BJT

Background

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Vacum tube:

- Expensive
- Large
- Power consumed
- Vacum leaks
- Repeated heating

Moore's Law

Moore's law is the observation that the number of transistors in a dense integrated circuit (IC) doubles about every two years.

It is an observation and projection of a historical trend. Rather than a law of physics, it is an empirical relationship linked to gains from experience in production.

Structure

- Three regions two pn junctions.
- Regions: Emitter, Base and collector
- Two types: npn and pnp
- Base in middle, emitter and collector are made of same semiconductor.

Base → Lightly doped and very thin.

Emitter → Heavily doped.

Collector → Moderately doped.

- Total width to that of the center layer ratio 150:1.
- Doping of sandwiched layer to outer layer 10:1 or less.
- Bipolar: Both electron and hole conduct current/carriers.

Operation (Amplifier)

- BE junction Forward-Biased and BC junction Reverse-Biased.

→ Heavily doped n-type emitter region → free electrons → diffuse through the forward biased BE junction → lightly doped p-type base region → Base has low density of holes → majority carrier → small percentage of electron recombine with holes → move as valance electron → base region and into the emitter region as hole current.

→ Electrons recombined with holes → leave the crystalline structure → become free electron in the metallic base lead and produce the external base current.

→ Most of the electrons don't recombine with hole (base thin) → swept across into the collector region → positive collector supply → move through collector external circuit and return emitter region with base current.

$$I_E = I_B + I_C$$

1. $\beta_{DC} = \dfrac{I_C}{I_B}$

$I_E = I_B + I_C$

2. $\alpha_{DC} = \dfrac{I_C}{I_E}$

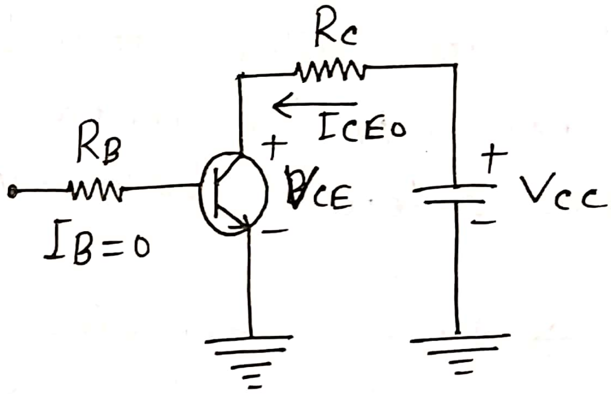
Region of Operation

Saturation: Both junctions are forward-biased.

Active/Linear: BE forward
BC reverse

Cutoff: Both reverse

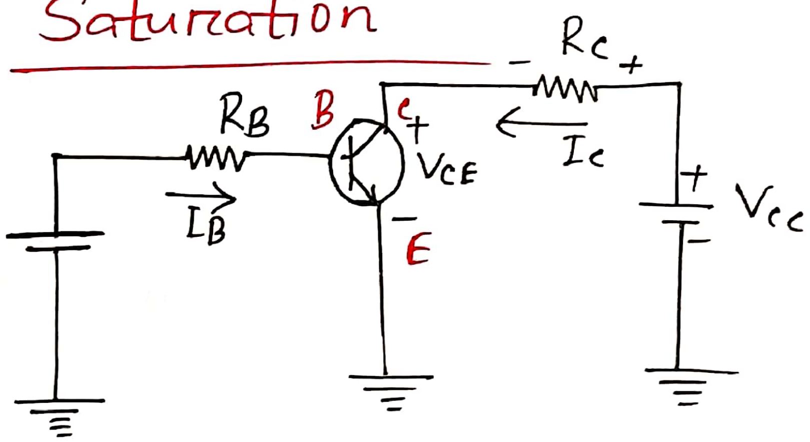
Cutoff



Base lead open.
$I_B = 0 \rightarrow$ cutoff

Small amount of collector leakage current, I_{CEO}.

Saturation



BE junction becomes forward → I_B increases

I_C also increases as $\boxed{I_C = \beta I_B}$ and

V_{CE} decreases. as $V_{CE} = V_{CC} - I_C R_C$

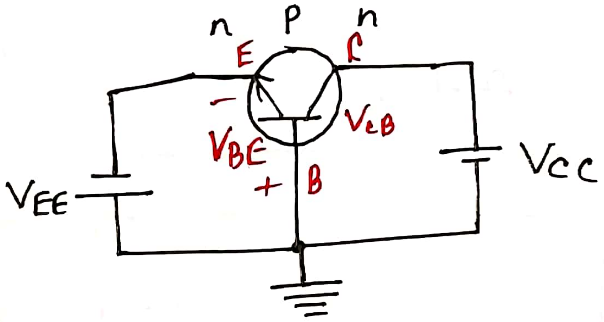
At saturation V_{CE} BC junction becomes forward biased, I_C can increase no farther, $I_C = \beta I_B$ not applicable.

DC Load Line

Common Base

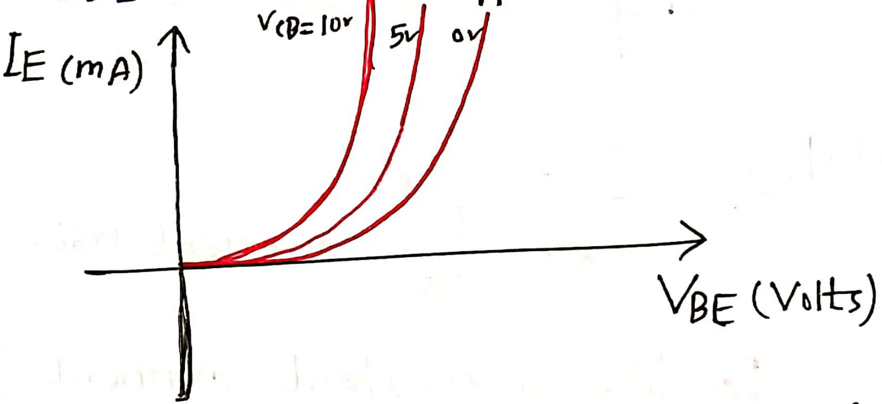
Input Characteristics : CB

- Base common
- Input: EB terminal and output: CB terminal.



- Same as the characteristics of Diode.

Input: I_E and V_{BE} || V_{CB} constant



As the V_{CB} increases, the curve shifts left side, I_E also increases. As reverse biase increases width of the deplation region also increases. Base narrow → Less voltage needed for forward biased. ∴ Curve shift.

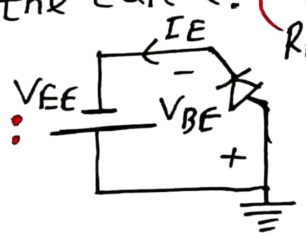
Input Impedance → slope of the curve. (Very low) $R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}$

small

huge change

Low

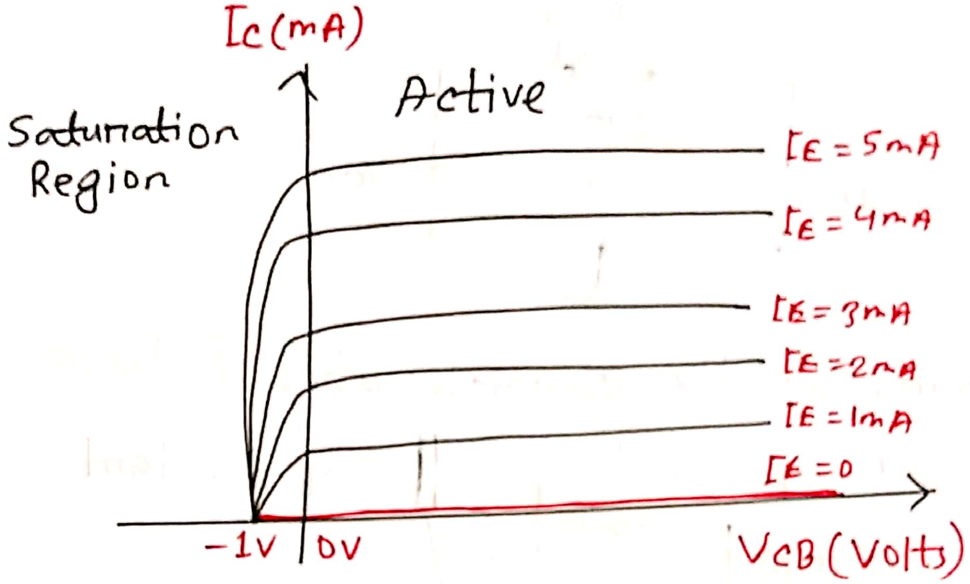
Keeping V_{CB} at zero voltage:



Output characteristics : CB

Voltage: V_{CB}
Current: I_C

$\boxed{I_E = \text{constant}}$



Active: $I_C = \alpha I_E$

$$\alpha = \frac{I}{I_E} \quad \text{current Gain}$$

Ic like a constant current source.

For a fixed value of Emitter Current, Ic is independent of V_{CB}. Region is used for Amplifier as Ic only depends on input current I_E.

Saturation:

V_{CB} Reduced → I_C starts reducing.

Reverse bias remove → electron can not able to collector junction → I_C reduced.

Both are forward → saturation.

Cutoff:

$I_E = 0$ → Even increases collector to Base voltage (V_{CB}) → $I_C = 0$

V_{BE} removed → $I_E = 0$

$$I_C = \alpha I_E$$

$$\therefore I_C = 0$$

But small leakage current for minority carrier.

I_{CBO}

$$I_{CT} = I_C + I_{CBO}$$

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

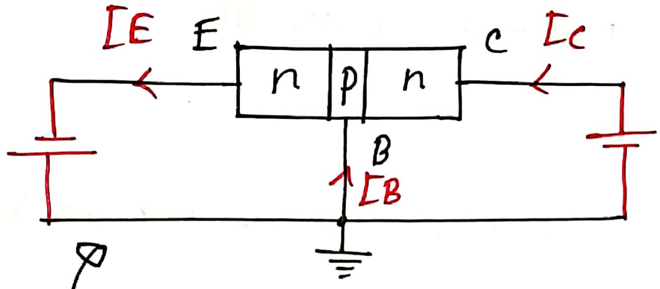
Output Impedance: $R_o = \dfrac{\Delta V_{CB} \rightarrow \text{High}}{\Delta I_C \rightarrow \text{low}}$

$\boxed{\text{very High}}$

Common Base

Input characteristics : CB

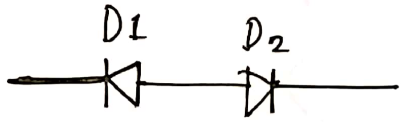
Forward Bias Diode.



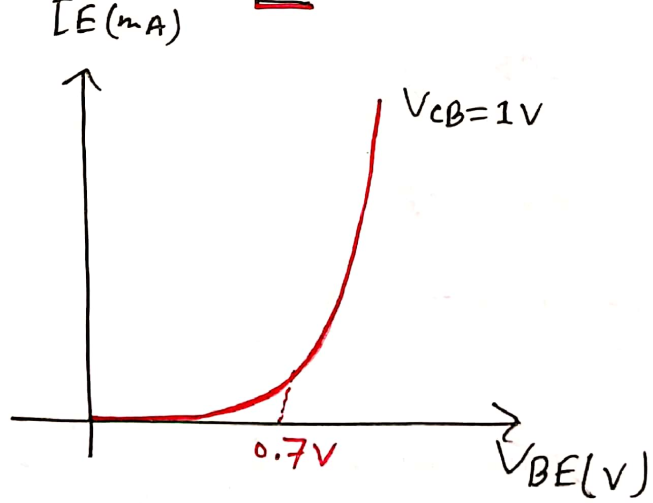
Active:

i/p $I = I_E$
i/p $V = V_{BE}$

o/p $I = I_C$
o/p $V = V_{CB}$

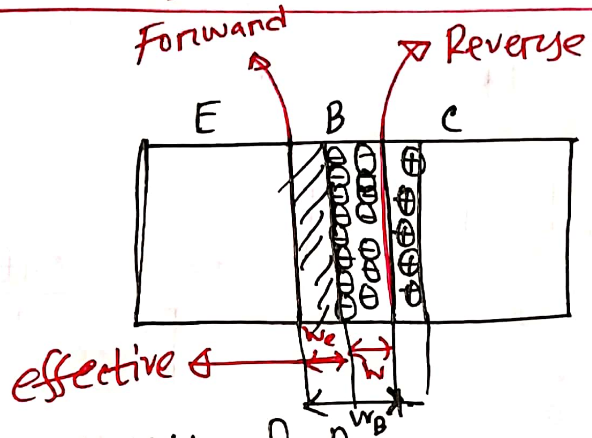


For active mode,
- D1 → Forward Bias
- D2 → Reverse Bias



Change V_{CB}: Early effect

Early effect / Base Width Modulation



Reverse : Depletion region increases, penitrated more in base region as lightly doped.

$W_B \rightarrow$ Width of Base

$$W_B = W_{eff} + W$$

$$W_{eff} = W_B - W$$

$V_{CB}\uparrow \Rightarrow W\uparrow \Rightarrow W_{eff}\downarrow$

$\swarrow$

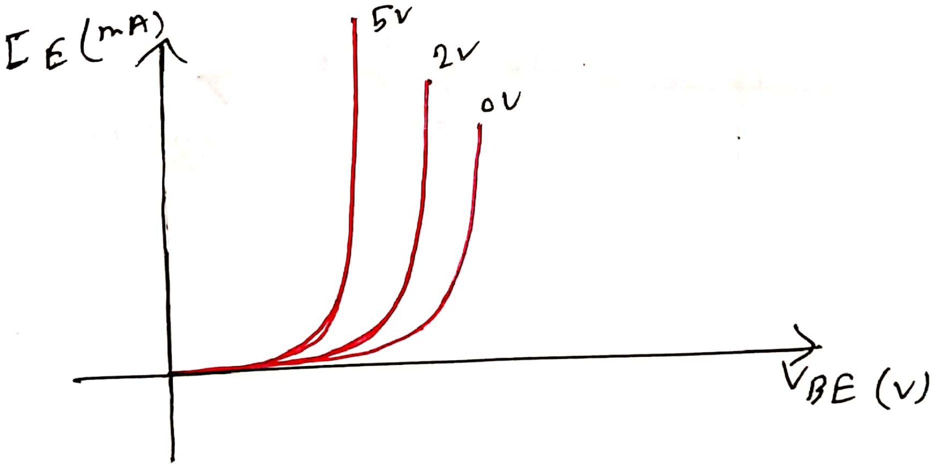
chance of recombination also decreases.

$\Downarrow$

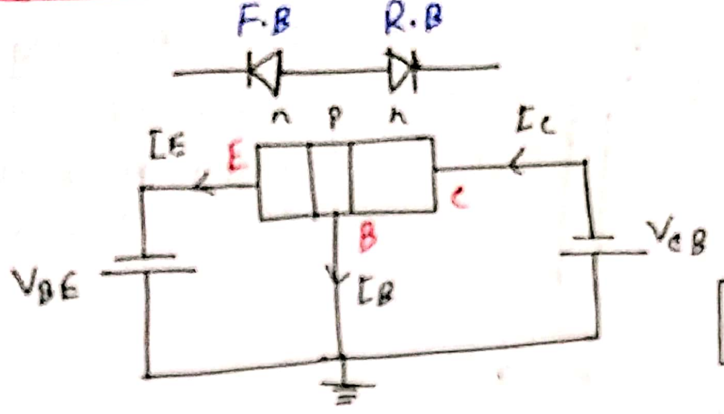
Input current $I_E \uparrow$

Concentration Gradient: Increases

Electron movement increase $\rightarrow I_E\uparrow$



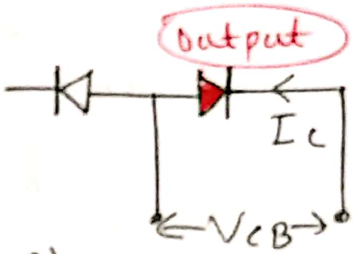
Output characteristics : CB



Output: $\boxed{V_{CB}}$ $\boxed{I_C}$

constant: I_E

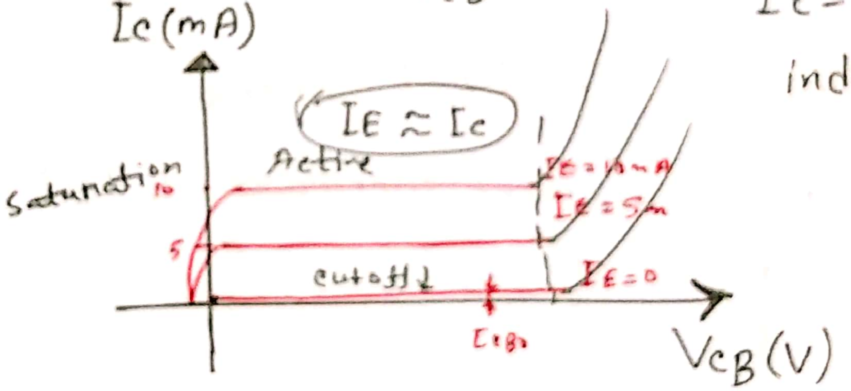
Active: BE → Forward, CB → Reverse } $I_E \approx I_C$



Reverse characteristics

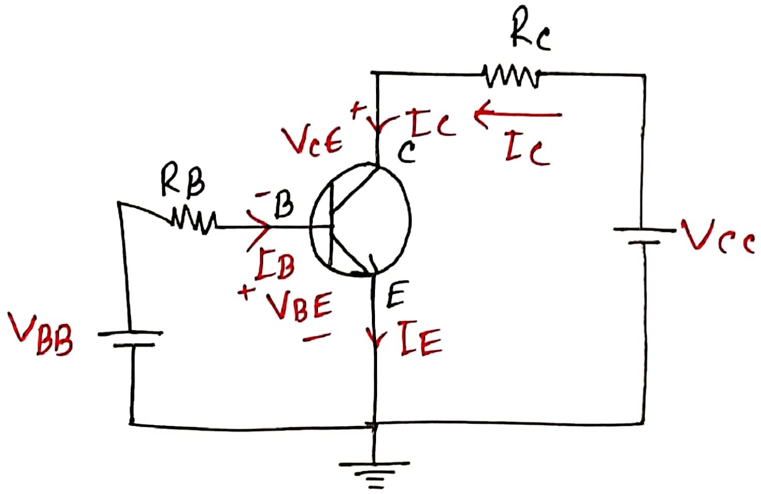
$I_C = \alpha I_E + I_{CBO}$

independent of V_{CB}

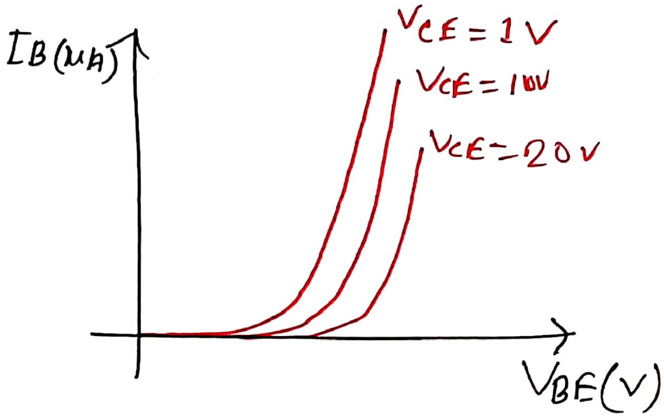


Common Emitter

Input characteristics : CE



The characteristics of the forward diode.

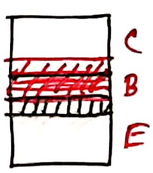


V_{CE} increases Base current I_B reduces.

$\uparrow V_{CE} = \uparrow V_{CB} + \boxed{V_{BE}}$ Fixed

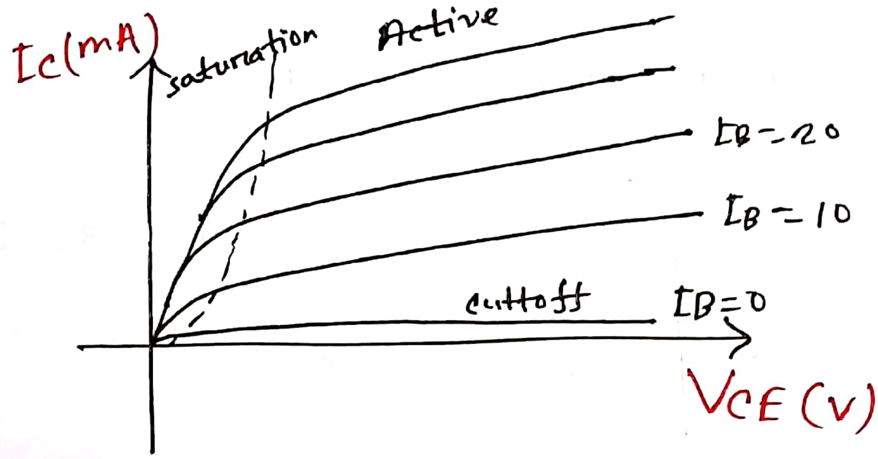
Reverse biase also increase in CB junction.

Recombination decreases.
Most of the electrons are collected by the collector terminal.



Output : CE

Output: I_C vs V_{CE}



Active: I_B increases $\rightarrow$ I_C increases

Not totally horizontal.

V_{CE} increases $\rightarrow$ V_{CB} also increases.

$$\boxed{V_{CE} = V_{CB} + V_{BE}}$$

V_{CE} increases $\longrightarrow$ I_C also increase.

$$I_C = \beta I_B$$

Saturation:

CB Forward Biased

Cutoff

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

Leakage current

Cutoff: $I_B = 0$

$I_C \rightarrow$ not zero (Large than CB)

$\boxed{I_B = 0}$

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

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

$$\Rightarrow (1-\alpha) I_C = \alpha I_B + I_{CBO}$$

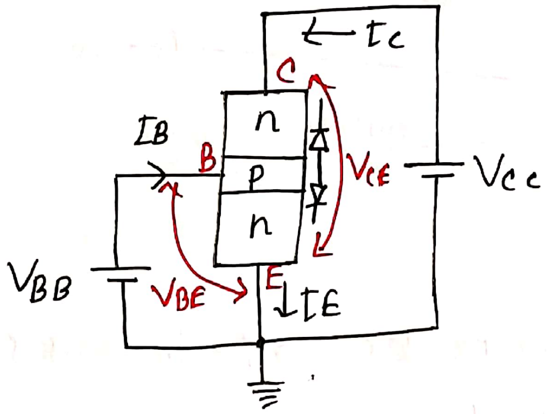
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \qquad I_C = \beta \underbrace{\cancel{I_B}}_{0} + \frac{1}{1-\alpha} I_{CBO}$$

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

I_C high

Common Emitter

Input characteristics: CE

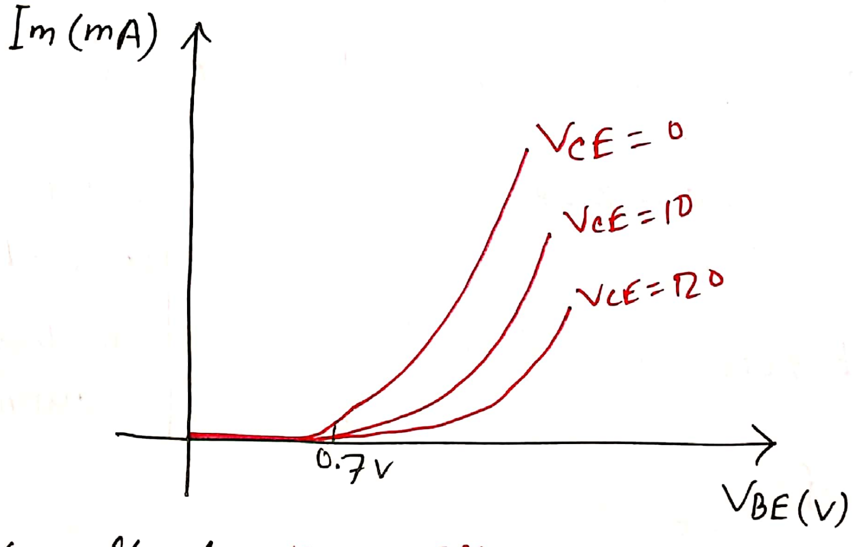


I/p : V_{BE}, I_B

V_{CE} constant

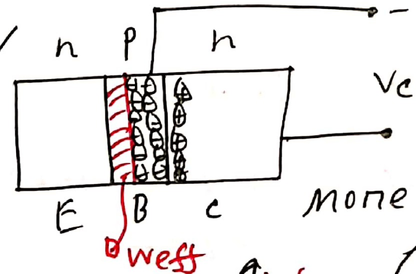
{ Current through the diode
Voltage across the diode

characteristics of Diode



V_{CE} effect: Early Effect

Recombination Reduced → I_B reduced



more in Base → width reduced (W_{eff})

$\uparrow V_{CE} = (V_{CB}\uparrow) + V_{BE}$

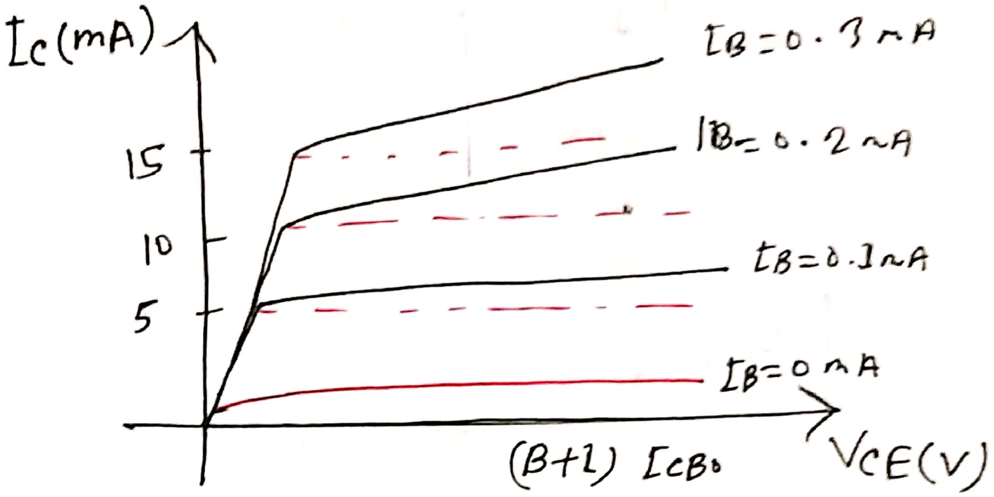
Width of depletion Region also increase.

Output characteristics: CE

O/P : I_C Vs V_{CE} [I_B constant]

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

$$I_C = (\beta+1) I_{CBO} \quad [I_B = 0]$$



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

I_C depends V_{CE}

$\uparrow V_{CE} = \uparrow V_{CB} + V_{BE}$

Weff decreases I_B decrease

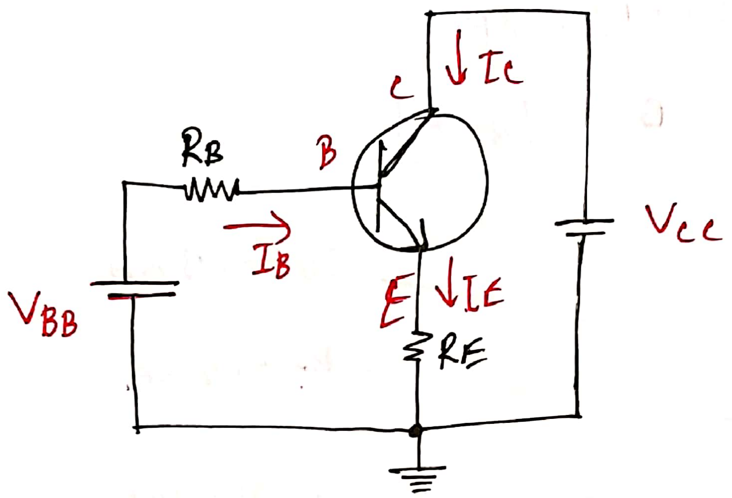
$\downarrow$

I_C current increases

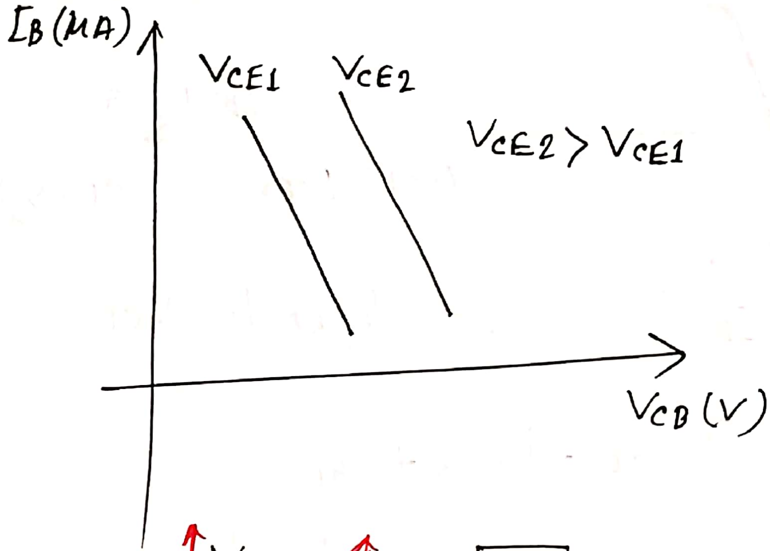
I_B depends on Both $\rightarrow V_{CE}$, $\rightarrow I_B$

Common Collector

Input characteristics : CC



I/P: I_B/V_{CB}



$V_{CE2} > V_{CE1}$

$\uparrow V_{CE} = \uparrow V_{CB} + \boxed{V_{BE}}$

Fixed

Depletion Region Increases
Weff decreases

<u>I_B reduces</u>

For V_{BE} increased → More electrons pushed → I_B increase.

$$\boxed{\gamma = \frac{I_E}{I_B}}$$

$$I_E = I_C + I_B$$

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

$$\boxed{\gamma = \beta + 1}$$

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

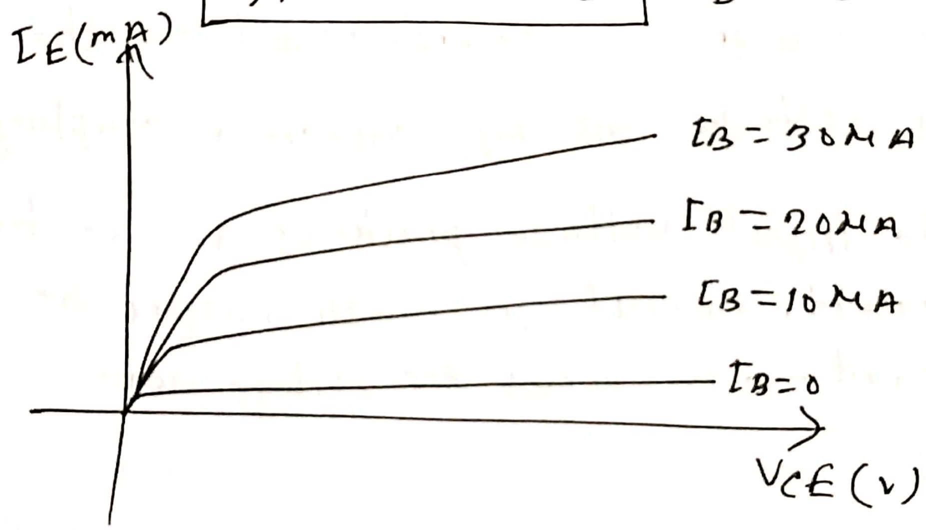
$$\therefore \gamma = \frac{\alpha}{1-\alpha} + 1 = \frac{1}{1-\alpha}$$

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

$$\alpha\gamma = \frac{\alpha}{1-\alpha} = \beta \qquad \boxed{\alpha\gamma = \beta}$$

Output Characteristics: CC

$\boxed{\text{O/P}: I_E \text{ vs } V_{CE}}$ I_B constant

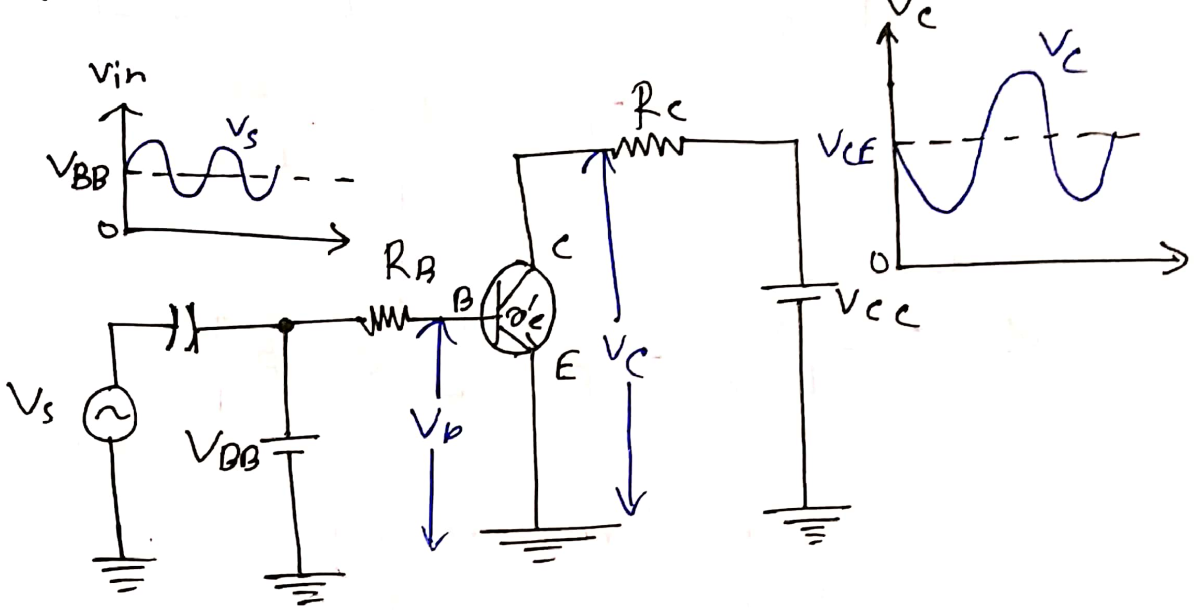


Same as CE configuration

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

BJT As An Amplifier

We know transistor amplifies current because the collector current is equal to βI_B.



- Ac voltage V_s superimposed on the dc bias voltage V_{BB} by capacitive coupling.

- Ac input voltage produces an ac base current, result in much larger ac collector current → Produces Ac voltage across R_C.

- Thus produce an amplified, inverted, reproduction of the ac input voltage in the active region.

→ FB B-E junction presents a very low resistance (r'_e), appear in series with R_b.

The ac base voltage:

$$V_b = I_e r'_e$$

The ac collector voltage:

$$V_c = I_c R_c = I_e R_c \quad [\text{as } I_e \simeq I_c]$$

$$= V_{out}$$

Again,

$$V_b = V_s - I_b R_b = V_{in}$$

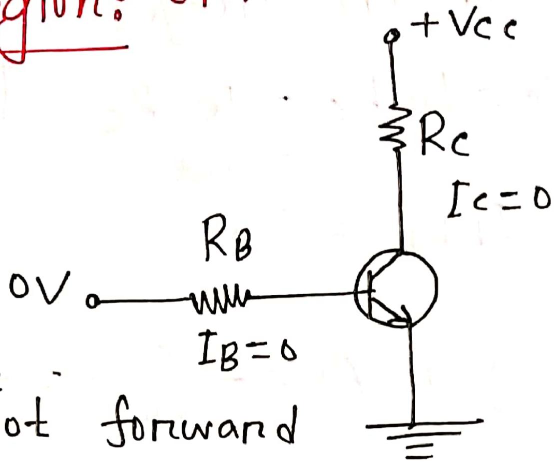
Voltage gain, $A_v = \dfrac{V_c}{V_b} = \dfrac{I_e R_c}{I_e r'_e}$

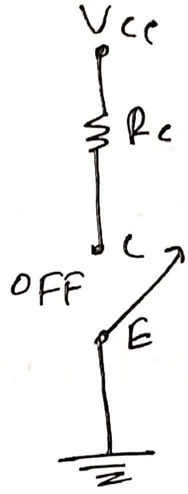
$$\therefore A_v = \frac{R_c}{r'_e}$$

Here R_c is always Larger than r'_e.

BJT as Switch

Cutoff Region: OFF

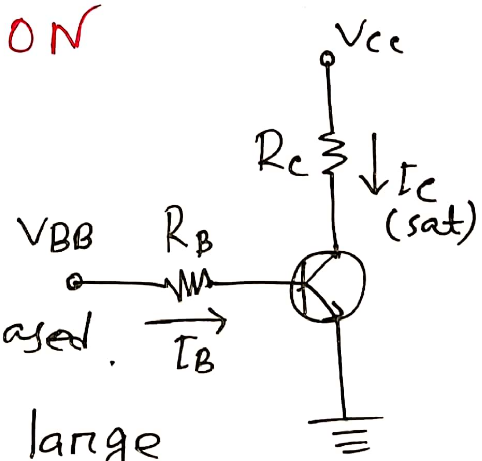


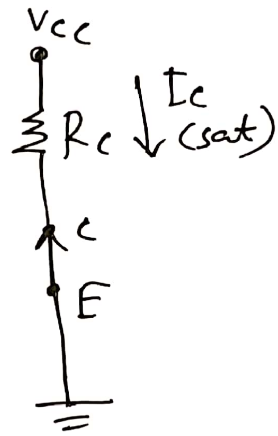


Base-emitter junction is not forward biased, ideally open between collector and emitter. Can be indicated by switch equivalent.

Neglecting leakage current, $V_{CE} = V_{CC}$.

Saturation: ON





BE and CB junctions both are forward biased.

Base current large enough to case the collector current to reach in saturation value. In this condition there is a short (ideally) between collector and emitter.

$$I_C(sat) = \frac{V_{CC} - V_{CE}(sat)}{R_C}$$ can be neglected

Minimum Base current for saturation:

$$I_B(min) = \frac{I_C(sat)}{\beta_{DC}}$$