Bipolar Junction Transistor

3 Qs ????

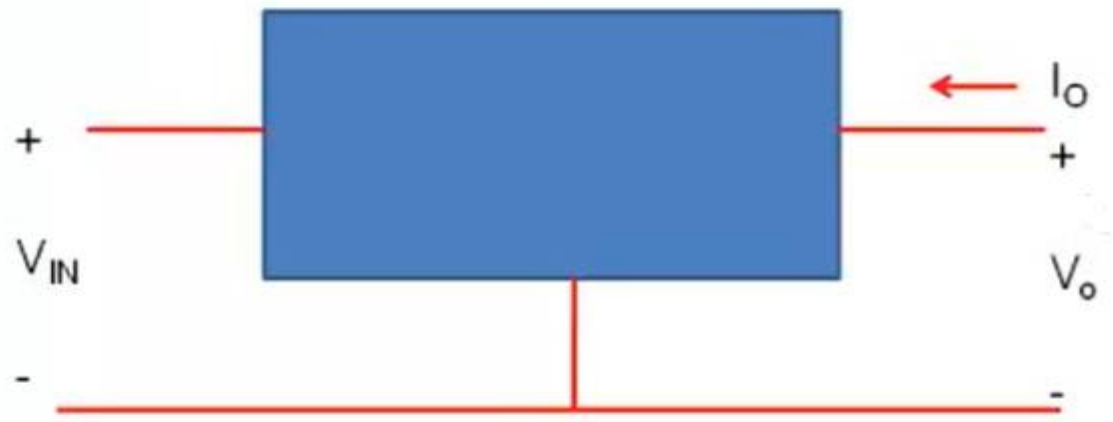
- What is transistor action and how does it occur in a BJT?

- Is BJT two back-to-back diodes connected together?

- How does a BJT amplify?

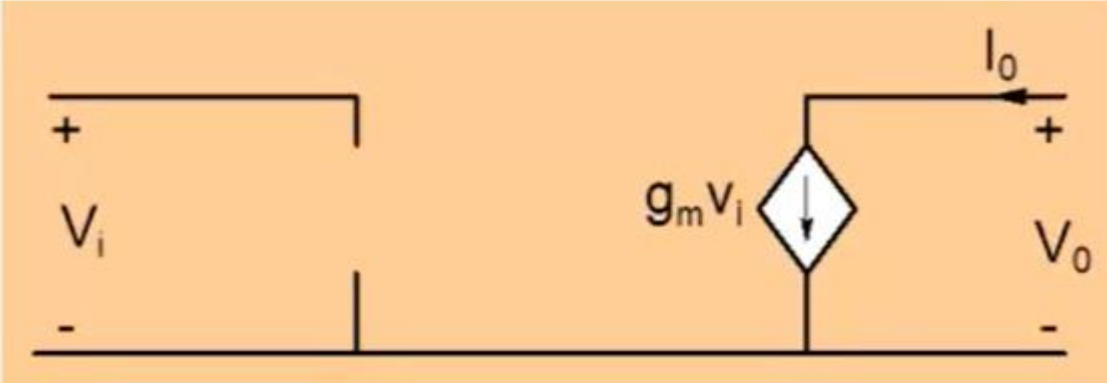
Transistor

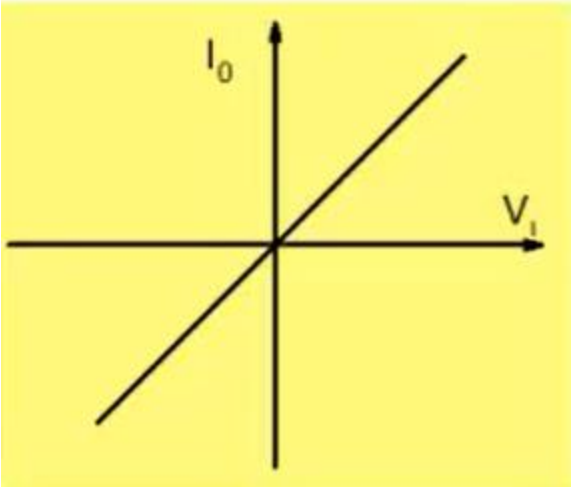
Trans-resistor



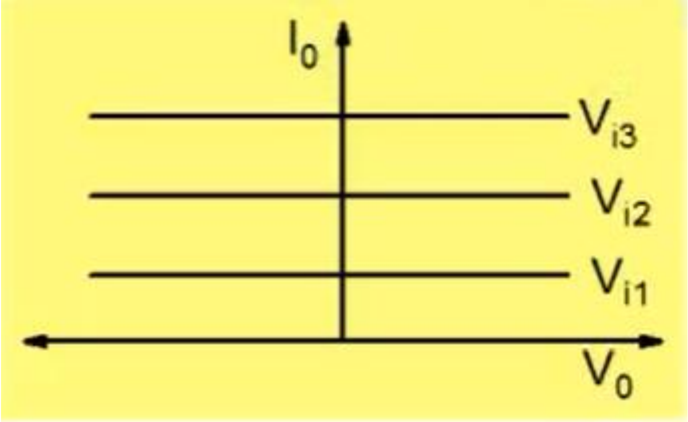
Current I_O is much more sensitive to V_{IN} than V_O

"Ideal Transistor"





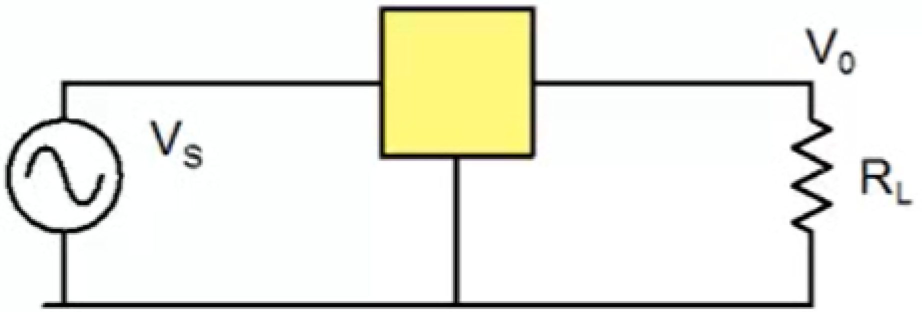
Transfer Characteristics

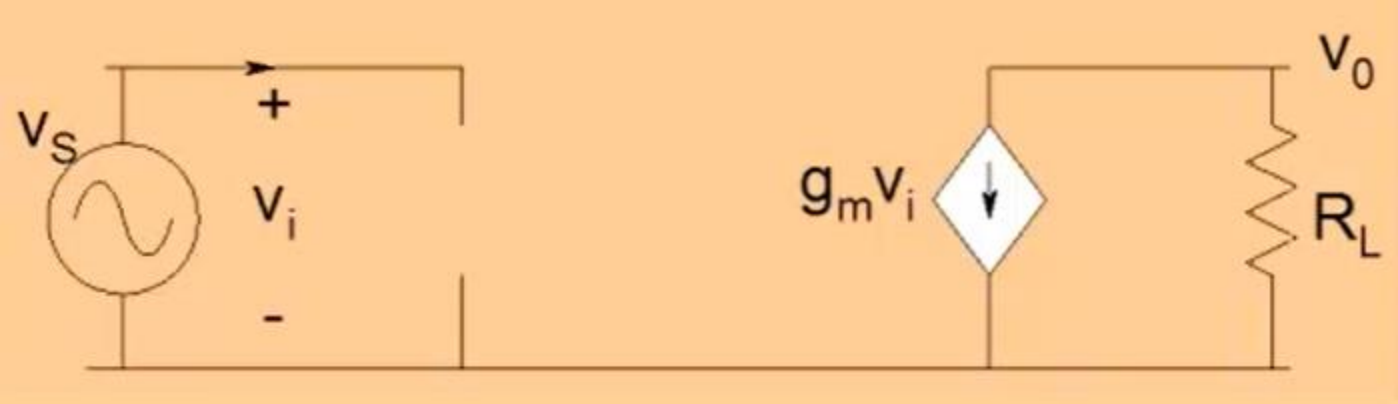


Output Characteristics

Voltage controlled Current Source (VCCS)

Transistors can be used for AMPLIFICATION

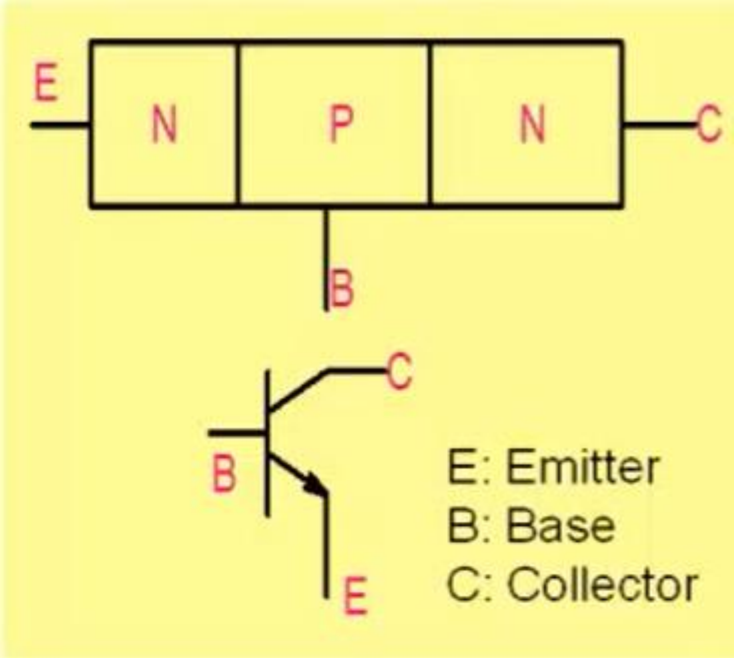




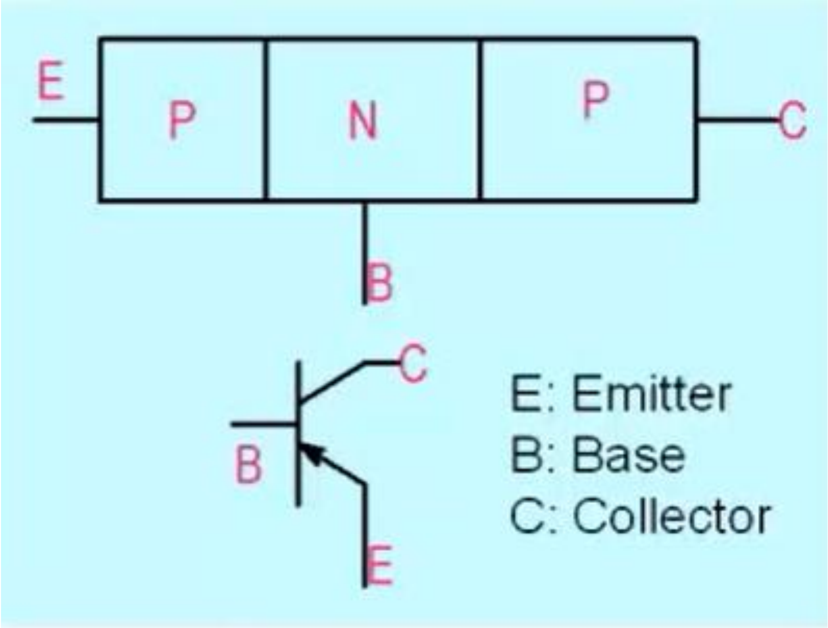
$$A_V = \frac{V_o}{V_s} = -g_m \times R_L$$

By choosing sufficiently larger load resistance, voltage gain can be obtained

Bipolar Junction Transistor (BJT)

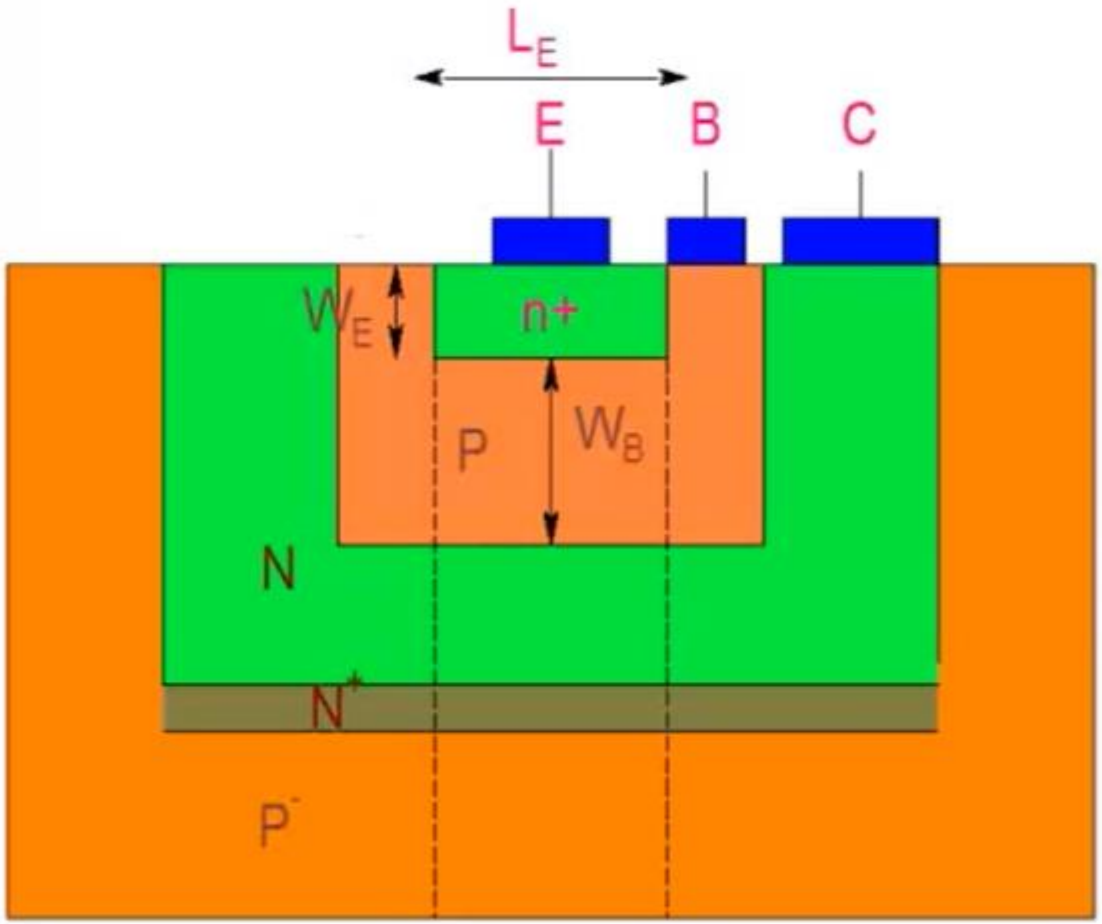


NPN



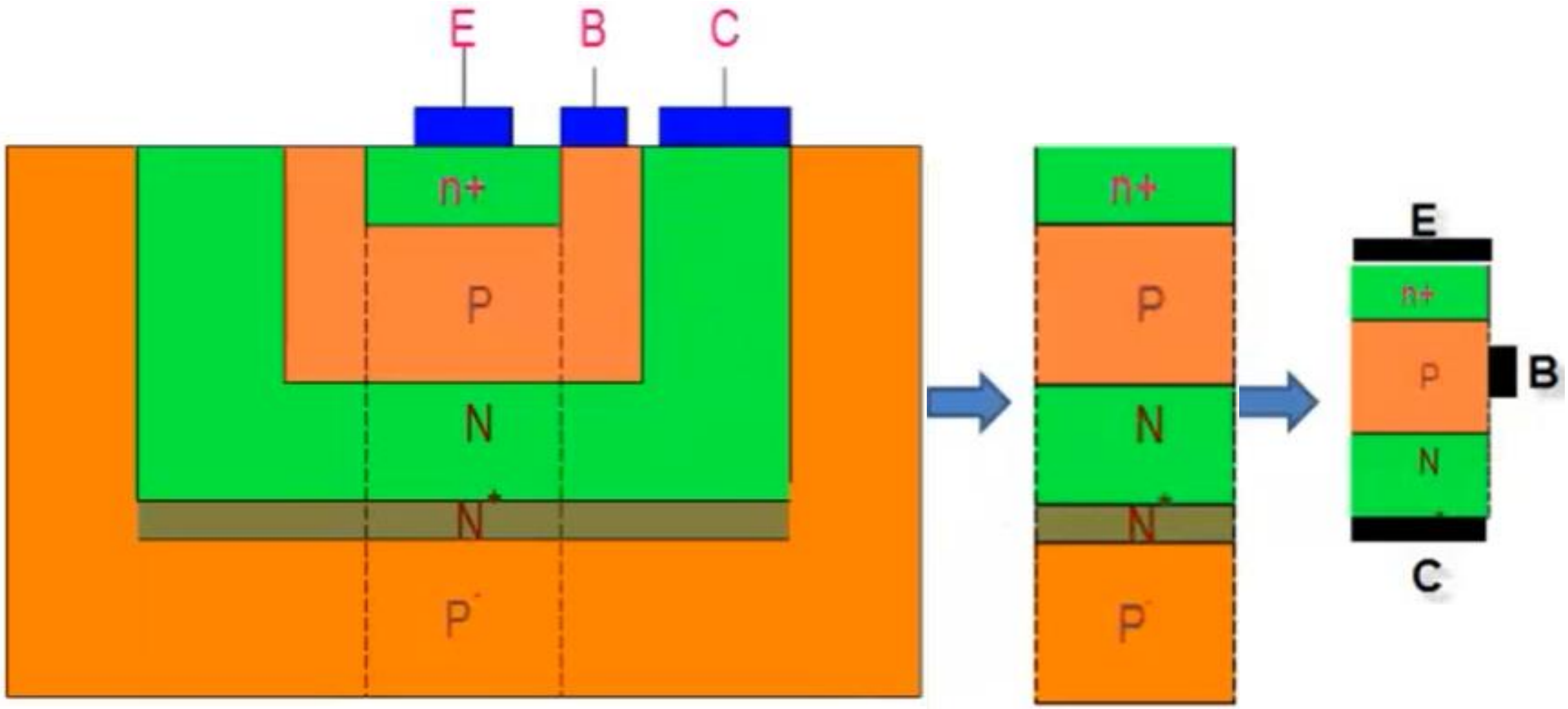
PNP

More Realistic View



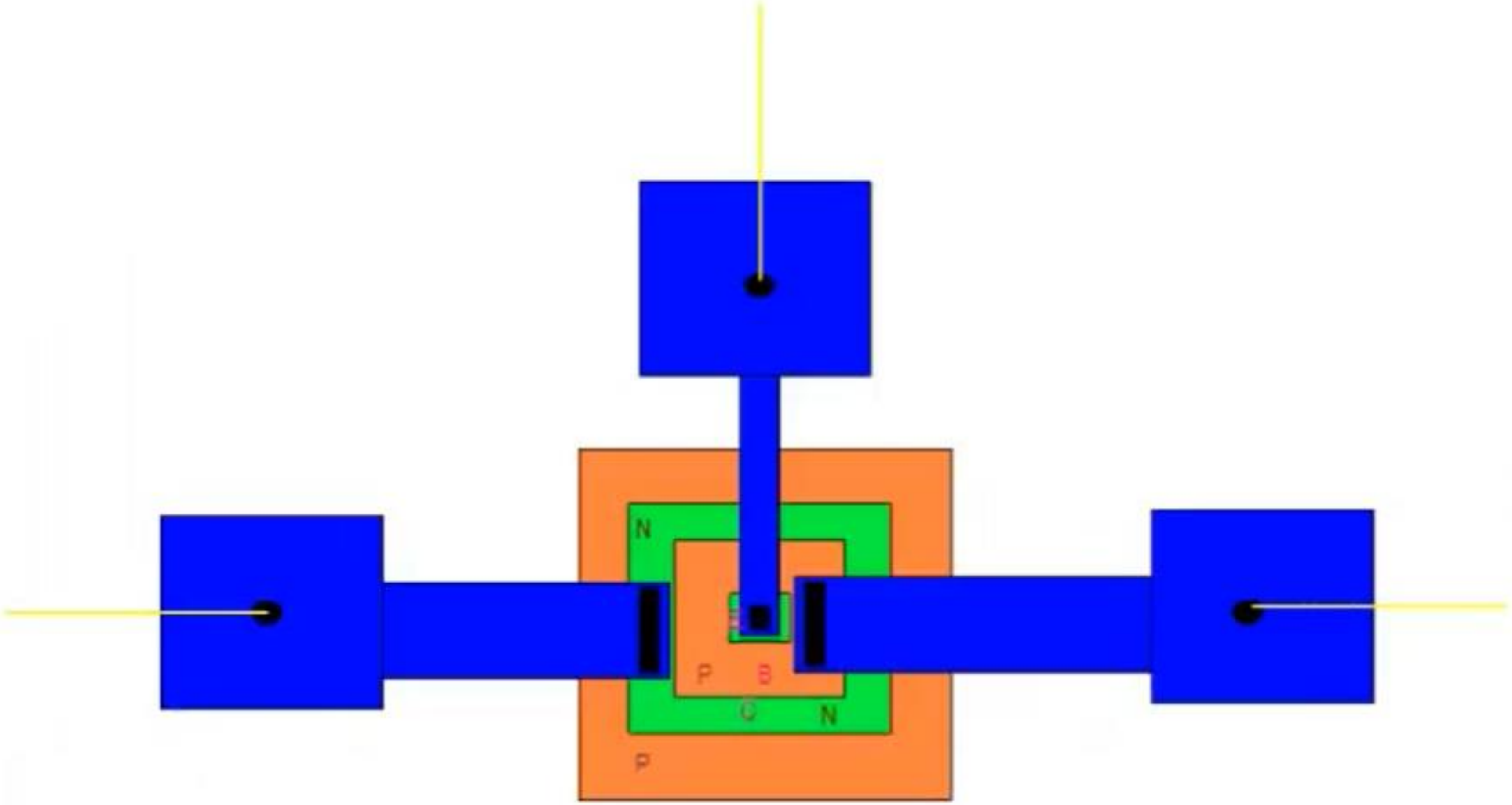
$$N_{DE} \sim 10^{19}\ cm^{-3}$$
$$N_{AB} \sim 10^{17}\ cm^{-3}$$
$$N_{DC} \sim 10^{16}\ cm^{-3}$$
$$W_B \sim 2000 A^\circ$$
$$W_E \sim 1000 A^\circ$$
$$L_E \sim 1 \mu m$$

BJT is not symmetric: emitter and collector cannot be simply interchanged

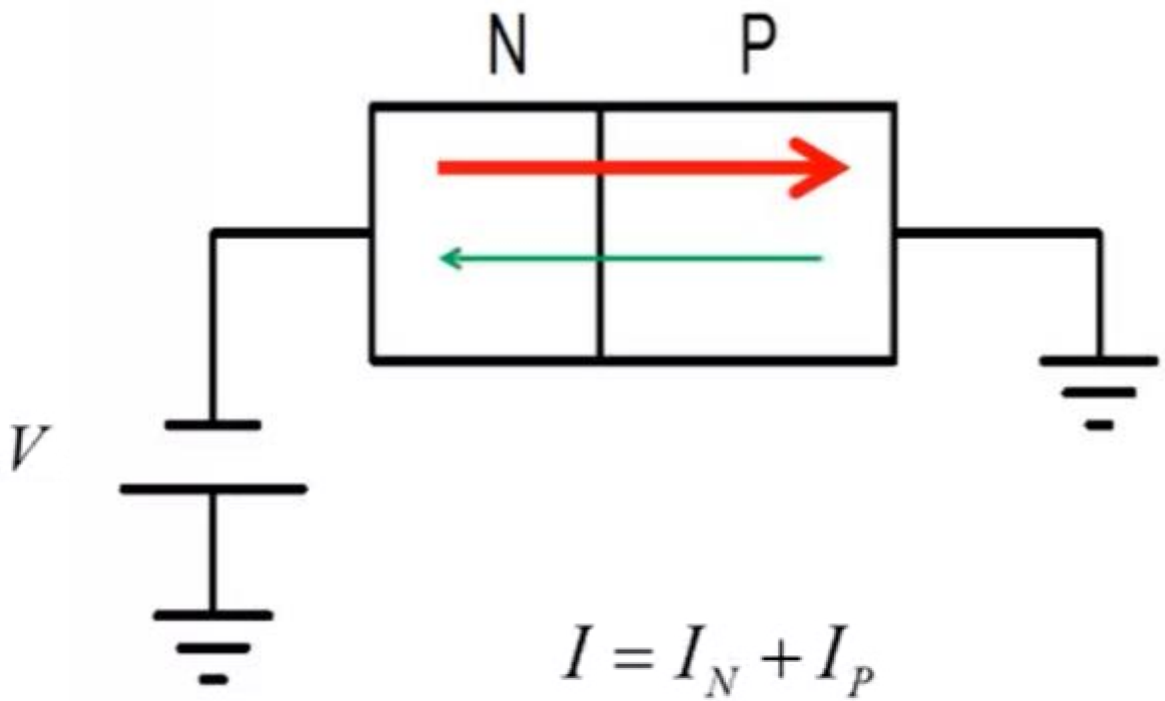


E
B
C
n+
P
N
N+
P-
n+
P
N
N+
P-
E
n+
P
B
N
C

Top View



Background

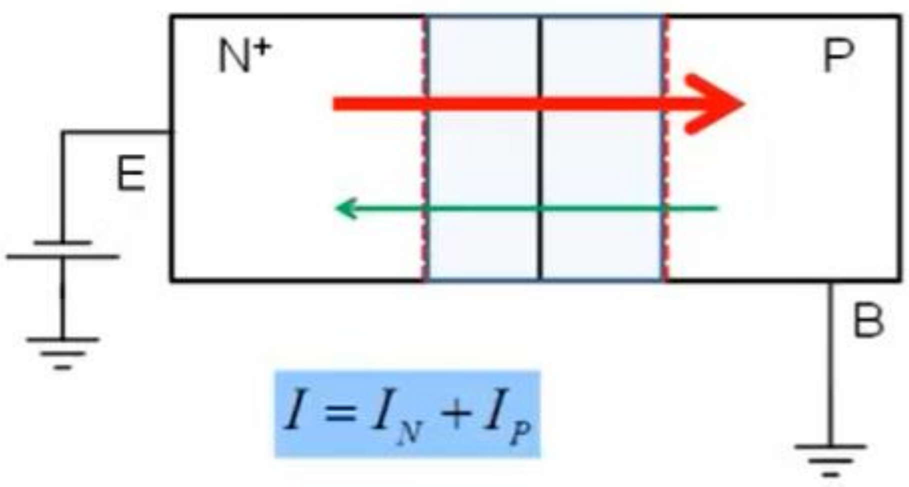


$$I = I_N + I_P$$

$$I_N; I_P \propto \exp(\frac{V}{V_T})$$

If doping in N region is much larger than doping in p region then $I_N >> I_P$

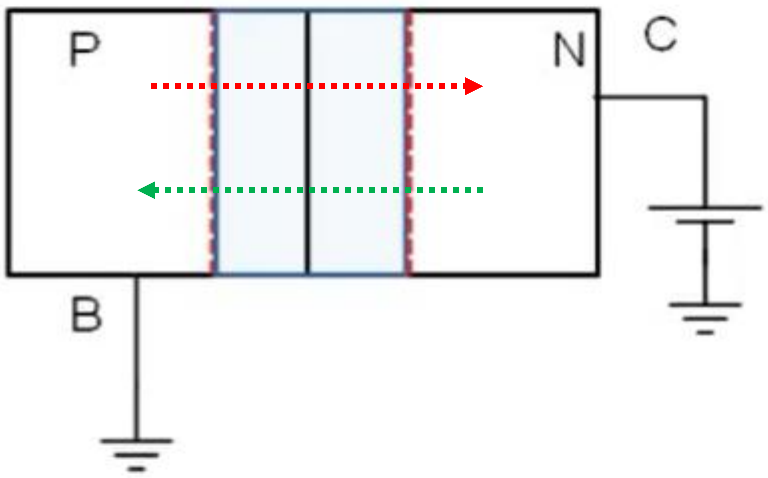
Basic Transistor Operation



$$I = I_N + I_P$$

We will assume that doping in emitter is much more than base so that electron current is much larger than hole current

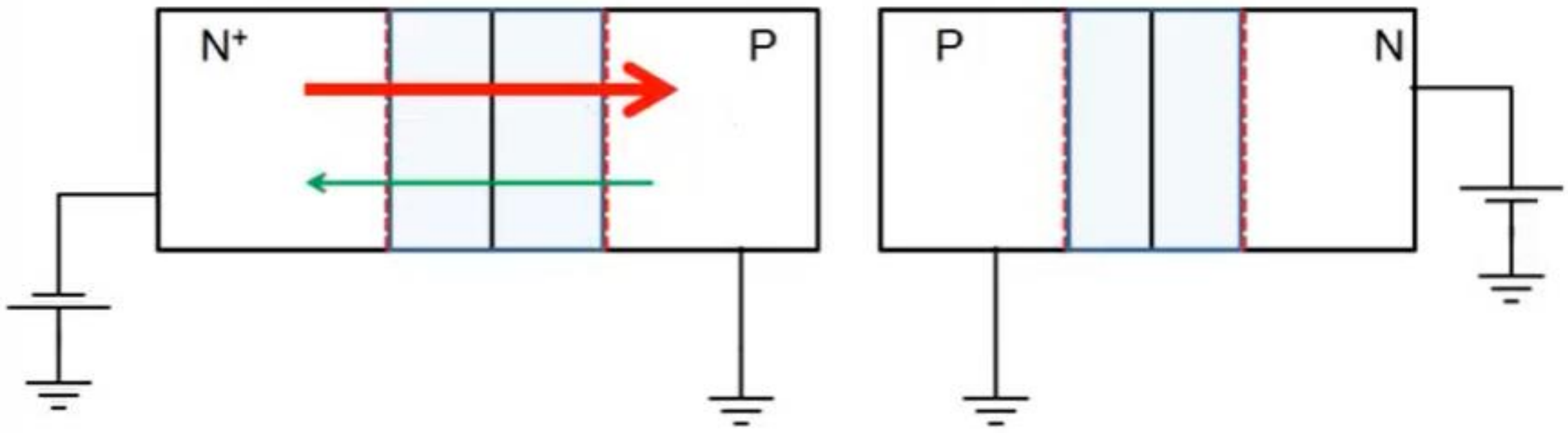
$$I_N >> I_P$$

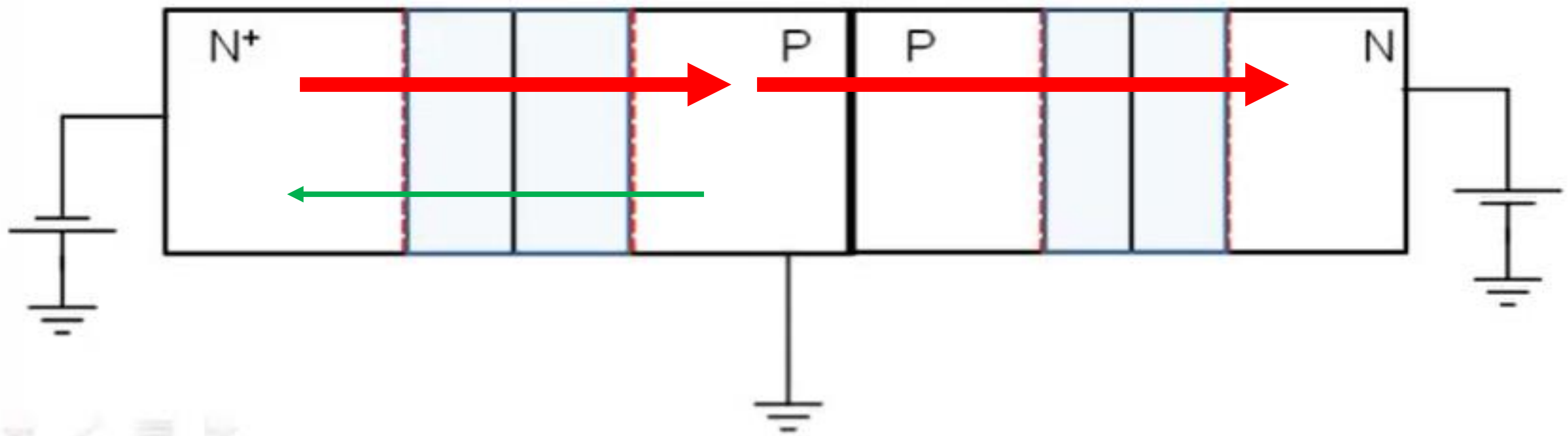


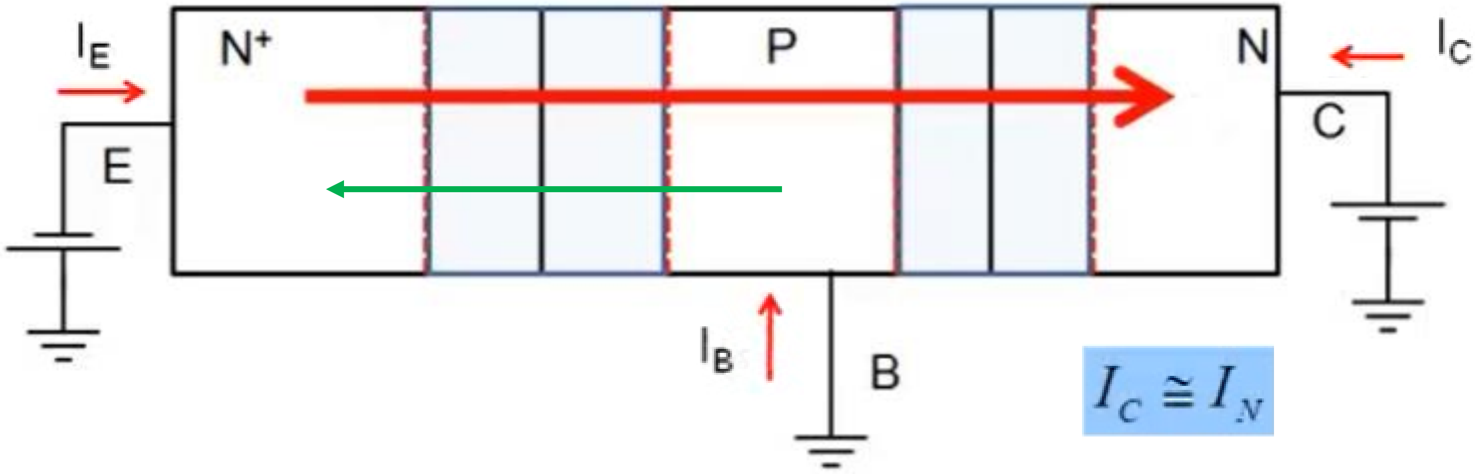
In the reverse biased junction current is small because there are very few electrons in P and holes in N-region

Basic Transistor Operation

$$I = I_N + I_P$$



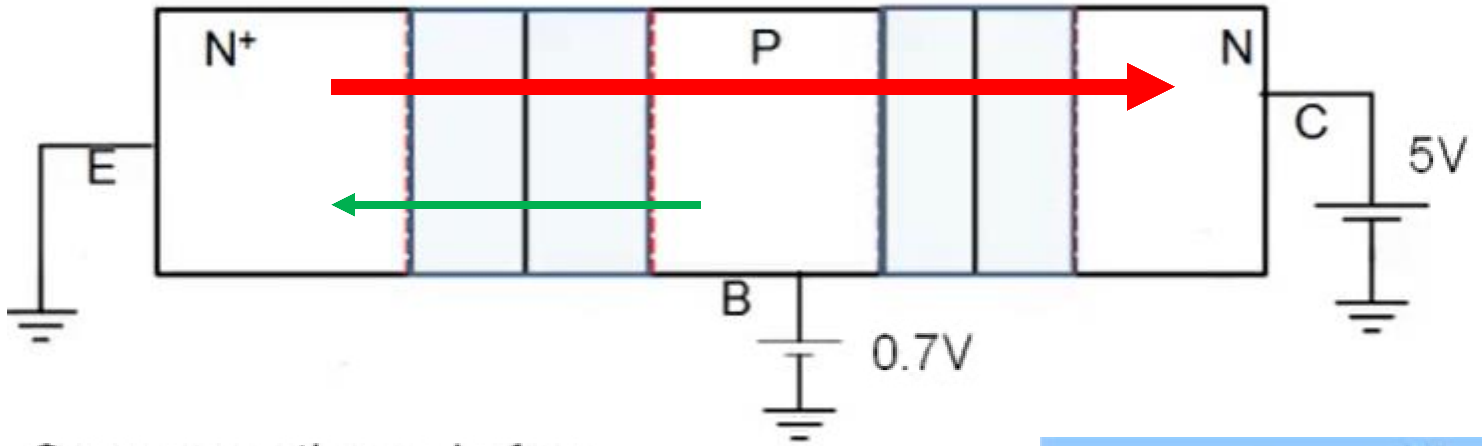




$$I_C \cong I_N$$

$$I_E = I_N + I_P \qquad I_B \cong I_P$$

$$Current\ Gain:\quad \beta = \frac{I_C}{I_B} = \frac{I_N}{I_P} >> 1$$

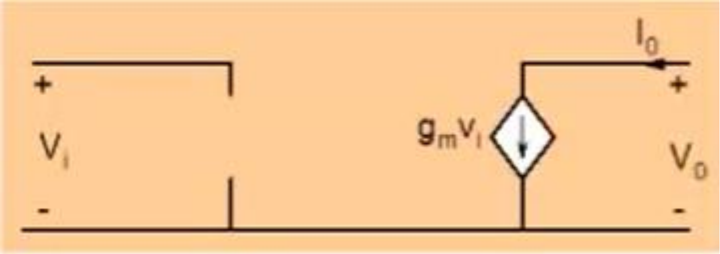


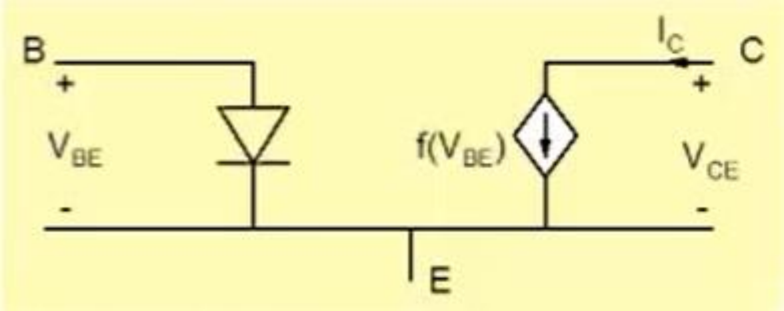
Same operation as before

$$I_C = I_N \propto \exp\left(\frac{V_{BE}}{V_T}\right)$$

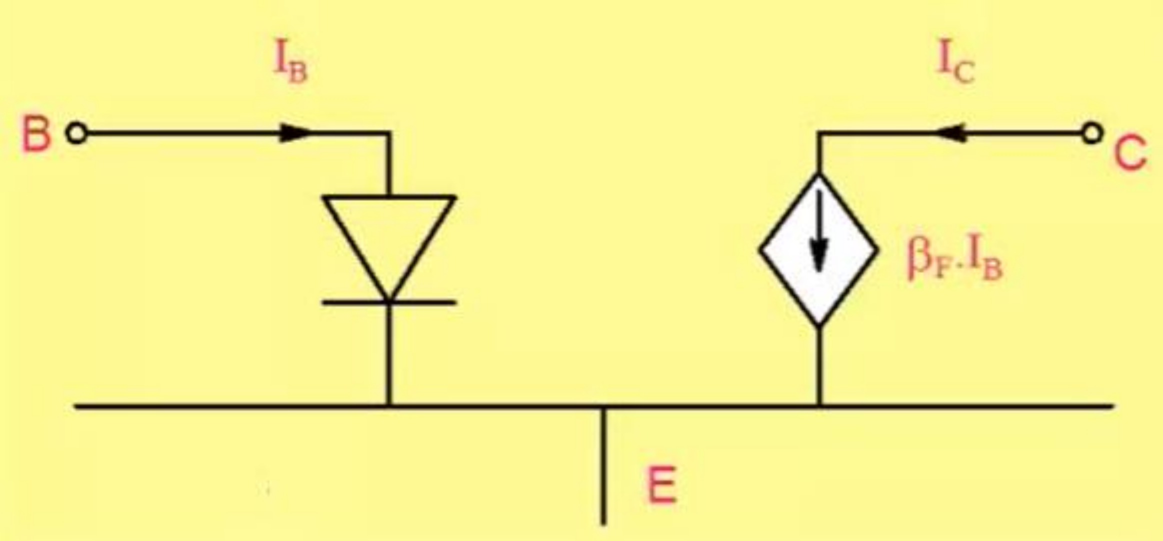
Transistor action

Current is affected by base-emitter voltage and not by collector-base voltage





Alternative representation



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

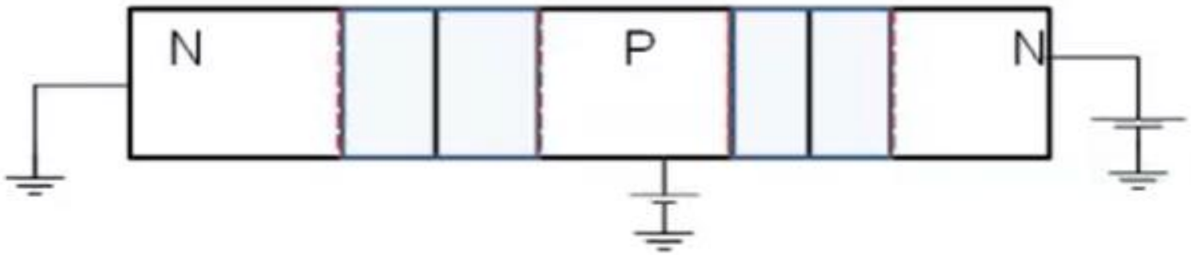
$$I_B = I_{BS}\left(\exp(\frac{V_{BE}}{V_T}) - 1 \right)$$

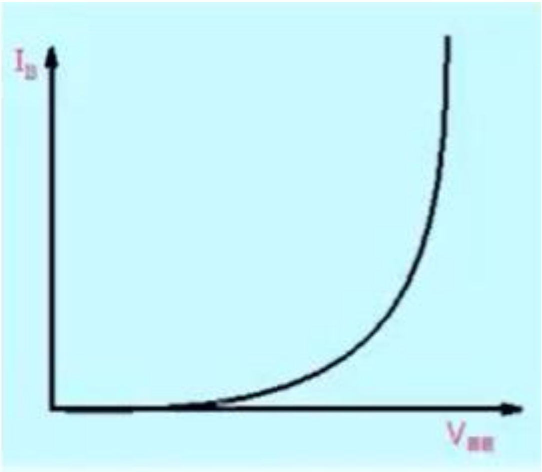
$$I_C = I_S\left(\exp(\frac{V_{BE}}{V_T}) - 1 \right)$$

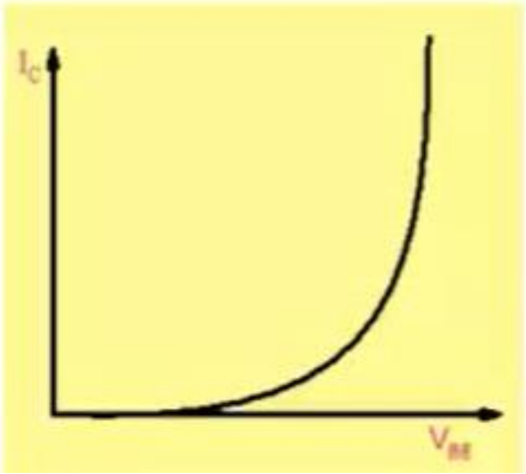
$$I_B = \frac{I_C}{\beta_F}$$

Transistor Characteristics

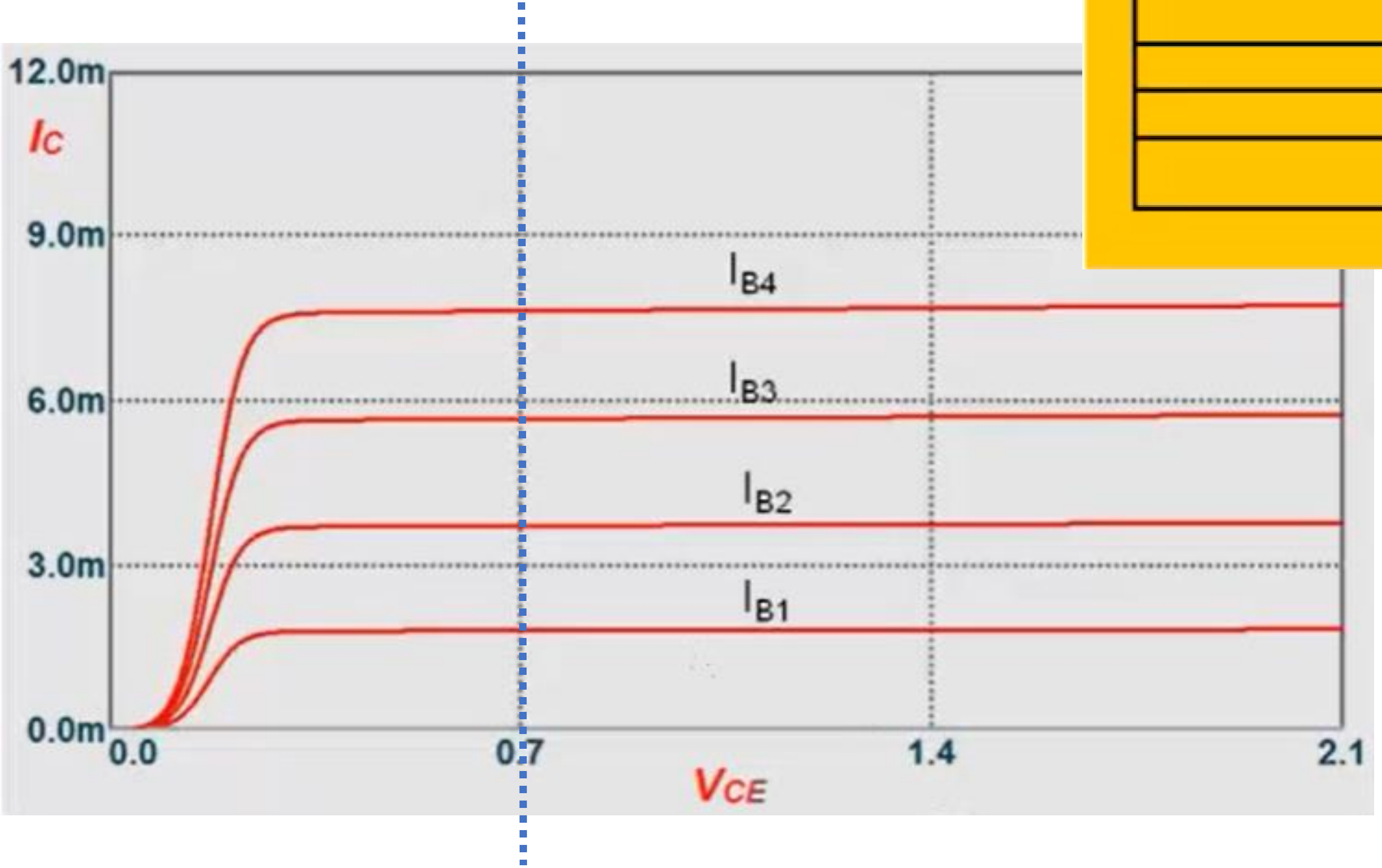
Forward Active Mode







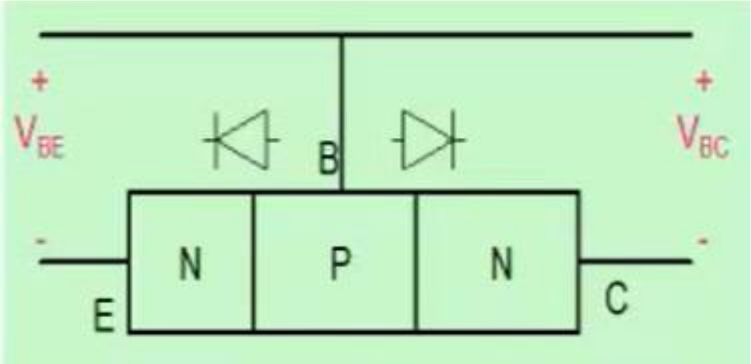
Output Characteristics of the transistor

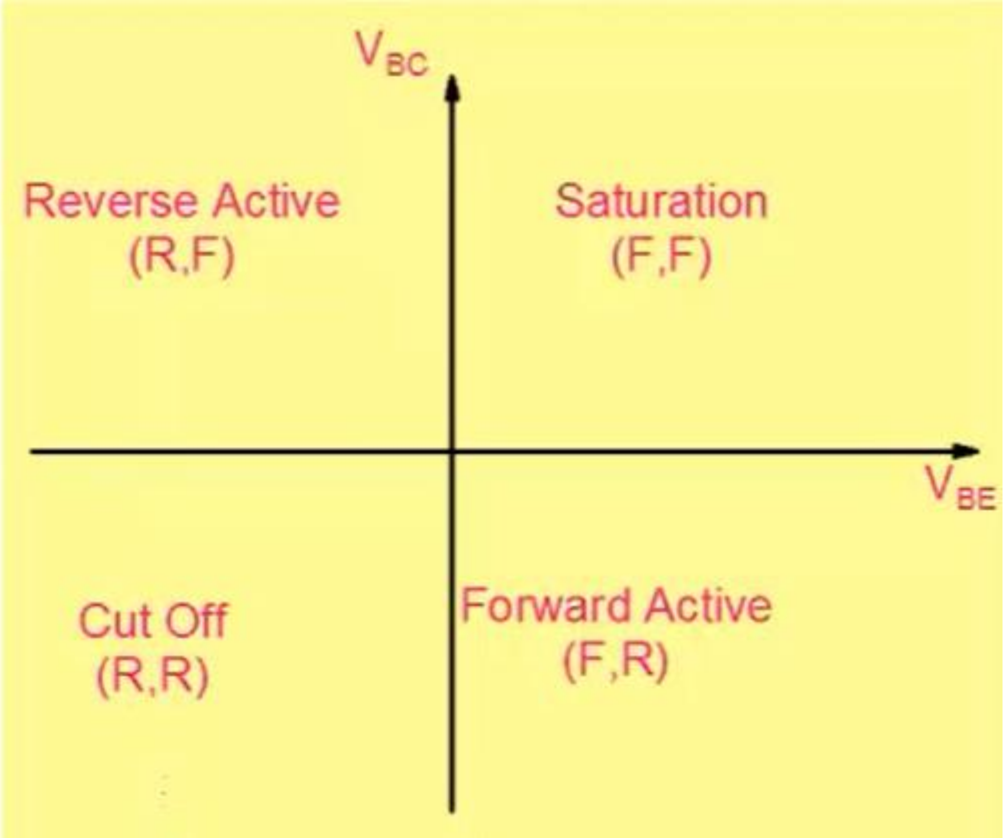


$$V_{CE} = V_{CB} + V_{BE}$$
$$= V_{BE} - V_{BC}$$

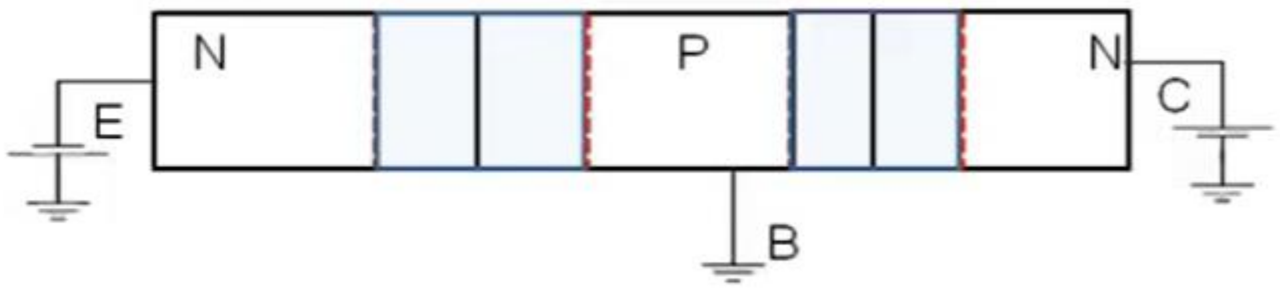
$$V_{CE} = 0.7 - V_{BC}$$

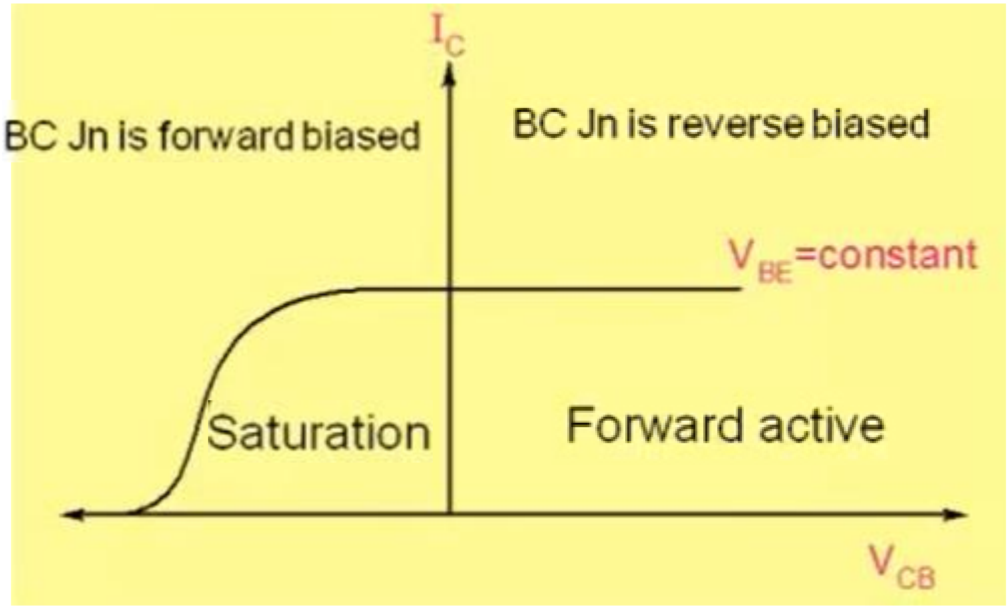
Modes of operation



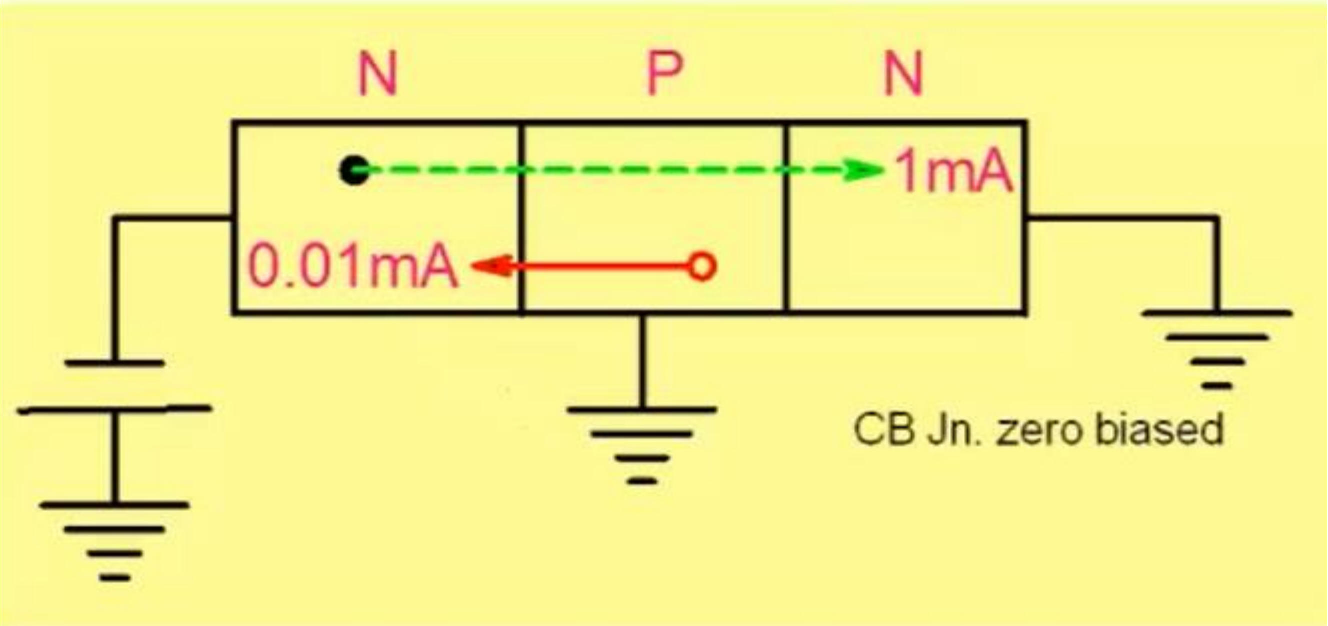


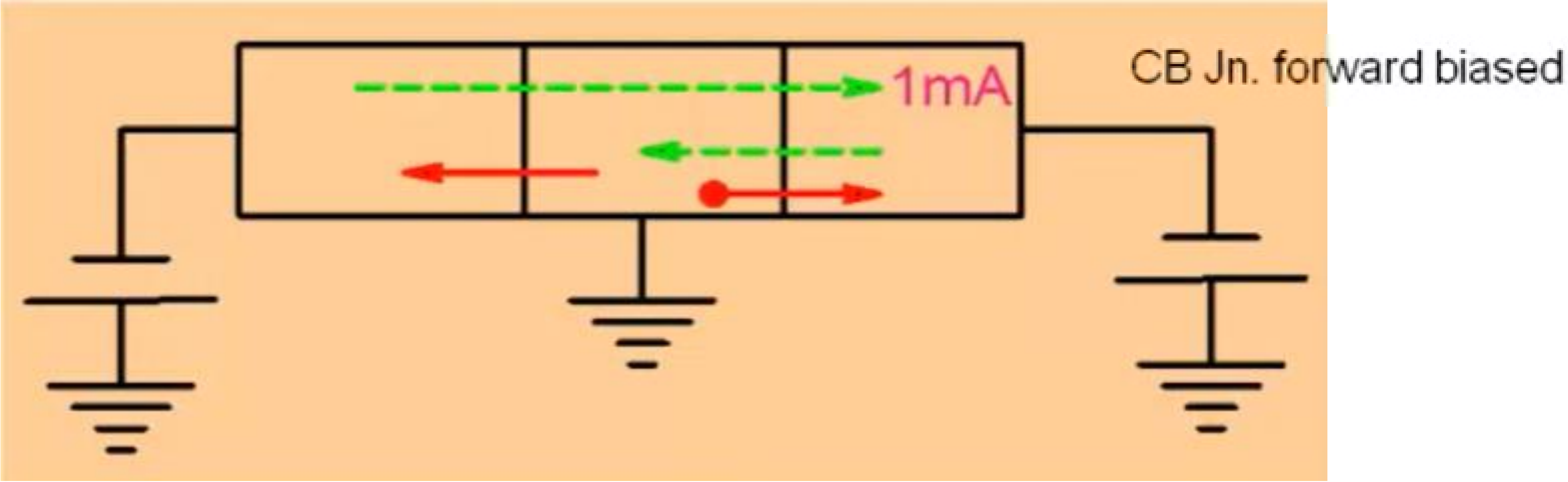
Saturation

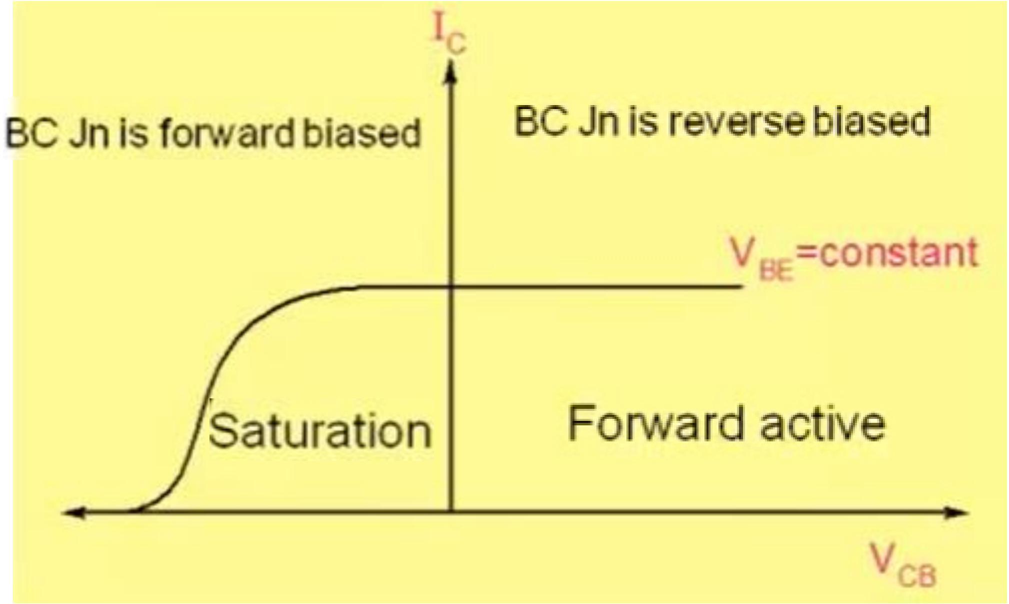

N
P
N
E
C
B

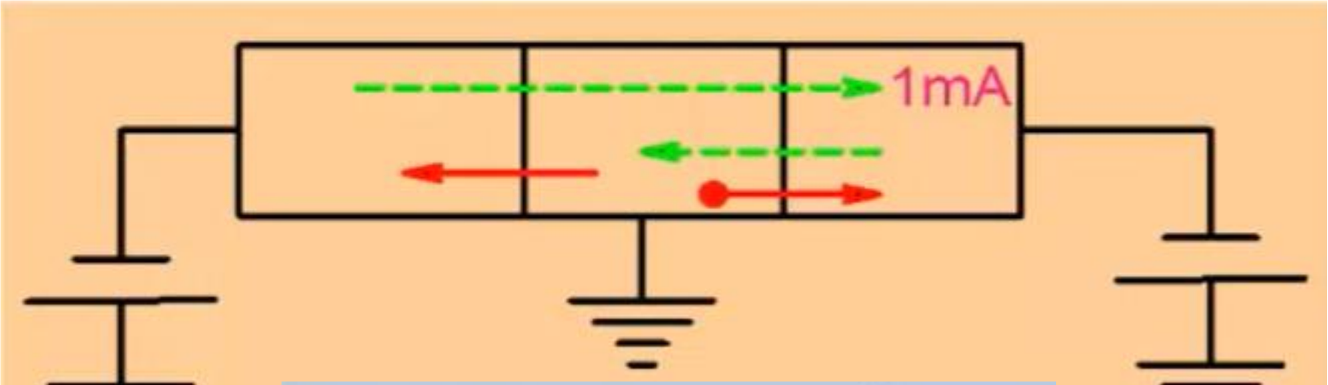

I_C
BC Jn is forward biased
BC Jn is reverse biased
V_BE=constant
Saturation
Forward active
V_CB

Why does I_C drop in saturation?

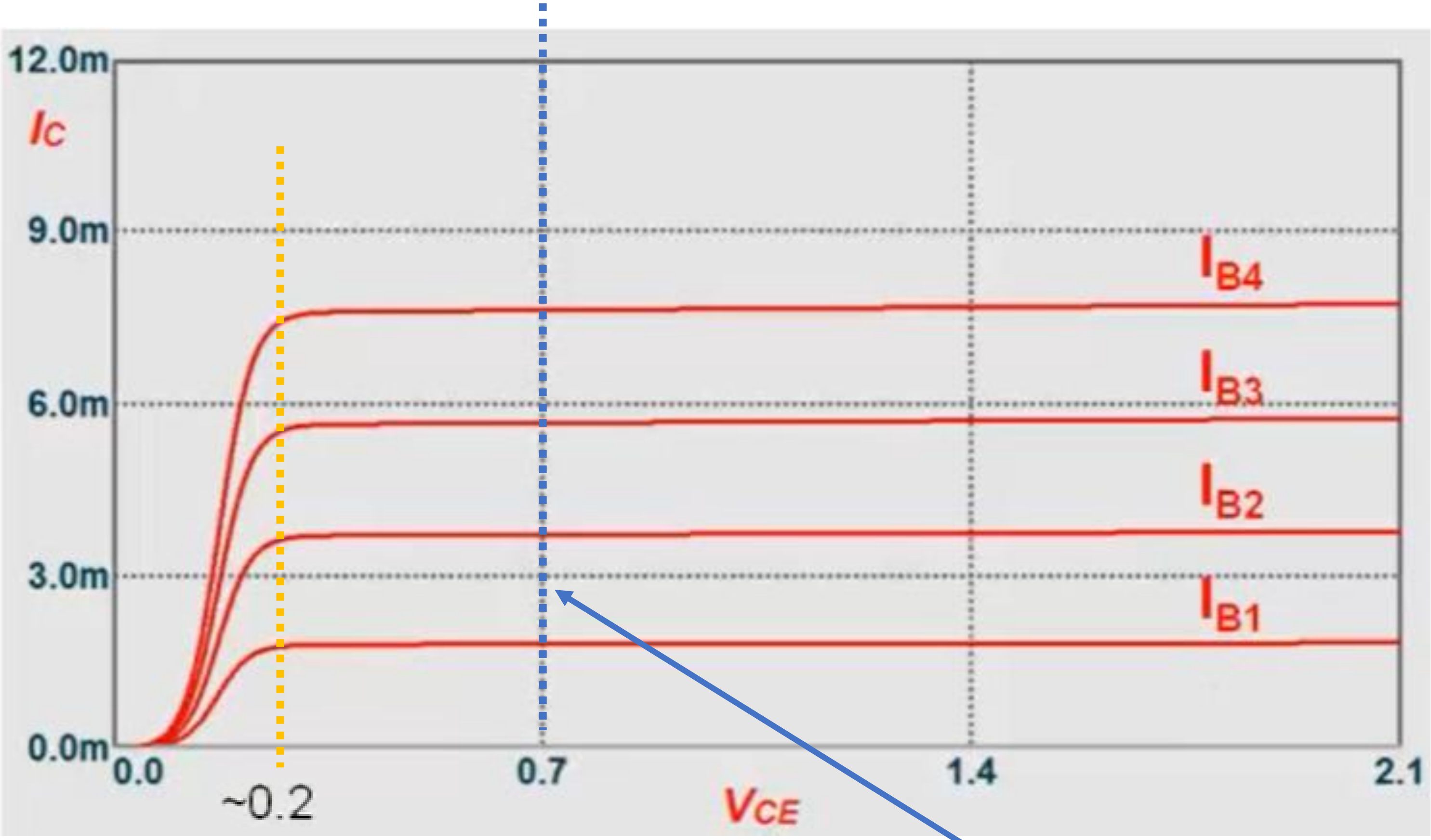








$$I_C \downarrow;\ I_B \uparrow \ \Rightarrow \ \frac{I_C}{\beta I_B} < 1$$



CB Jn start to get FB

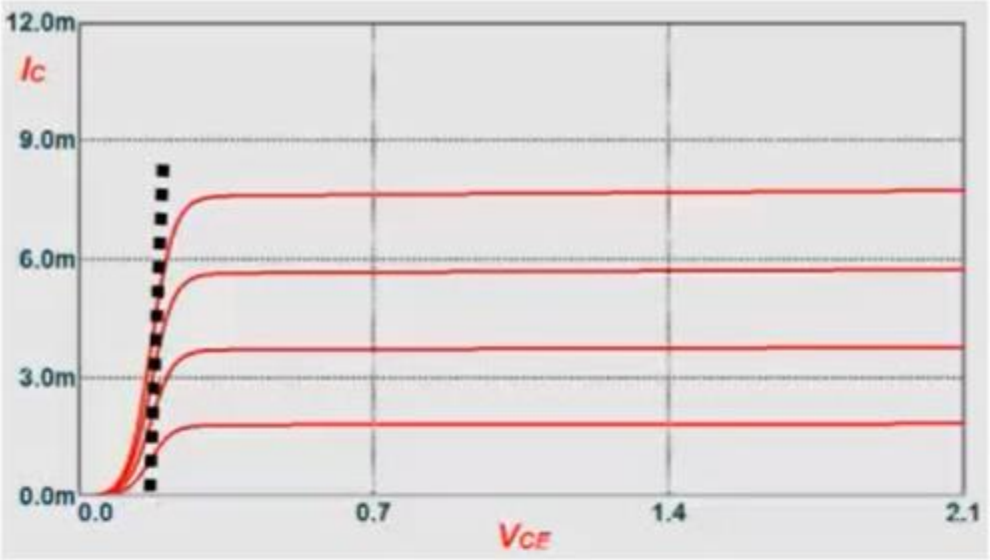
$V_{CE} = V_{CB} + V_{BE}$

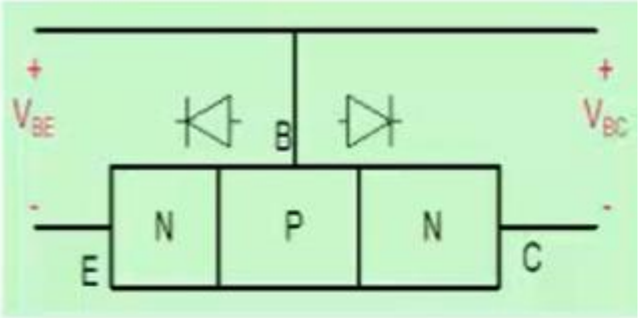
$= V_{BE} - V_{BC}$

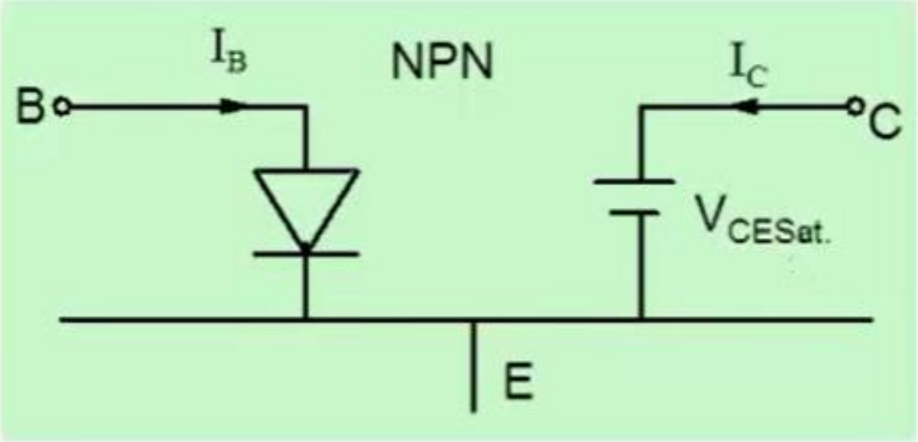
$$V_{CE} = 0.7 - V_{BC}$$

Note that in saturation: $\frac{I_C}{\beta I_B} < 1$

Model of a BJT in Saturation mode



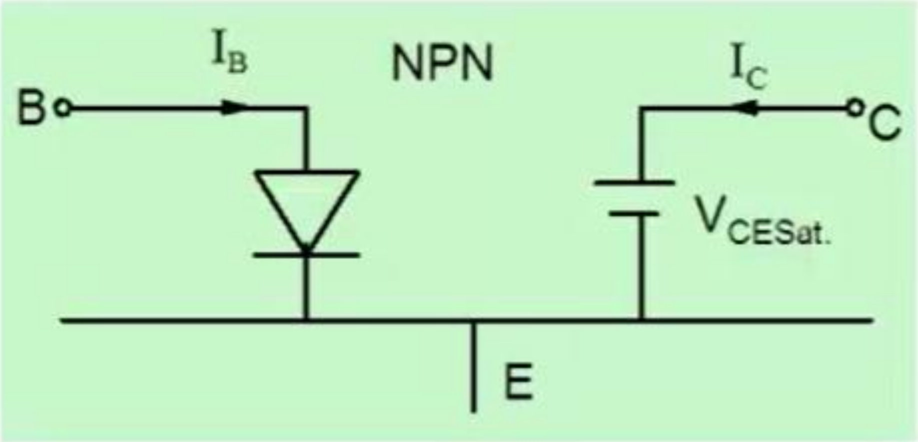


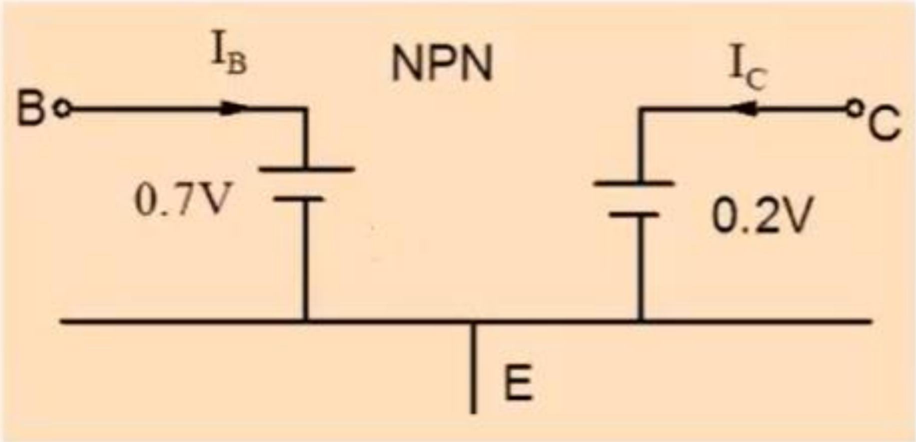


$$I_C \neq \beta_F I_B$$

$$V_{CESat.} \cong 0.2V$$

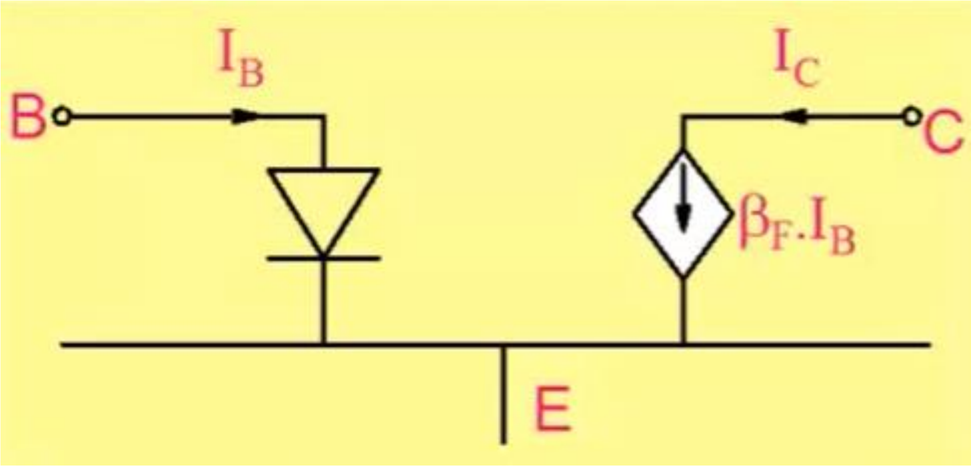
Model of a BJT in Saturation mode





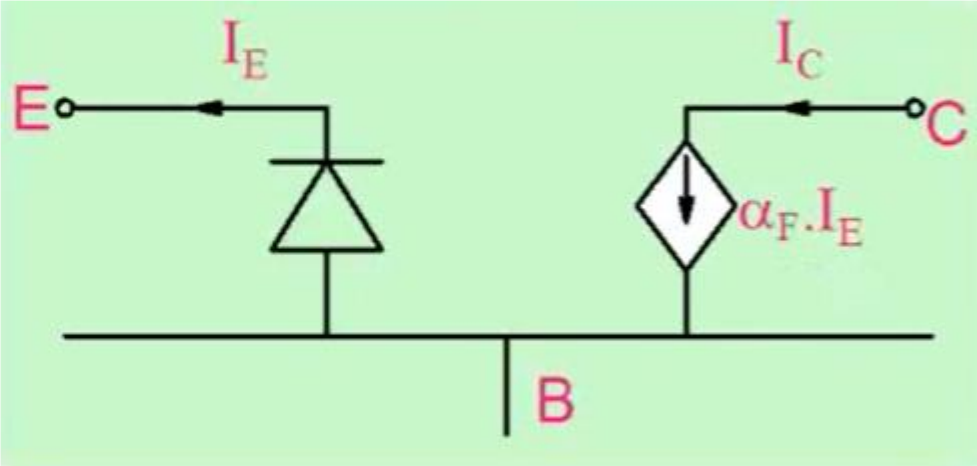
Generalized Transistor Model

Forward Active Mode



$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)$$

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



$$I_C = \beta_F \times I_B$$

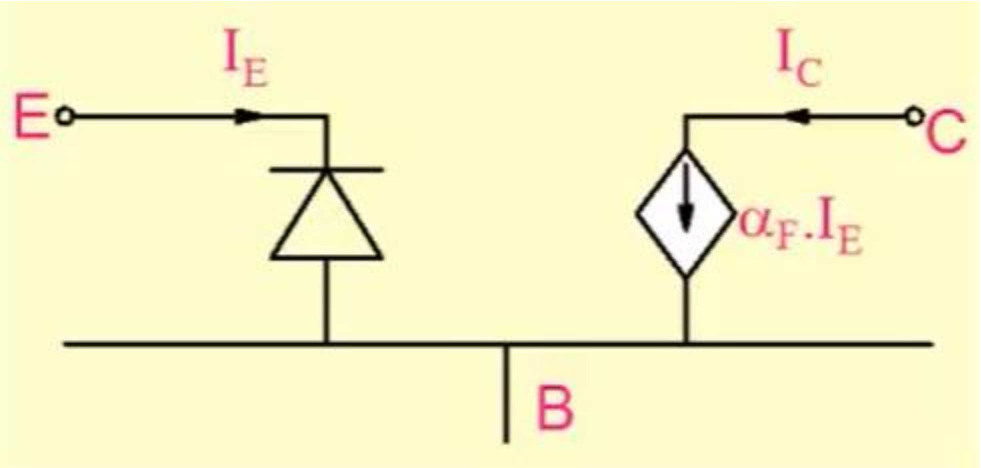
$$I_E = I_C + I_B$$

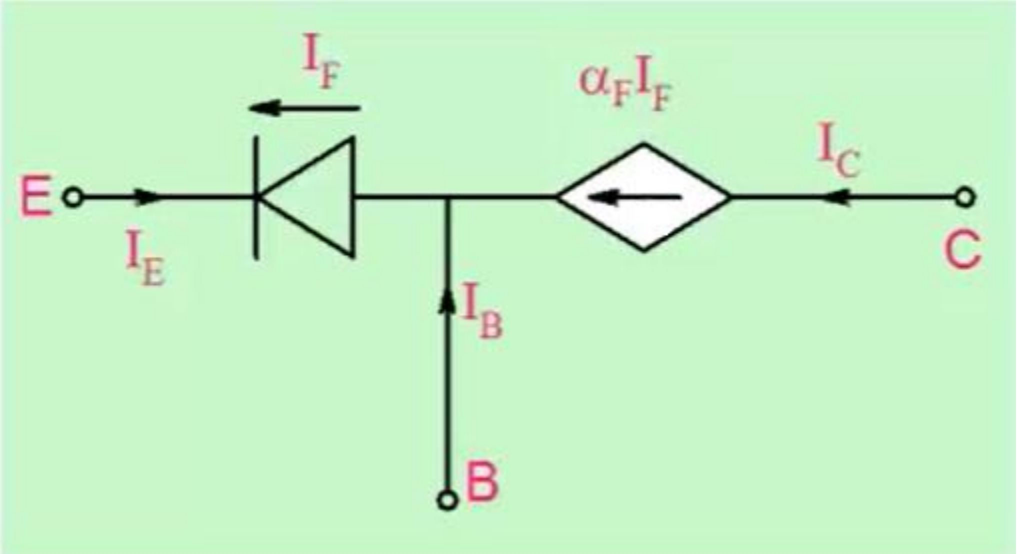
$$I_C = \alpha_F \times I_E$$

$$\alpha_F = \frac{\beta_F}{1+\beta_F}$$

β_F : Common Emitter Current Gain

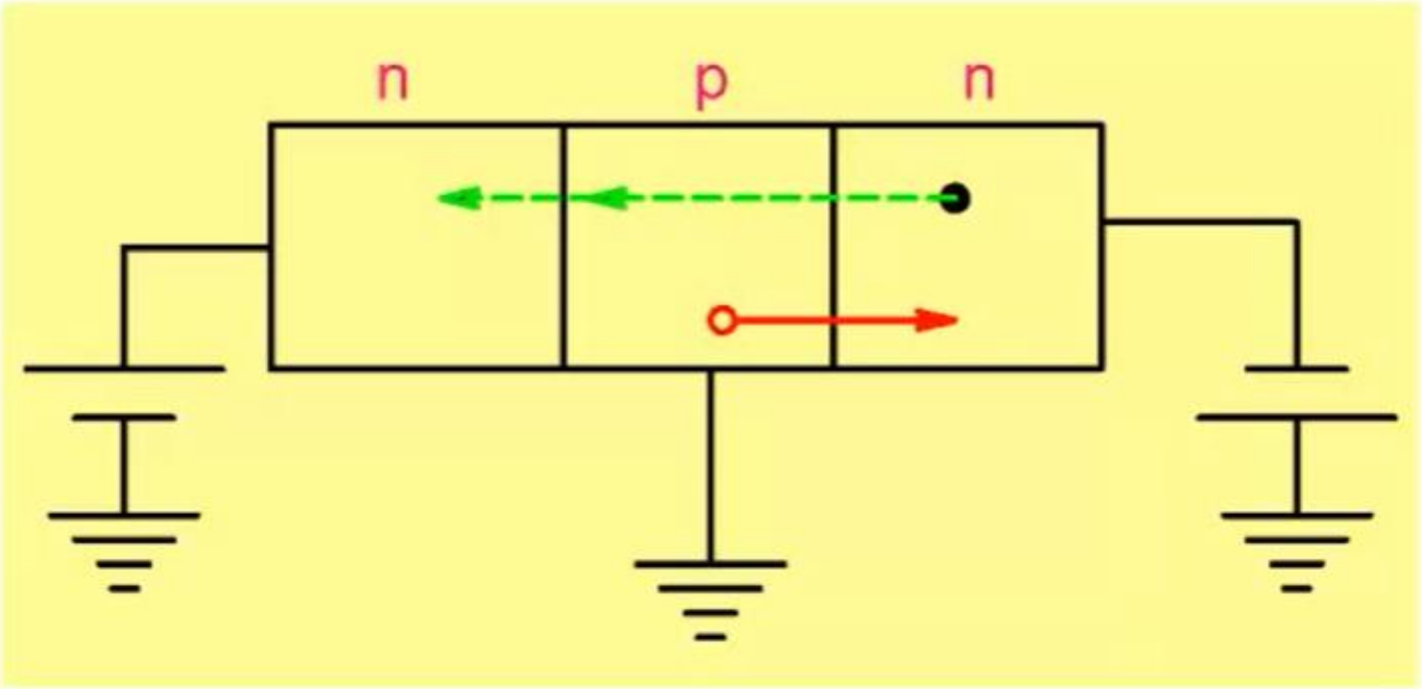
α_F : Common Base Current Gain

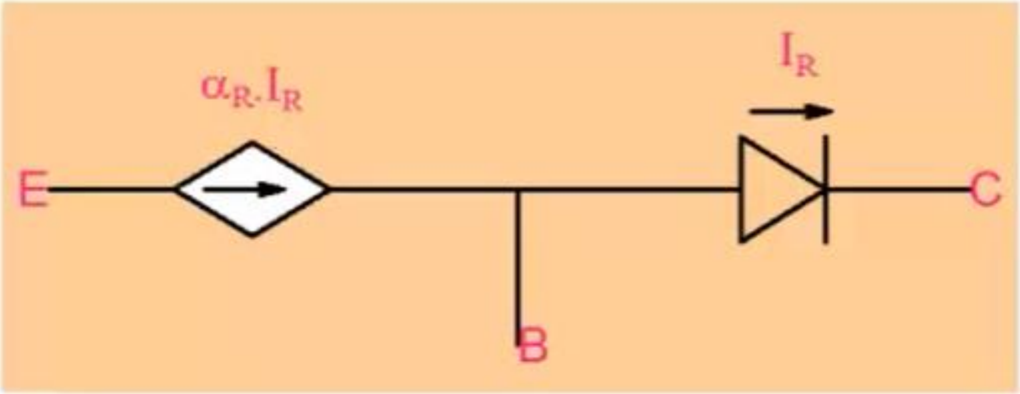




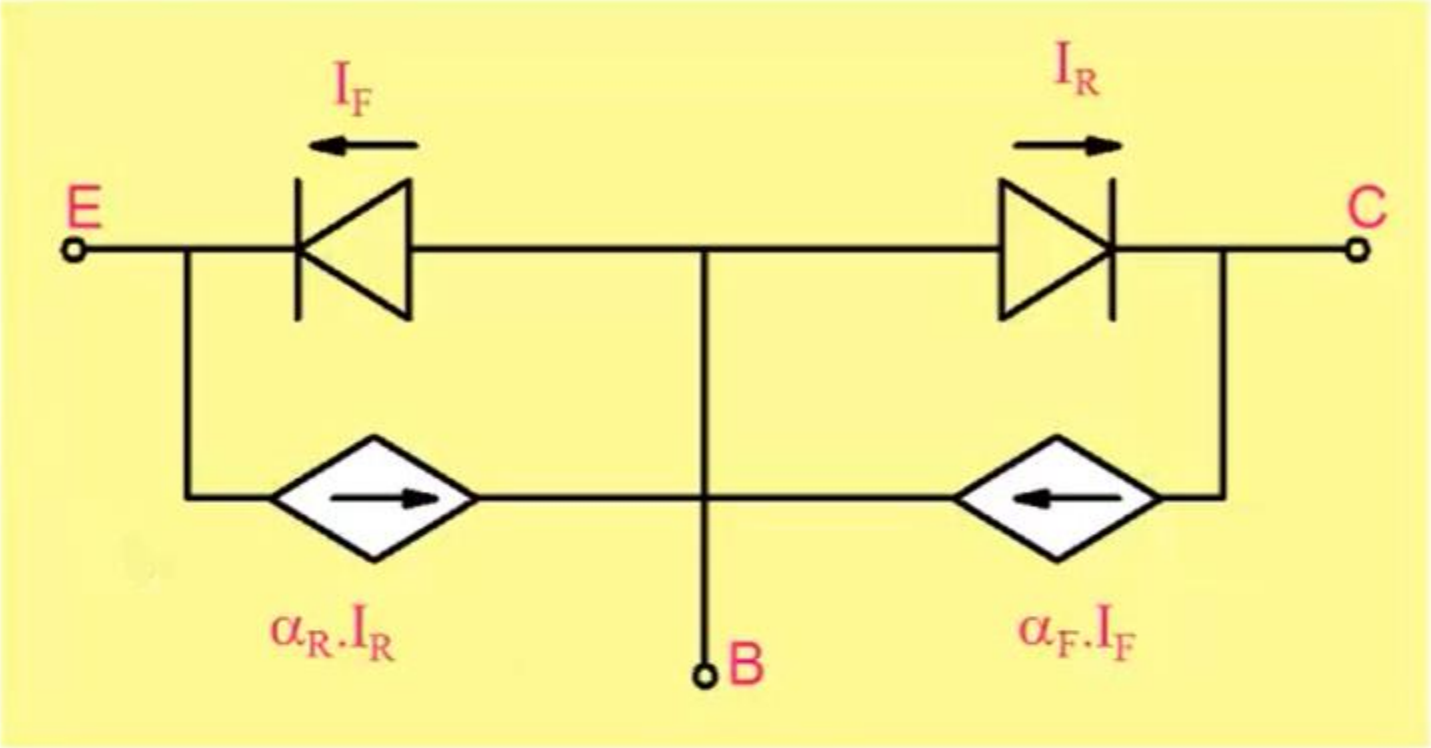
Forward Active Mode

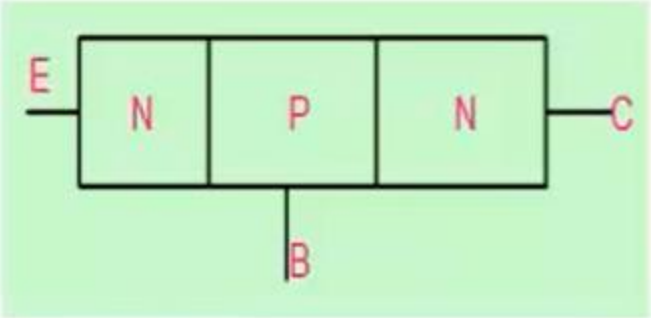
Reverse Active Mode

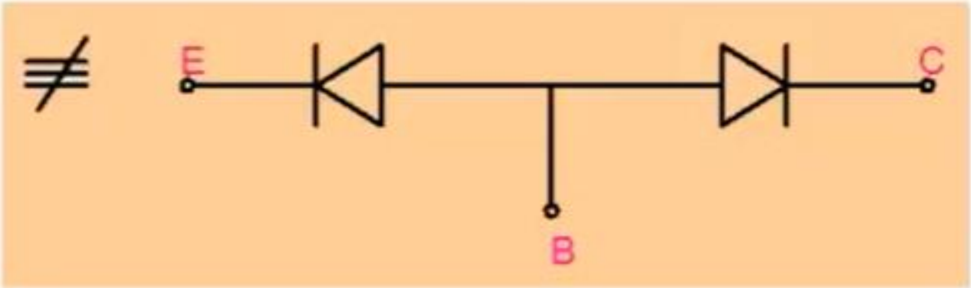


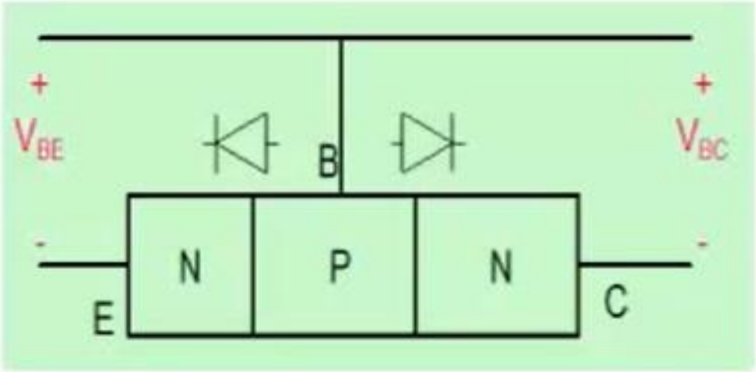


Ebers Moll Model

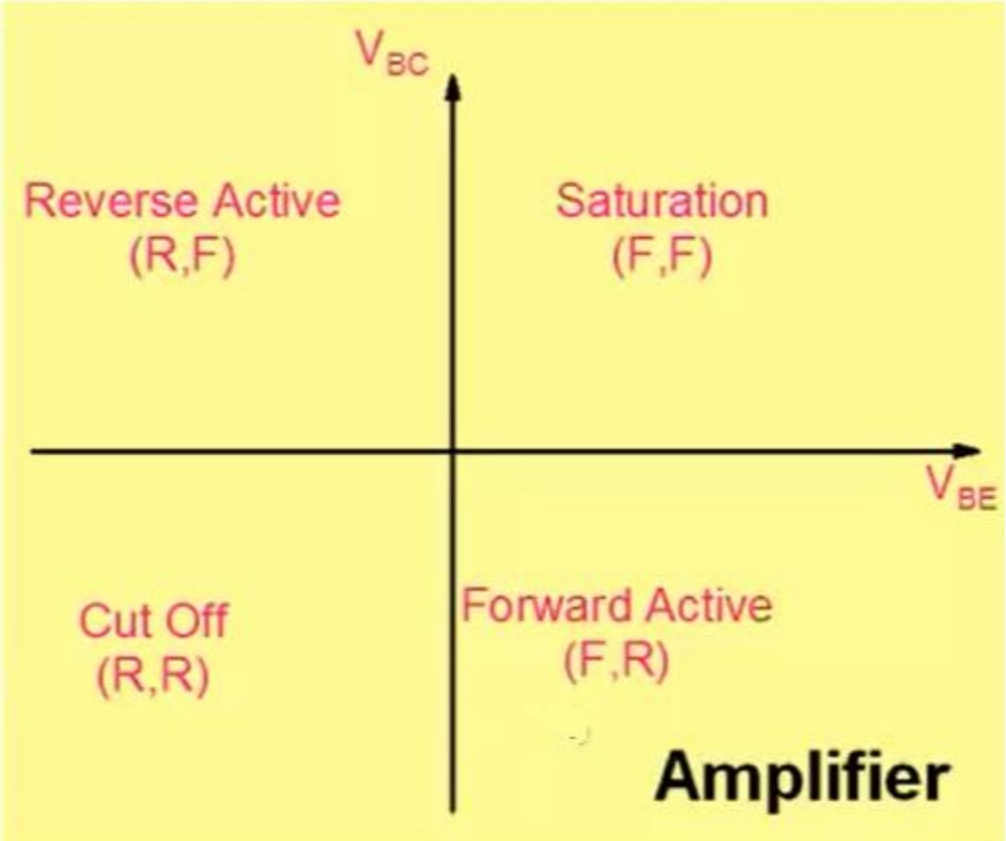






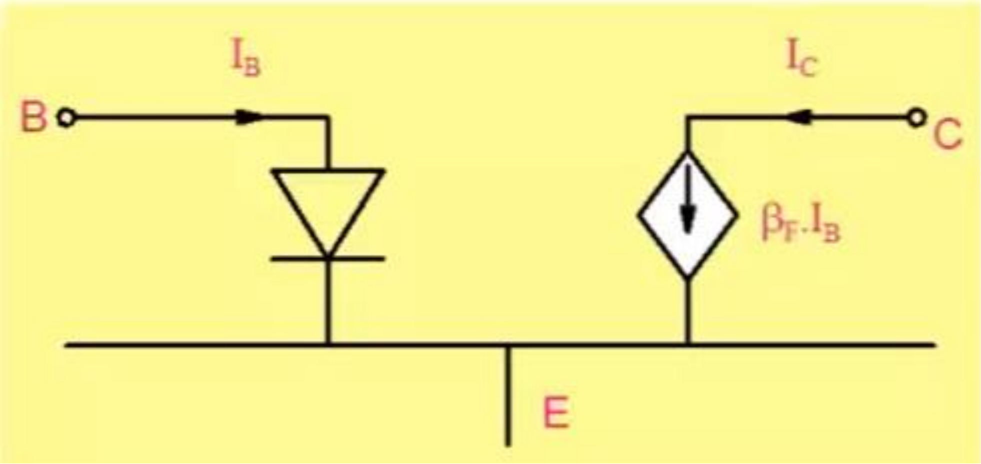


+
V_{BE}
-
+
V_{BC}
-
B
N
P
N
E
C



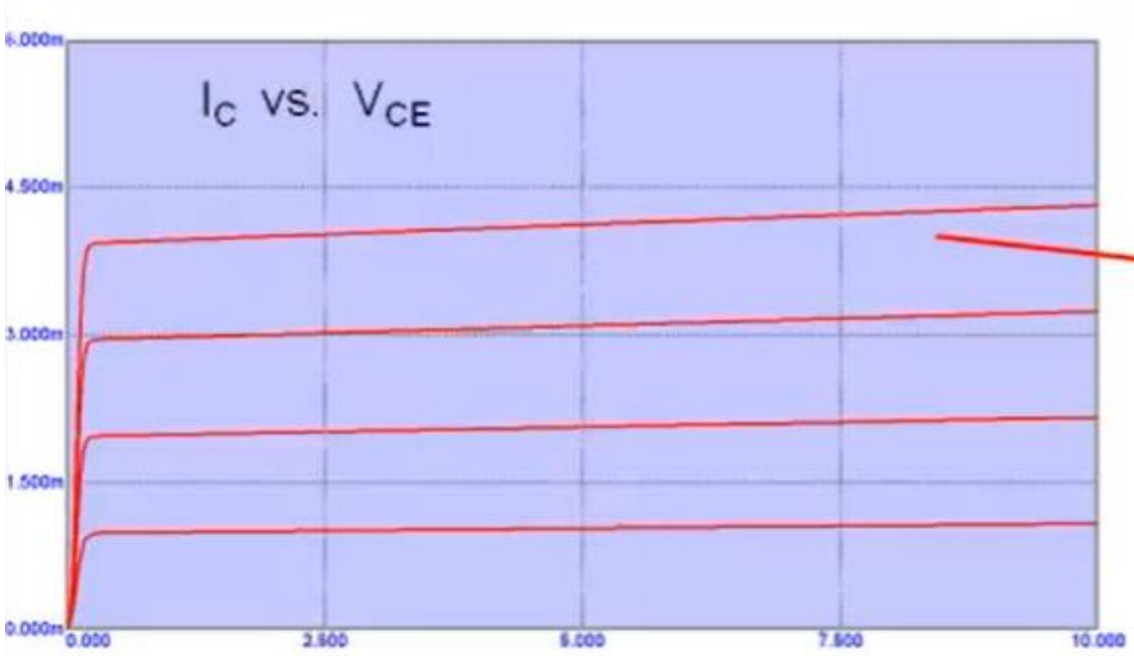
V_{BC}
V_{BE}
Reverse Active
(R,F)
Saturation
(F,F)
Cut Off
(R,R)
Forward Active
(F,R)
Amplifier

Forward Active Mode: Early Voltage



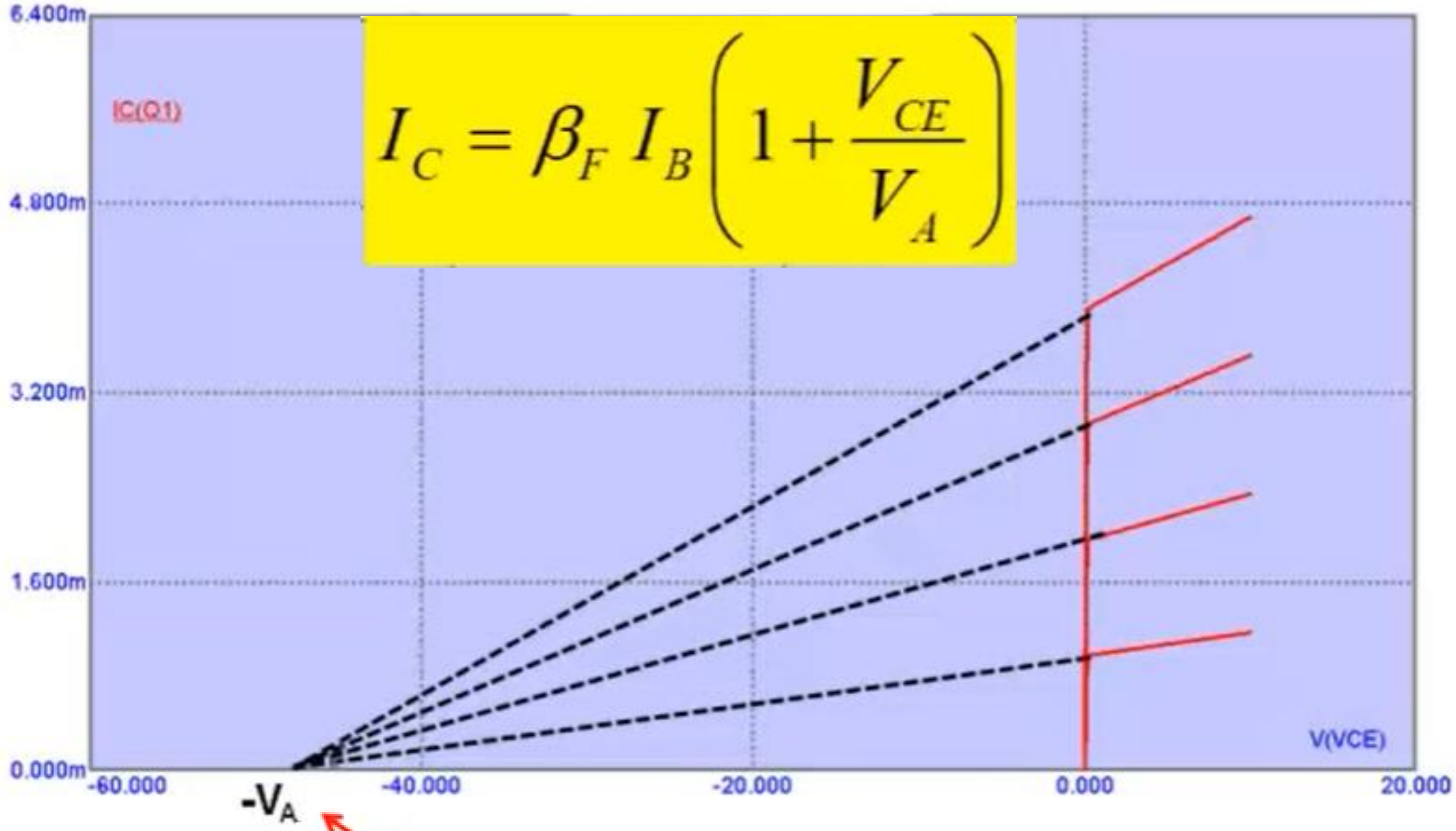
$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)$$

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



Current does increase with collector voltage through the increase is small

Early Voltage



$$I_C = \beta_F \, I_B \left(1 + \frac{V_{CE}}{V_A}\right)$$

Early Voltage