Bipolar Junction Transistor (BJT)

- Beside diodes, the most popular semiconductor devices is transistors. Eg: Bipolar Junction Transistor (BJT)

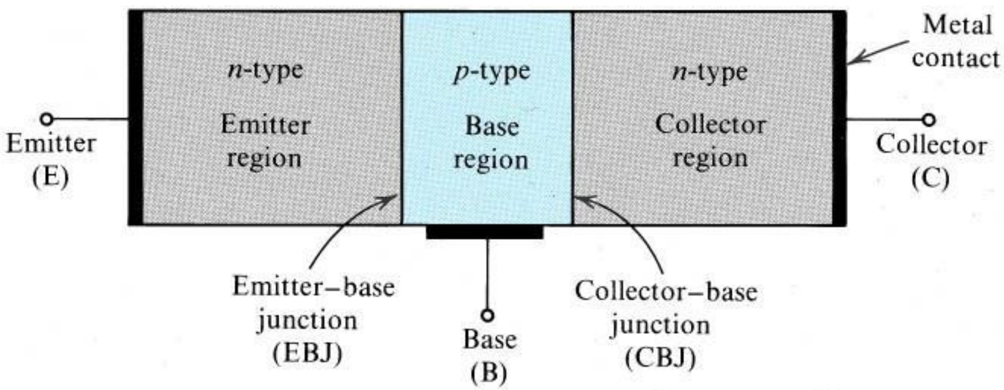
- Few most important applications of transistor are: as an amplifier as an oscillator and as a switch

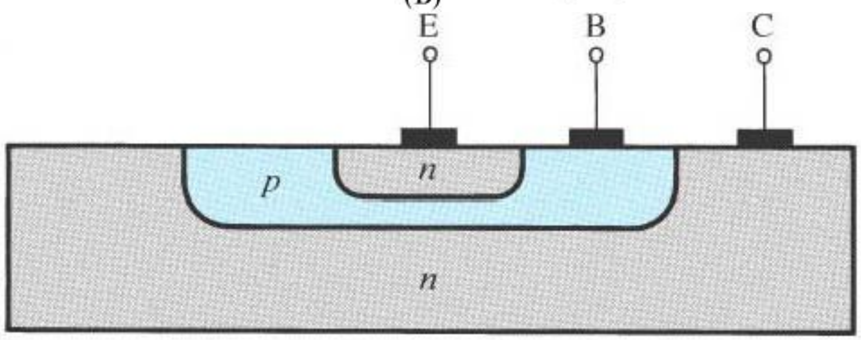
- Amplification can make weak signal strong in general, provide function called *Gain*

- BJT is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device
  - N-type regions contains free electrons (negative carriers)
  - P-type regions contains free holes (positive carriers)

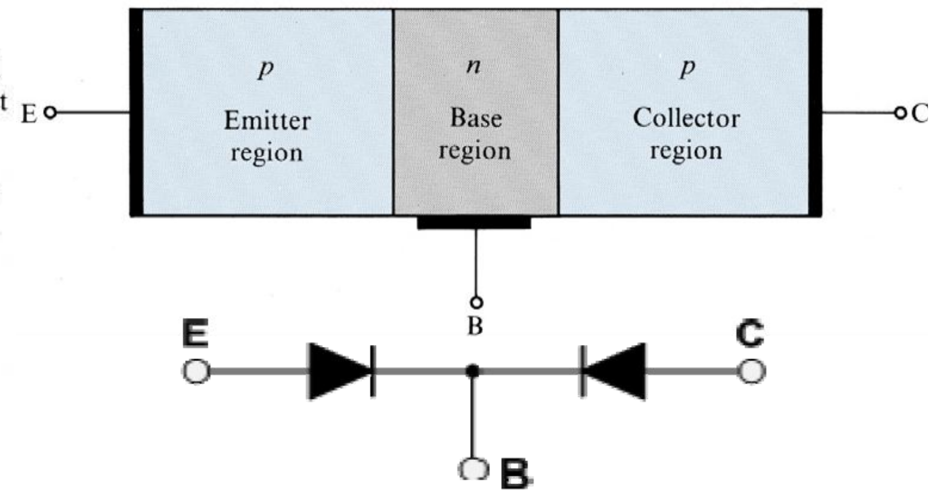
Bipolar Junction Transistor (BJT)

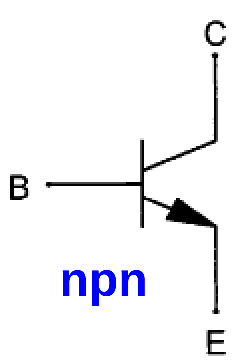
npnTransistor



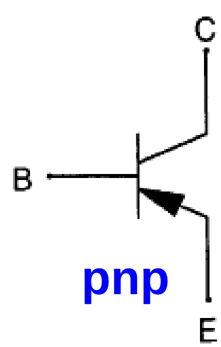


pnpTransistor





npn



pnp

- ➢BJT is a 3 terminal device. namely- emitter, base and collector
- ➢npn transistor: emitter & collector are n-doped and base is p-doped.
- ➢Emitter is heavily doped, collector is moderately doped and base is lightly doped and base is very thin. i.e. $N_{DE} >> N_{DC} >> N_{AB}$

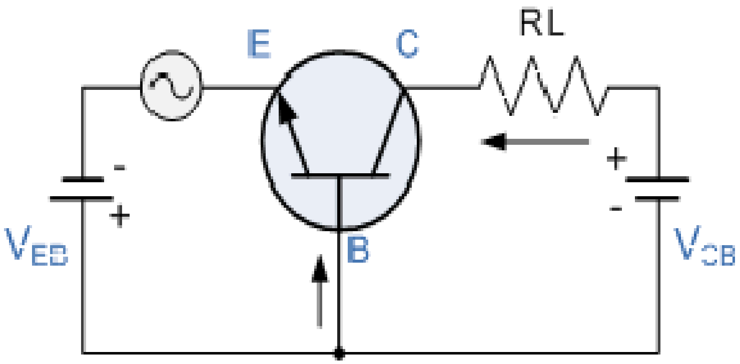
Mode of operation for BJT

Mode	V_{BE}	V_{BC}
Forward active	Forward bias	Reverse Bias
Reverse active	Reverse Bias	Forward Bias
Saturation	Forward bias	Forward bias
Cut off	Reverse Bias	Reverse Bias

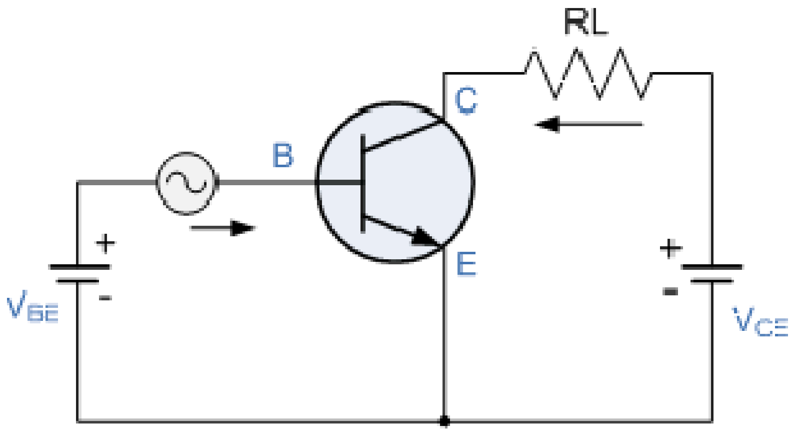
➢Forward active region is widely used and Reverse active region is rarely used.

Different configuration of BJT

Common base configuration

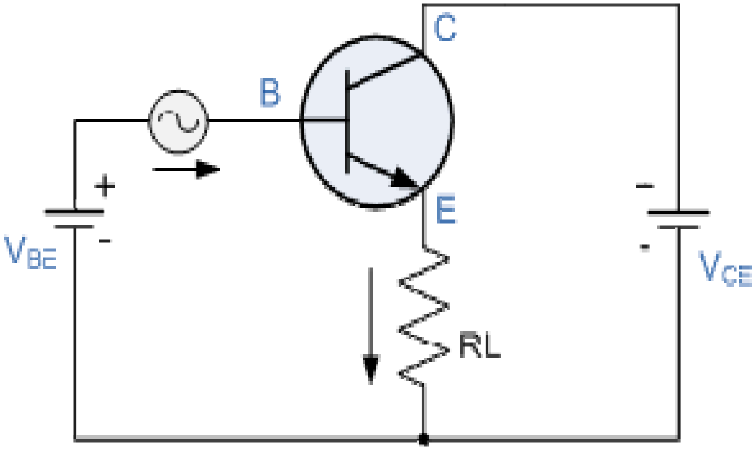


Non-inverting voltage amplifier circuit



Common emitter configuration

Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

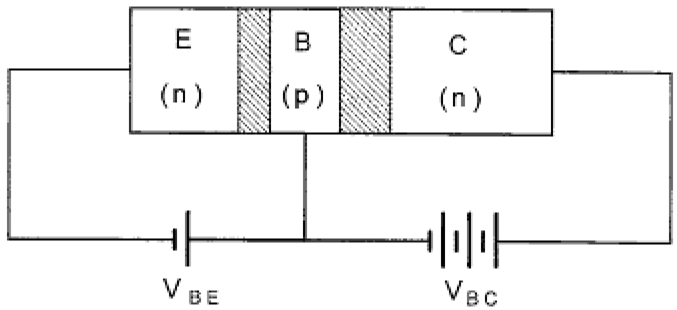
Summary of BJT characteristics for different configuration

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

➢The CB mode is generally only used in single stage amplifier circuits such as microphone pre-amplifier or RF radio amplifiers due to its very good high frequency response.

➢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.

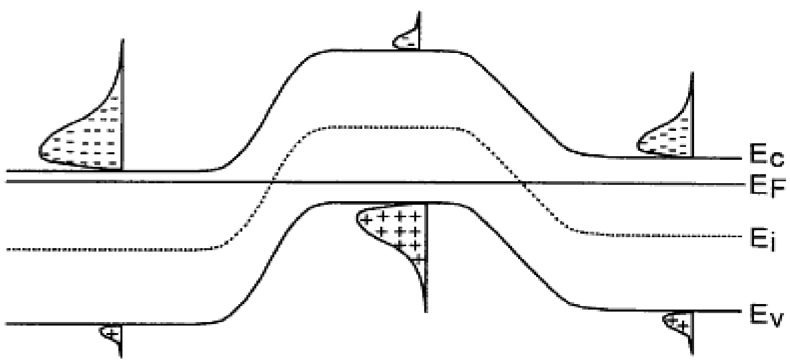
DC operation of npn BJT under forward active mode



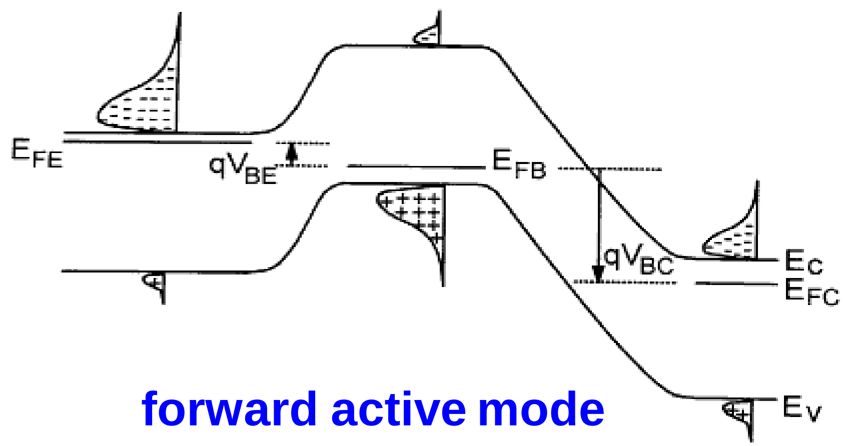
- For npn BJT in forward active mode:

  $V_{BE} > 0$ and $V_{BC} < 0$

Energy band diagram for npn BJT

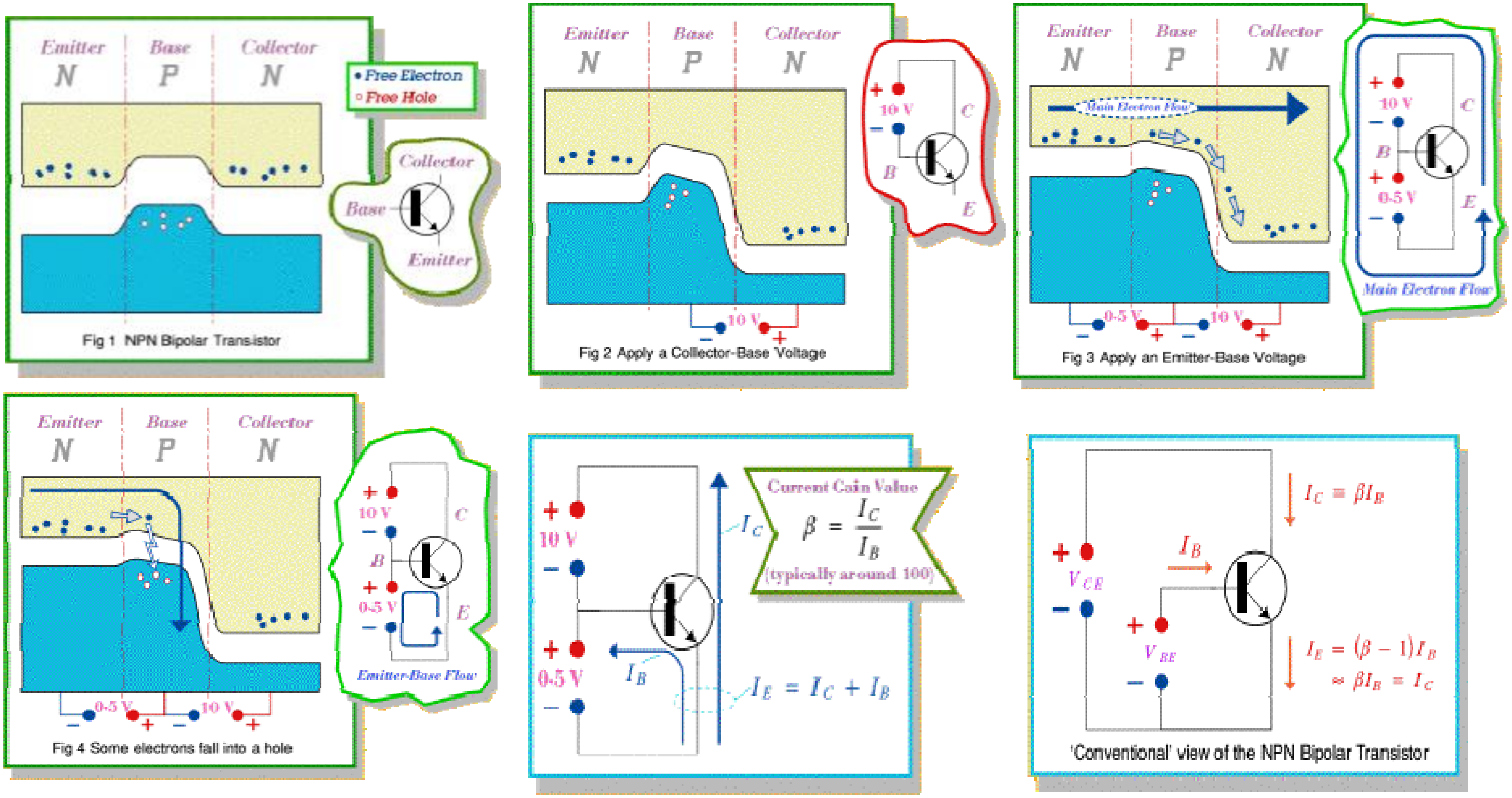


At equilibrium, $V_{BE} = V_{BC} = 0$



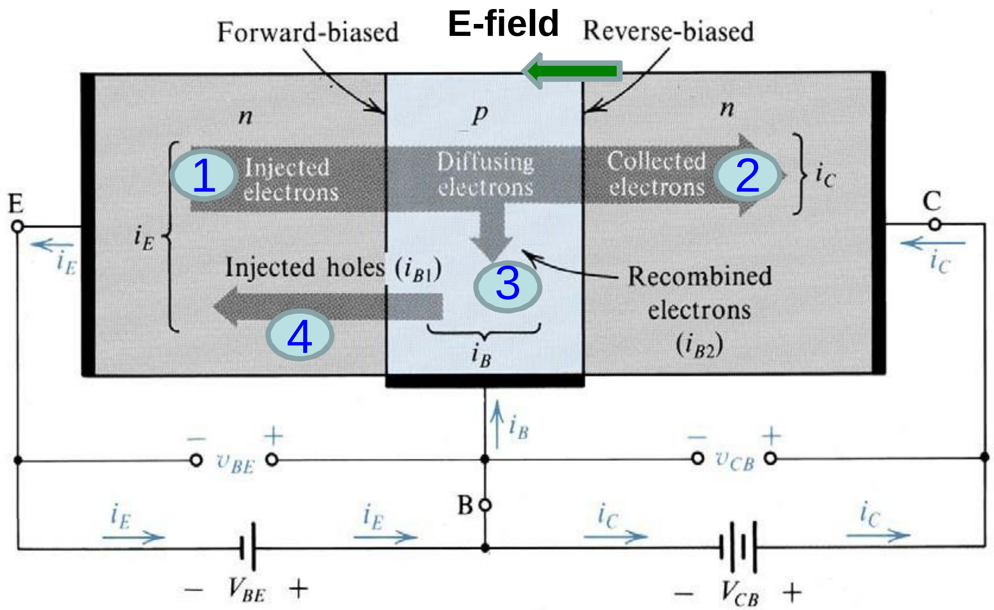
forward active mode

DC operation of npn BJT under forward active mode



Reference: From L.C.G. Lesurf's (University of St. Andrews) The Scot's Guide to Electronics

DC operation of npn BJT under forward active mode



- 1 . Forward bias of EBJ causes electrons to diffuse from emitter into base.
- 2. As base region is very thin, the majority of these electrons diffuse to the edge of the depletion region of CBJ, and then are swept to the collector by the electric field of the reverse-biased CBJ.
- 3. A small fraction of these electrons recombine with the holes in base region.
- 4. Holes are injected from base to emitter region. (4) << (1).

- The two-carrier flow from [(1) and (4)] forms the emitter current (I_E).

DC operation of npn BJT under forward active mode

Collector current

Collector-base diode is reverse biased therefore $V_{CB} > 0$

$$I_C = I_s\left[e^{\left(\frac{eV_{BE}}{kT}-1\right)}\right]$$

where

$$I_s = \frac{qA_eD_nn_{po}}{W} = \frac{qA_eD_nn_i^2}{N_AW}$$

A_e	Area of base-emitter junction
W	Width of base region
N_A	Doping concentration in base
D_n	Electron diffusion constant
n_i	Intrinsic carrier concentration = f(T)

I_C is independent of collector voltage

Base current

➢ Base current consists of two components: *i_{B1} and i_{B2}:*

❖ *i_{B1}, due to forward bias of EBJ, is an exponential function of V_{BE}.*

❖ *i_{B2}, due to recombination, is directly proportional to the numbers of* electrons injected from the emitter, which in turn is an exponential function of *V_{BE}.*

Forward Active Mode common base current gain (α)

In common base configuration, the **current transfer mode ratio (α) of a bipolar transistor in the forward active mode is defined as the ratio of the collector current** (I_C) to the emitter current (I_E):

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

$$I_E = I_C + I_B$$

Forward Active Mode common emitter current gain (β)

The **current gain (β) of a bipolar transistor under common emitter forward active mode is defined as the ratio of the collector current** (I_C) to the base current (I_B):

$$\beta = \frac{I_C}{I_B}$$

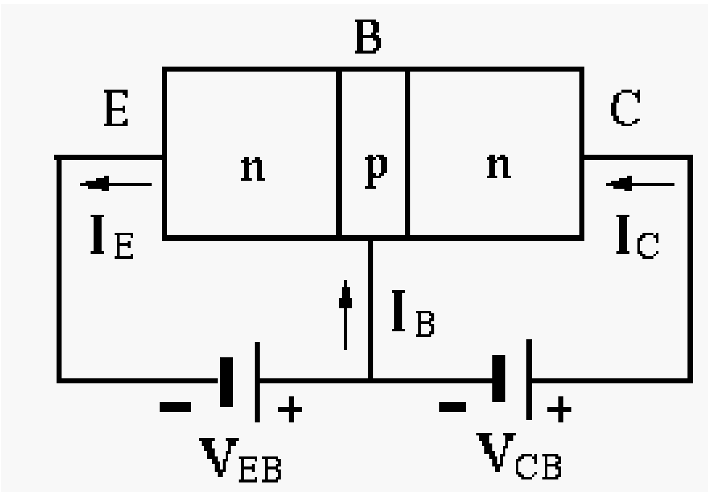
$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

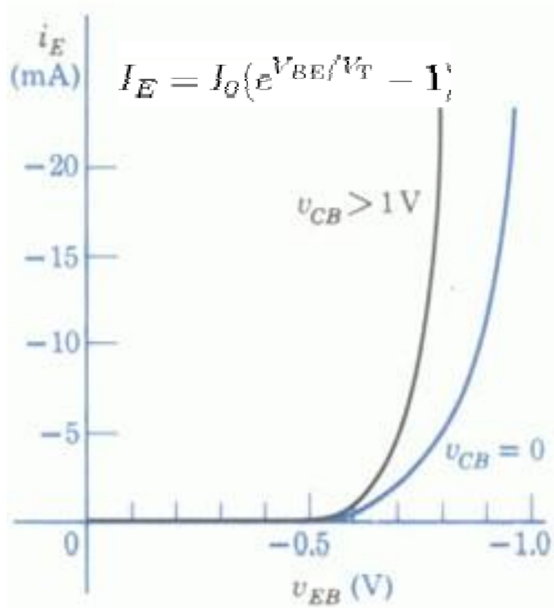
$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

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

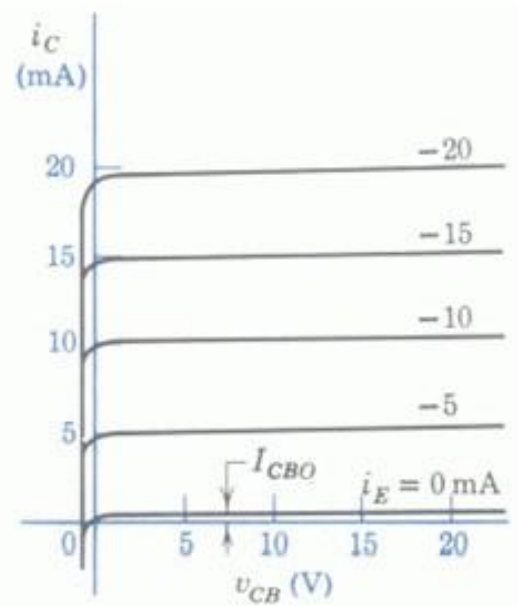
I-V Characteristics of npn BJT under forward active mode

Common Base configuration





Input characteristics



Output characteristics

➢Input characteristics are like a normal forward biased diode. As V_{CB} increased I_E also increased due to Early Effect (increased reverse biased at CB junction causes reduction in effective base width) .

➢As the CB junction is reverse biased, the current I_C depends totally on I_E. When I_E=0 , I_C=I_{CB0} is the current caused by the minority carriers crossing the pn-junction. I_{cB0} is leakage current called as collector base current with emitter open. When I_E is increased, I_C is increased correspondingly. $I_C = \alpha I_E + I_{CB0}$