased	Reverse biased	As a switch
Active	Forward biased	Reverse biased	As an amplifier
Saturation	Forward biased	Forward biased	As a switch

BJT Configurations



Common Emitter(CE):

Input = VBE & IB

Output = VCE & IC

Common-Base (CB)

Input = VEB & IE

Output = VCB & IC

Common-Collector (CC)

Input = VBC & IB

Output = VEC & IE

Common Base Transistor

Biasing in CB mode:

- Emitter–Base junction (EBJ): **Forward biased** → allows electrons to flow from emitter into base.
- Collector–Base junction (CBJ): **Reverse biased** → attracts electrons from base into collector.

So, **base is common**, emitter acts as input, collector as output.

Working Principle

Electron Injection (Emitter → Base):

Forward bias at EBJ pushes electrons (majority carriers of emitter) into the base.

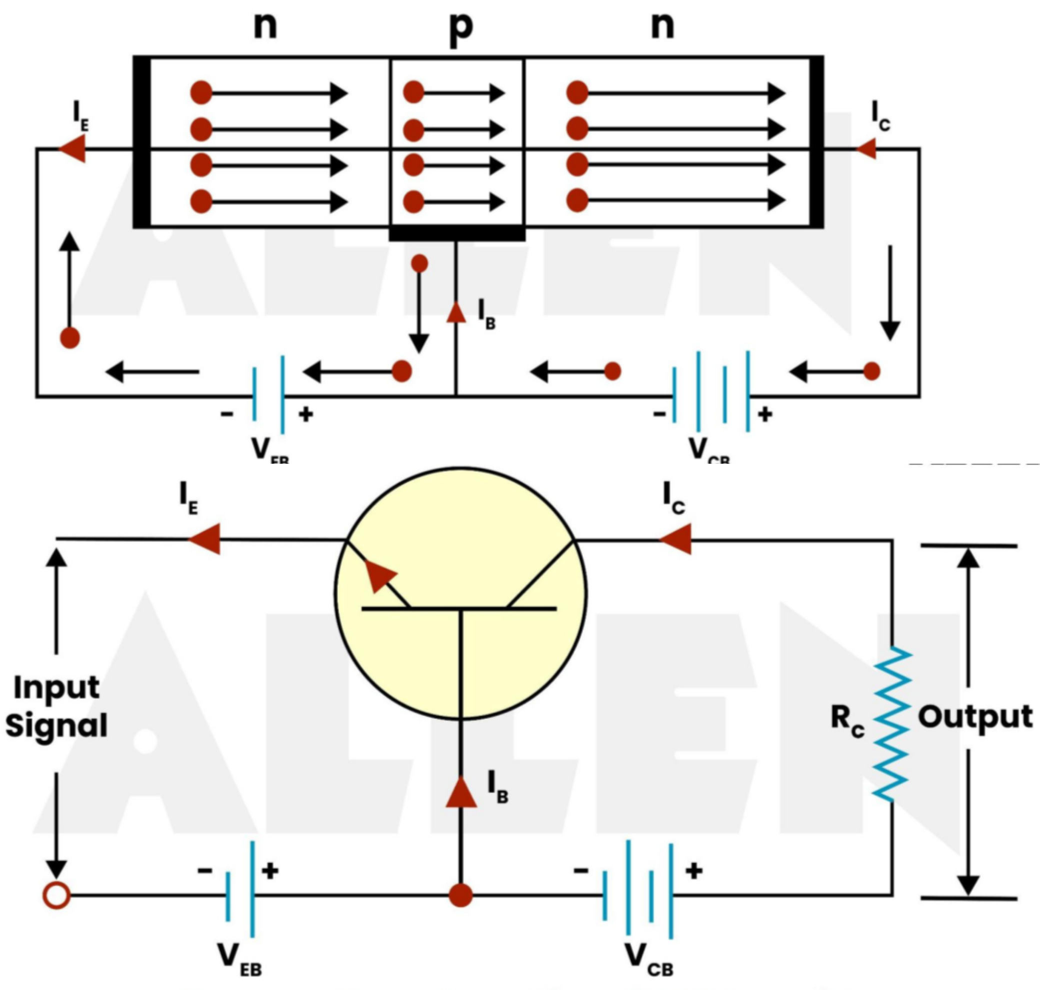
Carrier Transport through Base:

The base is very **thin and lightly doped**, so only a few electrons recombine with holes.

Most electrons diffuse across the base into the collector region.

Electron Collection (Base → Collector):

Reverse-biased CBJ creates a strong electric field. This field sweeps electrons from the base into the collector → large ***collector current***. *Thus,* ***emitter current flows → majority of it appears as collector current***, with a very small base current due to recombination.



Common Base Conection of NON Transistor

Current Relations and equations

$\boldsymbol{I_E}$ **= Emitter Current ,** $\boldsymbol{I_B}$ **= Base Current,** $\boldsymbol{I_c}$ **= Base Current**

(a) KCL $I_E = I_B + I_c$

(a) Current gain (α) in CB:

$$\boxed{\alpha = \frac{I_c}{I_E}, \; 0.95 \le \alpha \le 0.99}$$

(c) Collector Current equation:

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

Where I_{CBO} = reverse leakage current of CB junction (small)

(d) Input equation (Diode-like behaviour): Since EBJ is forward biased

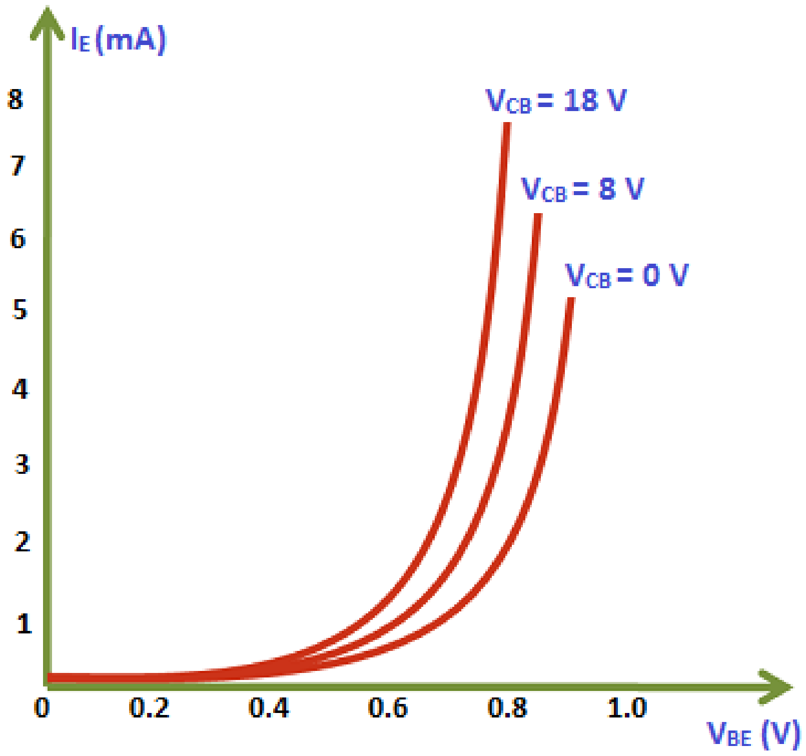
$$\boxed{I_E \approx I_s\left(e^{\frac{V_{BE}}{V_T}} - 1\right)}$$

Where I_s = saturation current , $\boldsymbol{V_T}$ **= 26 mV** at $300^o K$

(e) Output relation:

$$\boxed{I_c \approx \alpha I_E \quad (\text{since} \ll I_E)}$$

Input characteristic (CB)



I/p characteristics CB configuration

$\boldsymbol{I_E}$ **vs** $\boldsymbol{V_{BE}}$ (like diode curve).

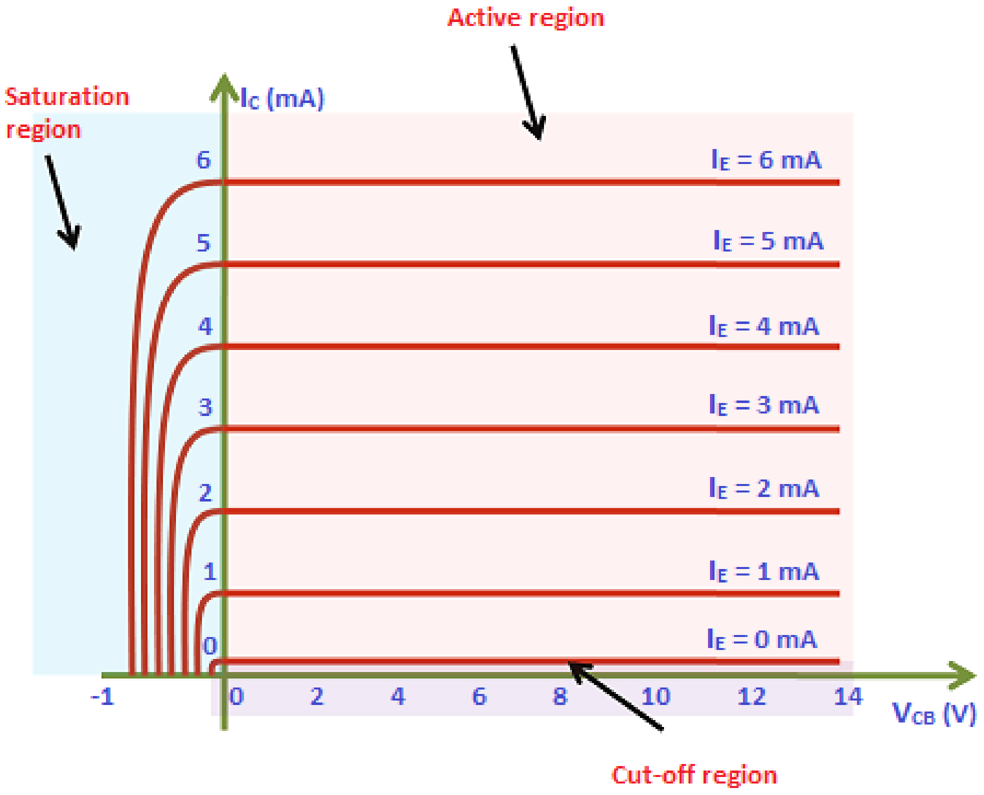
•The **input circuit (Emitter–Base junction)** is a **forward biased p–n junction**, so it behaves like a **diode characteristic**.
• For small $V_{BE}, I_E \approx 0$.
• After crossing the threshold (~0.3 V for Ge, ~0.7 V for Si), emitter current rises rapidly (Exponential) with small increase in V_{BE}

Input resistance $\boldsymbol{R_{in}}$: very **low** (tens of ohms)

$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}$$

The I_E ↑ with V_{CB} (The reason is base width modulation)
When V_{CB} increases, the depletion region at CB junction widens inside the base. A thinner base means less chance of recombination of electrons (from emitter) with holes in the base. So, more electrons injected from the emitter can cross into the collector.

Output characteristic (CB)



O/P characteristics CB configuration

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

O/P resistance R_{out}: very high(kΩ)

$$R_{out} = \frac{\Delta V_{CB}}{\Delta I_c}$$

O/p chara. is relationship between output current I_c and output voltage V_{cB} keeping input current I_E constant.

When $I_E = 0$ mA, the transistor operates in the cut-off region.

In saturation region both emitter base junction and collector base junction are forward biased.

Nature of curve:

•**For small V_{cB} :** a little rise in I_c (due to Early effect).

•**After that:** I_c remains **almost constant** for given I_E , independent of V_{cB}

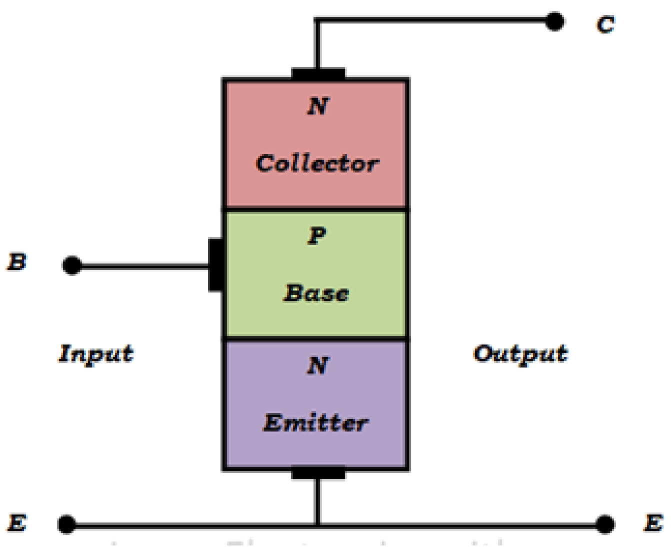
•Different curves for different I_E values

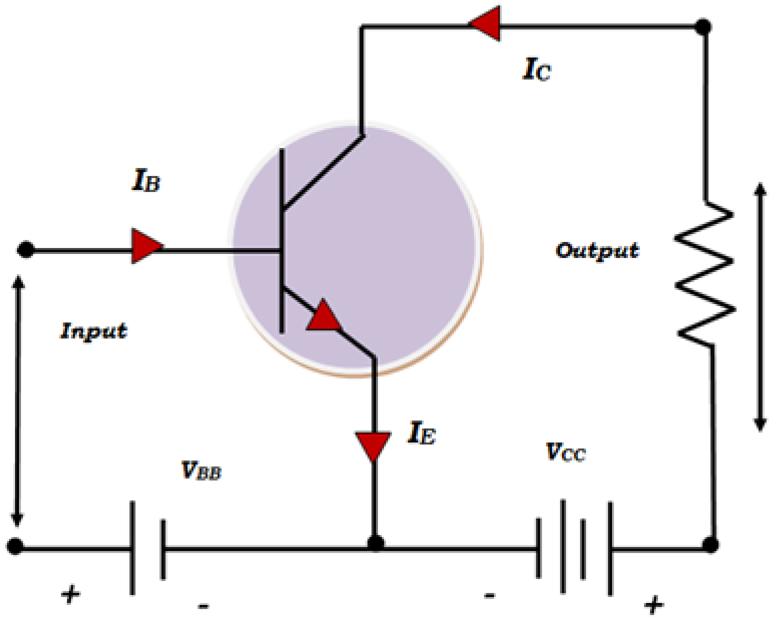
Regions in Output Characteristics

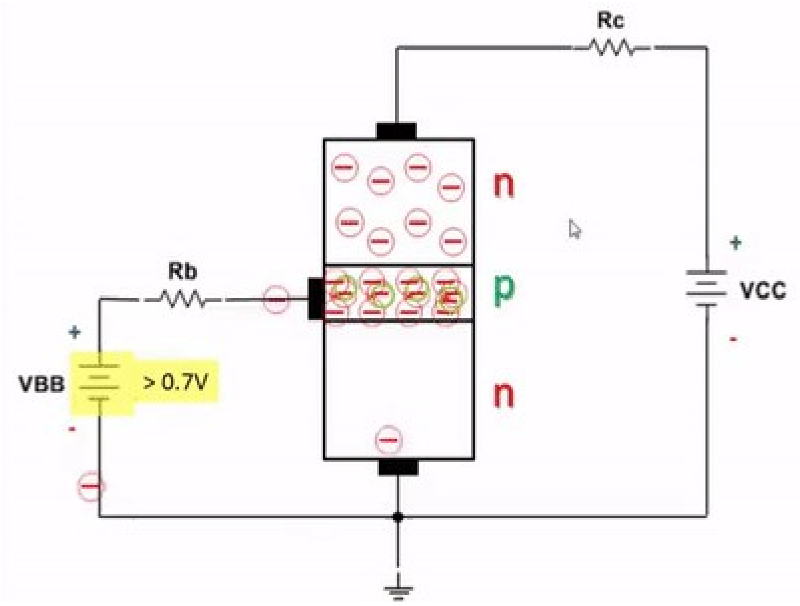
- **Cut-off region:** $I_E = 0$ mA, so $I_c \approx 0$ mA (tiny leakage current).
- **Active region:** CBJ reverse biased, EBJ forward biased → transistor action occurs (amplifier mode).
- **Saturation region:** Both junctions forward biased → I_c increases sharply, transistor cannot amplify.

Common Emitter Transistor

- ✓ In CE configuration, the emitter terminal is grounded and the input signal is applied between the base and emitter terminals while the output signal is taken between the collector and emitter terminals
- ✓ It is most widely used configuration.
- ✓ The common emitter amplifier has medium input and output impedance levels.
- ✓ The **current gain** and **voltage gain** of the **common emitter** amplifier is medium. However, the power gain is high.
- ✓ Input current I_B is measured in µA because the base region is very lightly doped







Input Characteristics (CE mode)

Variation of I_B with V_{BE} at constant V_{CE}

Behaviour:

•The **input junction (B–E)** is a **forward-biased diode**.

•For **small** $V_{BE} \rightarrow I_B \approx 0$

•When V_{BE} exceeds ~ 0.7 V (Si) or ~0.3 V (Ge), I_B increases **exponentially**.

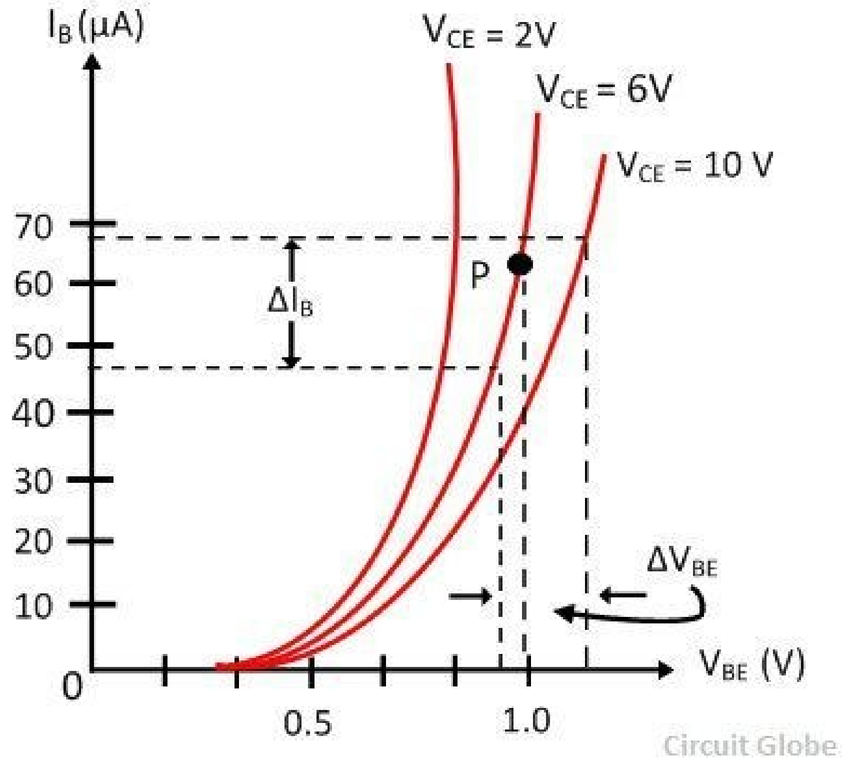
•With **higher** V_{CE} **:**

- The collector-base depletion region widens (Early effect). Base width reduces → less recombination → slightly less base current needed for same V_{BE} .
- So, input curve shifts a little downward with increasing V_{CE} .

$$I_E = I_C + I_B$$

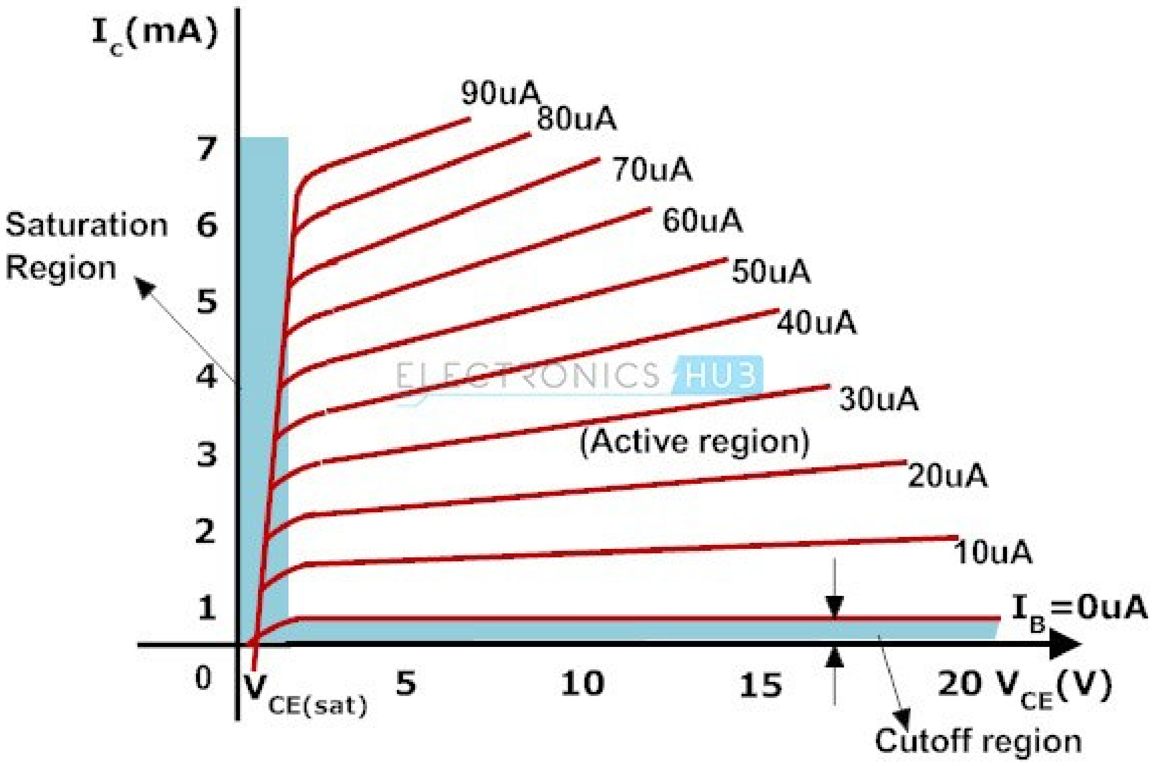
Current gain $\beta = \frac{I_c}{I_B}$ (20–500 *typically*)

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



Output Characteristics (CE mode)

Variation of I_c with V_{CE} at constant I_B



Cut-off Region ($I_B = 0$):

- Both junctions reverse biased
- Only a tiny leakage current flows (I_{CBO}).

Active Region:

- I_c increases almost linearly with I_B .
- For a given I_B , $I_c \approx \beta I_B$
- Output curves (for different I_B) are nearly flat but rise slightly with V_{CE} (Early effect).

Saturation Region:

- When V_{CE} is small ($\leq$ 0.2 V), both junctions FB
- $\boldsymbol{I_c}$ increases sharply → transistor fully ON.

$\uparrow V_{CE} = \uparrow V_{CB} + V_{BE}$, *hence* $I_B \downarrow$ $I_c \uparrow$

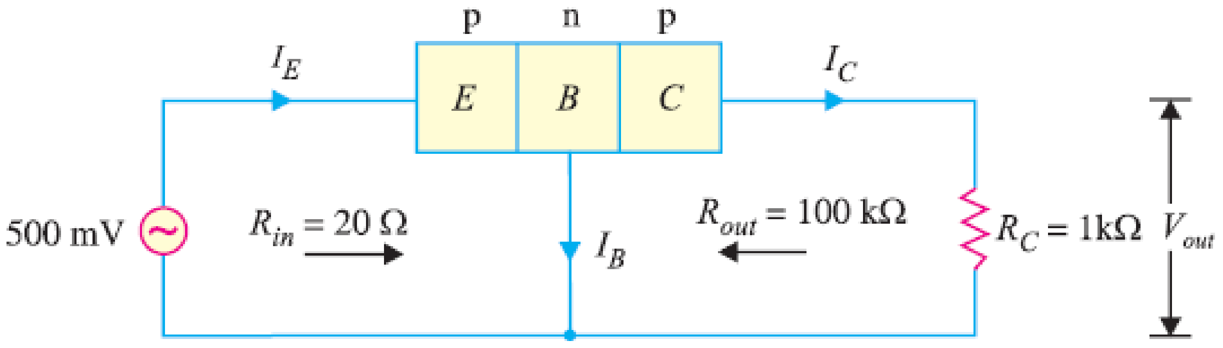
"Base width Modulation or early effect"

O/P resistance $R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_c}\right|_{I_B}$ typically high (kΩ)

BJT Configurations-Comparison

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	HIGH	MEDIUM	LOW
CURRENT GAIN	LOW	MEDIUM	HIGH
POWER GAIN	LOW	HIGH	MEDIUM
INPUT RESISTANCE	LOW	MEDIUM	HIGH
OUTPUT RESISTANCE	HIGH	MEDIUM	LOW

Q1. A common base transistor amplifier has an input resistance of 20 Ω and output resistance of 100 kΩ. The collector load is 1 kΩ. If a signal of 500 mV is applied between emitter and base, find the voltage amplification. Assume α_{ac} to be nearly one.

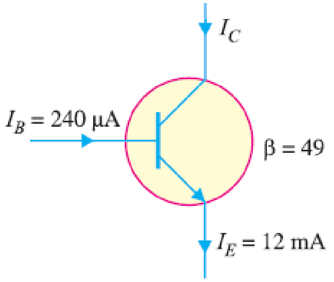


Q2. In a common base connection, current amplification factor is 0.9. If the emitter current is 1mA, determine the value of base current.

Q3. In a common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50 µA. Find the total collector current. Given that α = 0.92.

Q4. Calculate I_E in a transistor for which β = 50 and I_B = 20 µA. (1.02 mA)

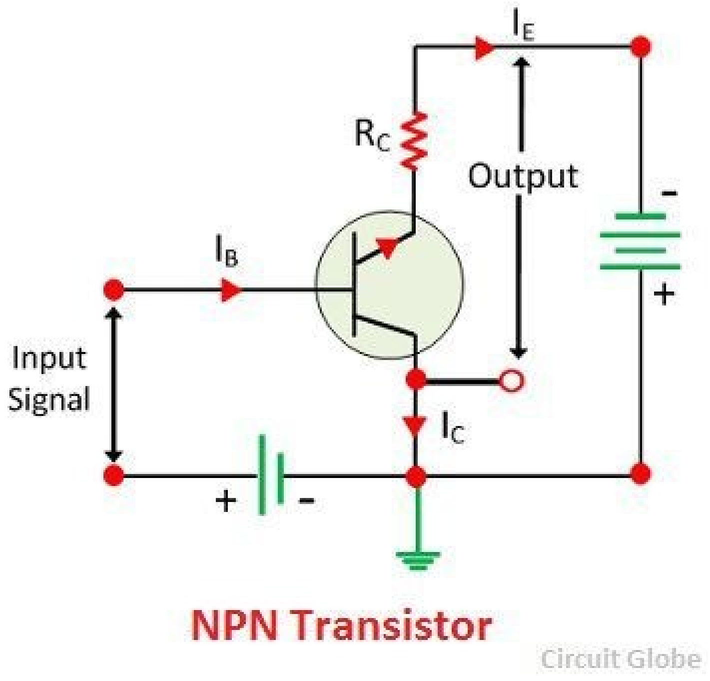
Q5. **Find the α rating of the transistor shown in Fig. 4. Hence determine the value of I_C using bot the transistor. (Ic =11.76 mA)**



Common Collector Transistor (CC)

The input circuit is connected between ***emitter and base*** and the output is taken from the ***collector and emitter***, collector is common between emitter and base

The ratio of change in emitter current to the change in base current is known as the **current amplification factor**



Relation Between Υ and α

$$\Upsilon = \frac{\Delta I_E}{\Delta I_B} \qquad \alpha = \frac{\Delta I_E}{\Delta I_B}$$

$$I_E = I_c + I_B$$

$$\Delta I_E = \Delta I_c + \Delta I_B$$

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

$$\Upsilon = \frac{\Delta I_E}{\Delta I_E - \Delta I_c}$$

$$\Upsilon = \frac{\Delta I_E / \Delta I_E}{\Delta I_E / \Delta I_E - \Delta I_c / \Delta I_E}$$

$$\Upsilon = \frac{\Delta I_E / \Delta I_E}{\Delta I_E / \Delta I_E - \Delta I_c / \Delta I_E}$$

$$\Upsilon = \frac{1}{1 - \Delta I_c / \Delta I_E}$$

$$\boxed{\Upsilon = \frac{1}{1-\alpha}}$$

Υ is nearly equal to β , this arrangement input resistance is high, and output resistance is very low.

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

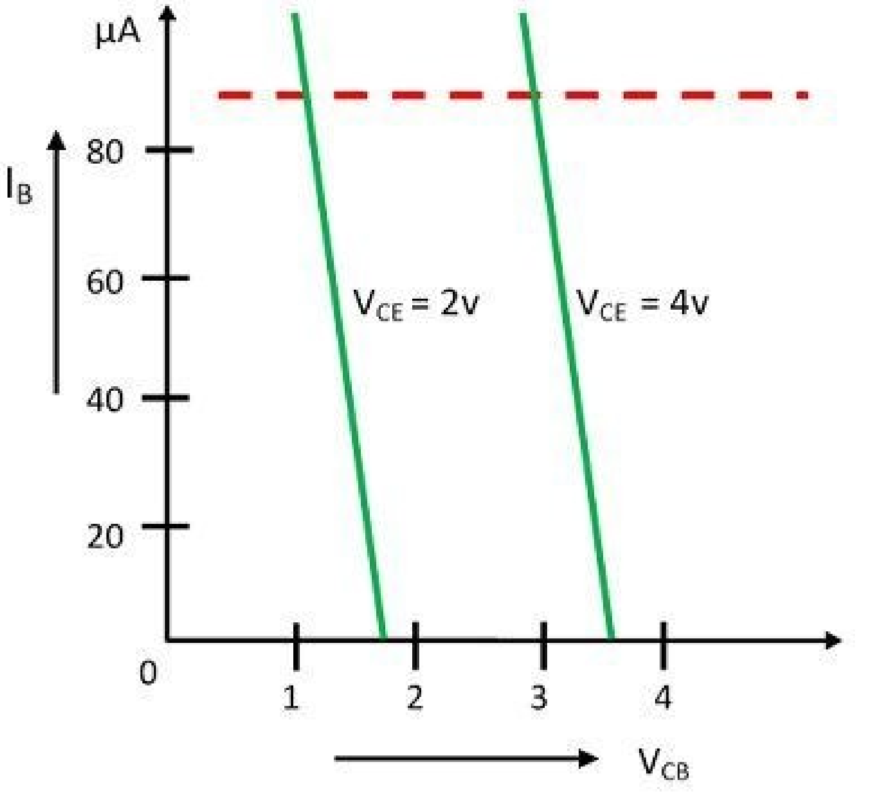
$$I_E = I_c + I_B = (\alpha I_B + I_{CBO}) + I_B$$

$$I_E\,(1-\alpha) = I_{CBO} + I_B = = \frac{I_{CBO}}{(1-\alpha)} + \frac{I_B}{(1-\alpha)}$$

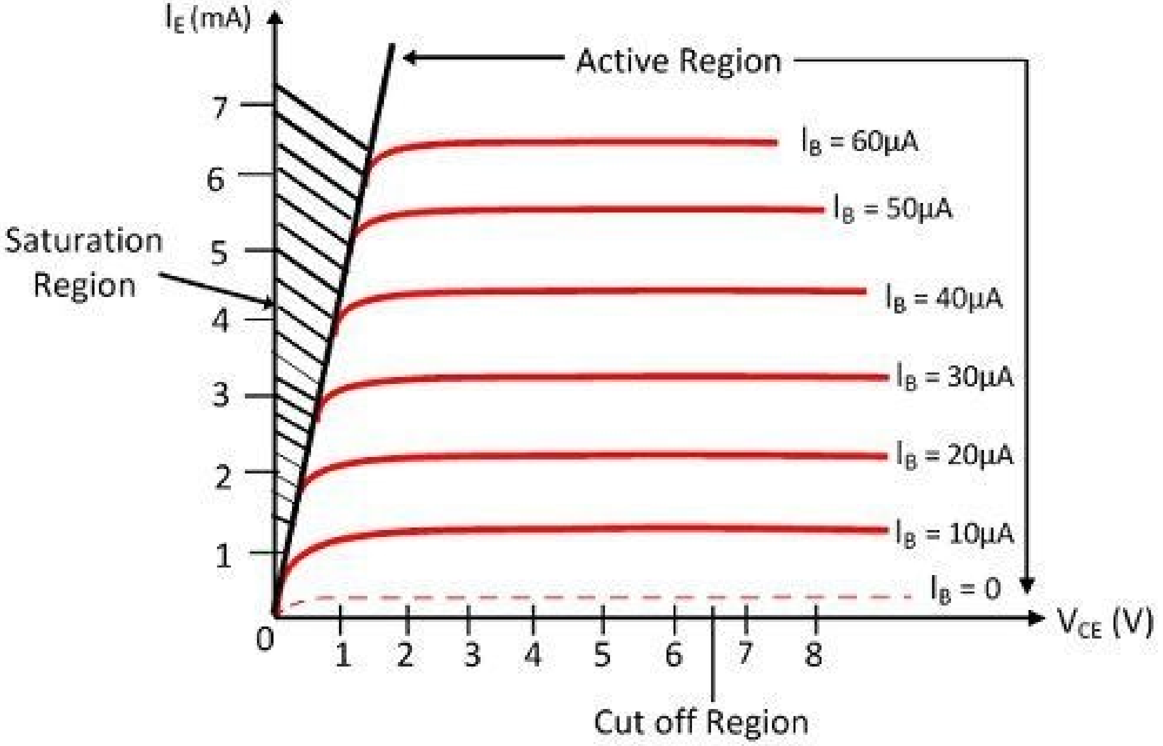
$$\boxed{I_E = I_B(1+\beta) + I_{CBO}(1+\beta)}$$

Input / Output Characteristic Curve

The voltage gain of the resistance is very low. T
his circuit arrangement is mainly used for impedance matching.



Input Characteristic Curve



Output Characteristic Curve