EE210: Microelectronics-I

Lecture-10 : Bipolar Junction Transistor-3

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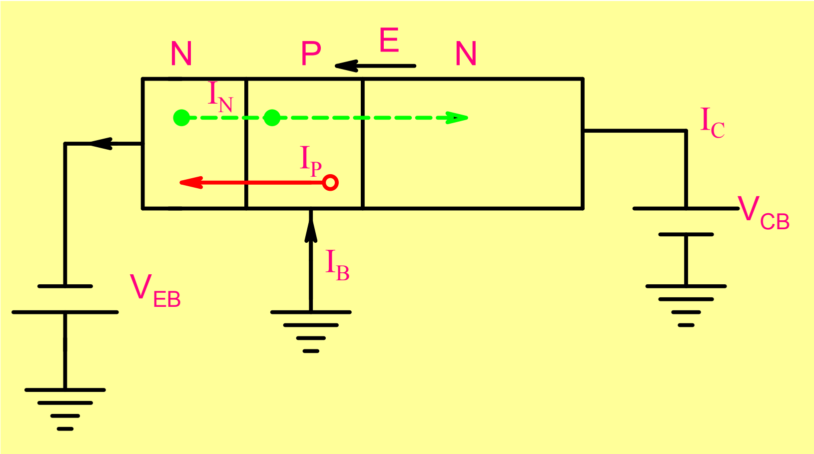
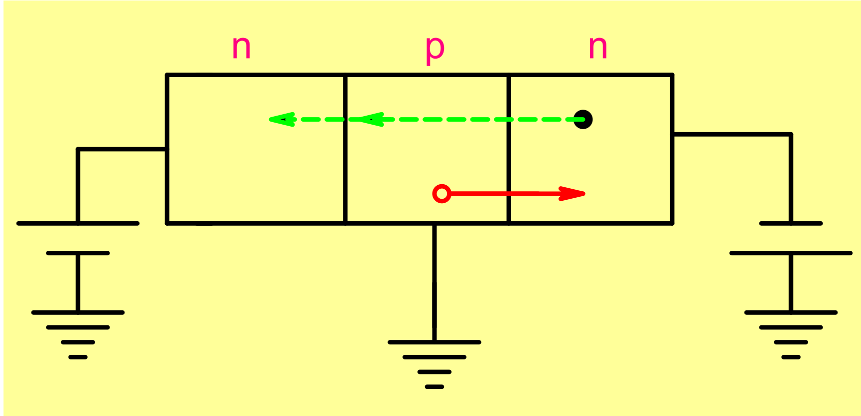
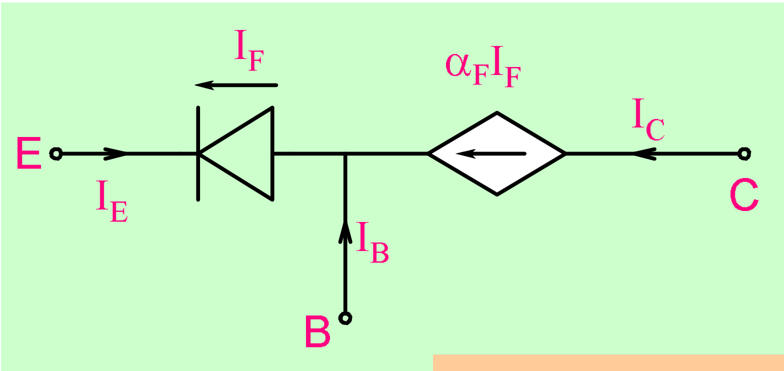


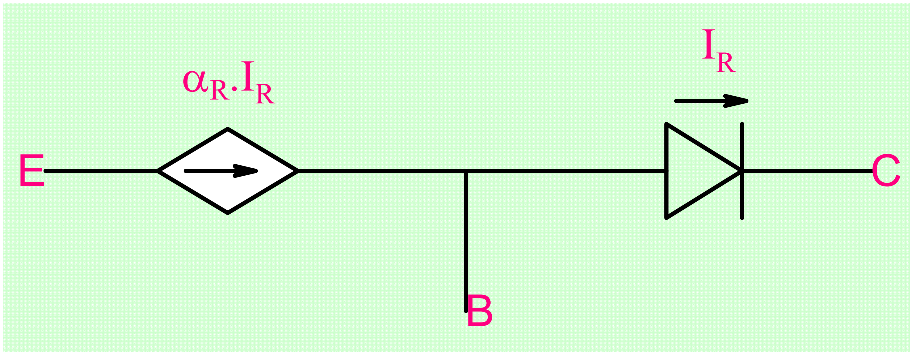
N
P
E
N
I_N
I_P
I_C
V_{CB}
I_B
V_{EB}



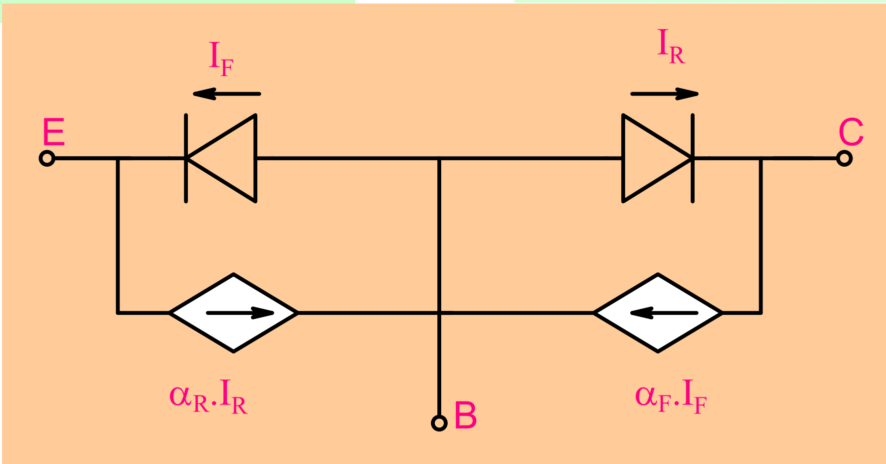
n
p
n



I_F
$\alpha_F I_F$
I_C
E
I_E
C
I_B
B



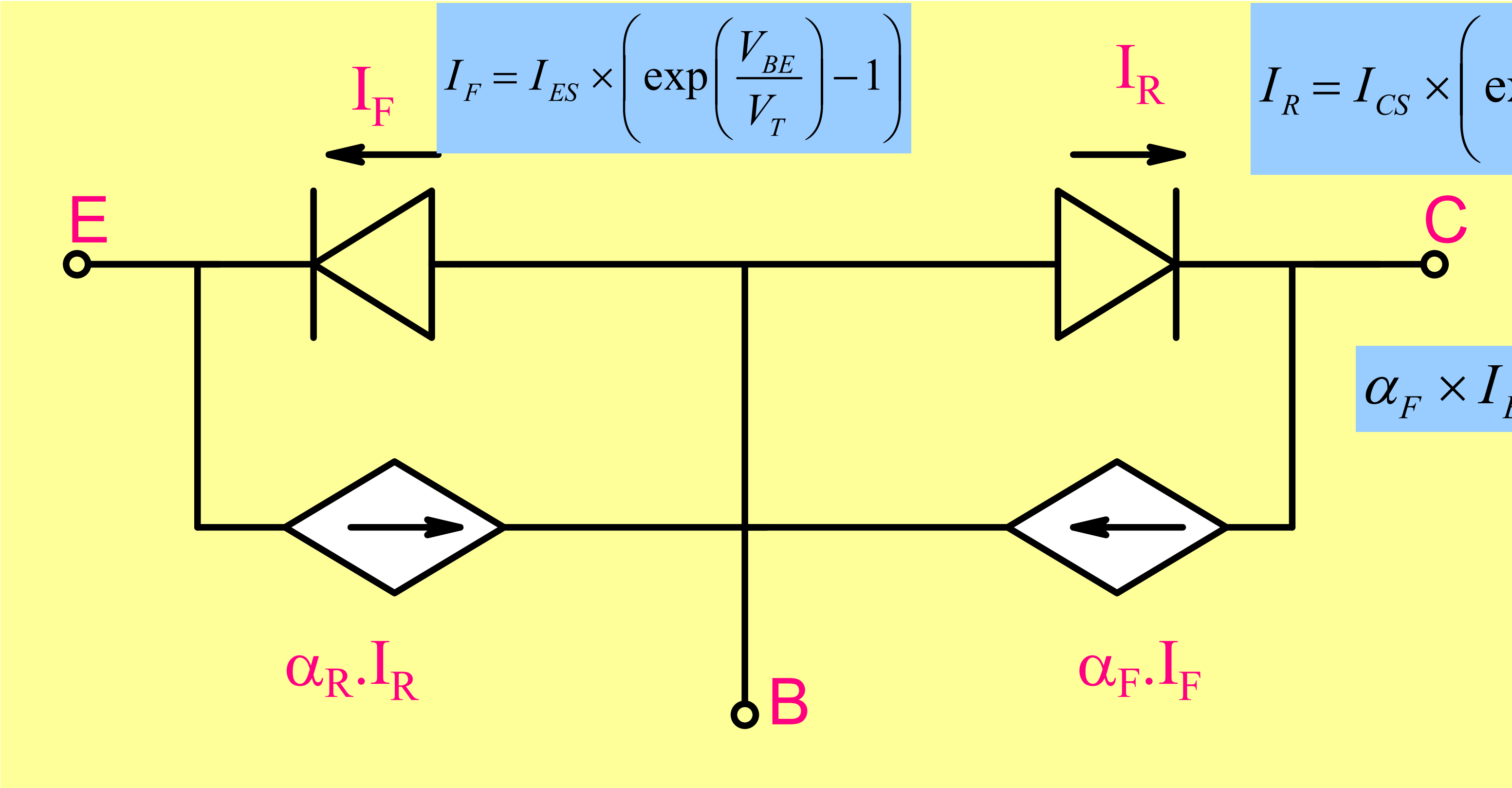
I_R
$\alpha_R.I_R$
E
C
B



I_F
I_R
E
C
$\alpha_R.I_R$
B
$\alpha_F.I_F$

G-Number

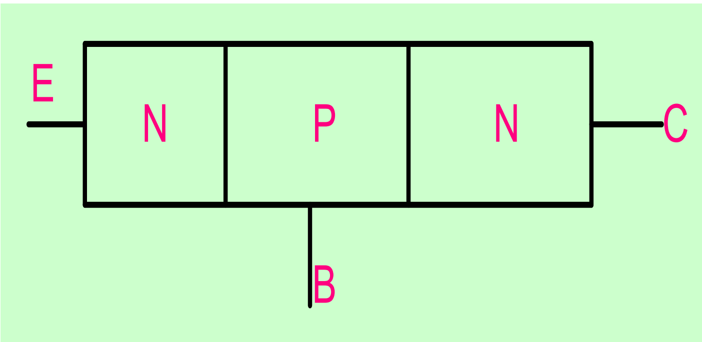
Ebers Moll Model

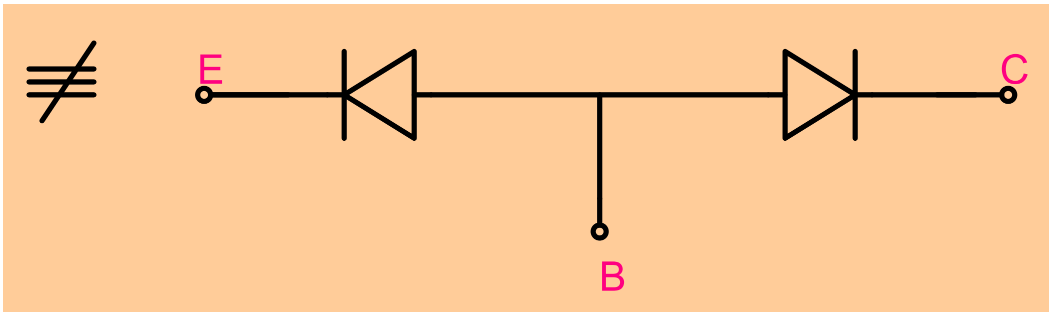


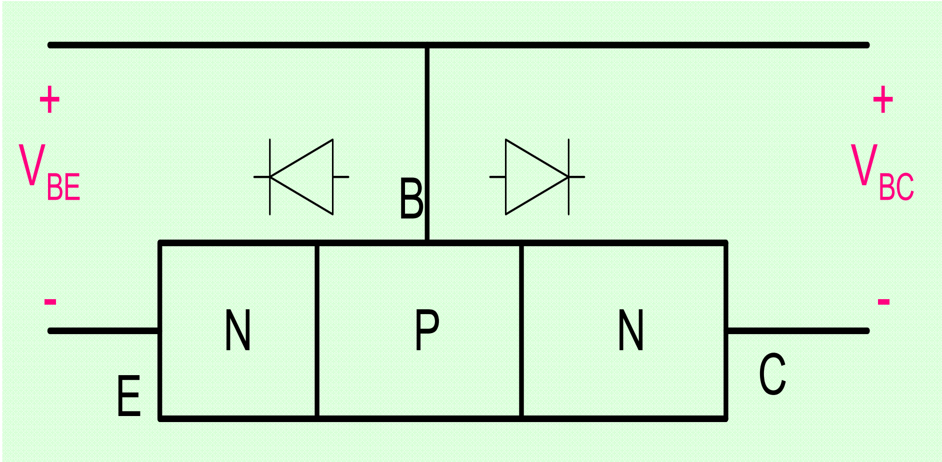
$$I_F = I_{ES} \times \left(\exp\left(\frac{V_{BE}}{V_T} \right) - 1 \right)$$

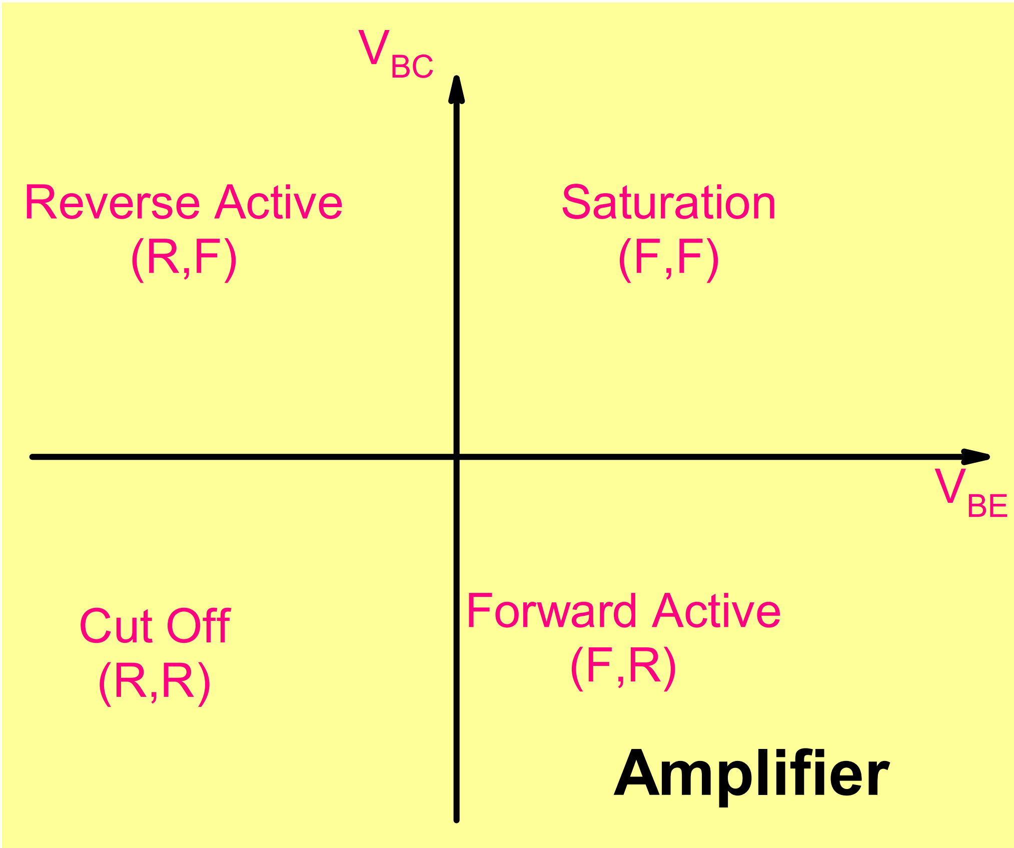
$$I_R = I_{CS} \times \left(\exp\left(\frac{V_{BC}}{V_T} \right) - 1 \right)$$

$$\alpha_F \times I_{ES} = \alpha_R \times I_{CS}$$

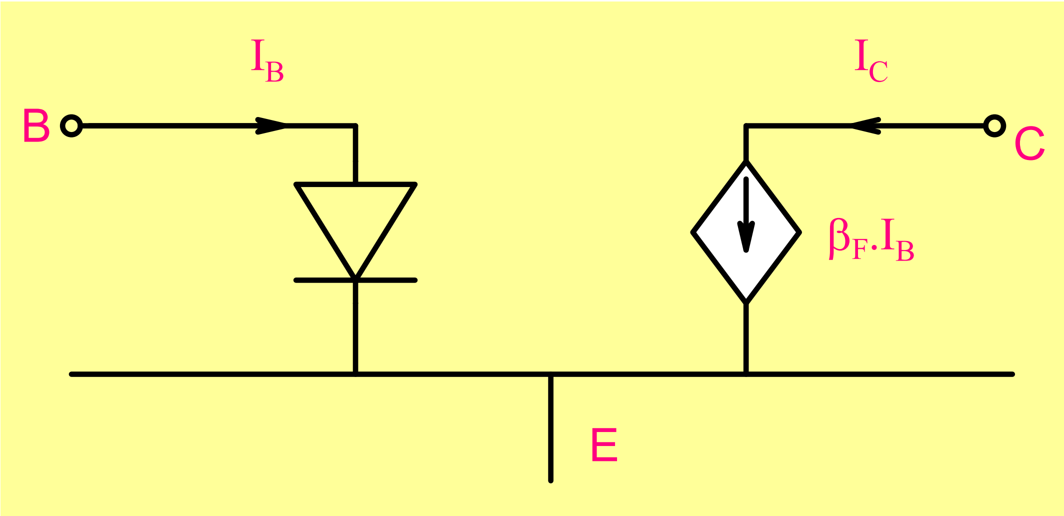





+
V_{BE}
-
B
N
P
N
E
C
+
V_{BC}
-

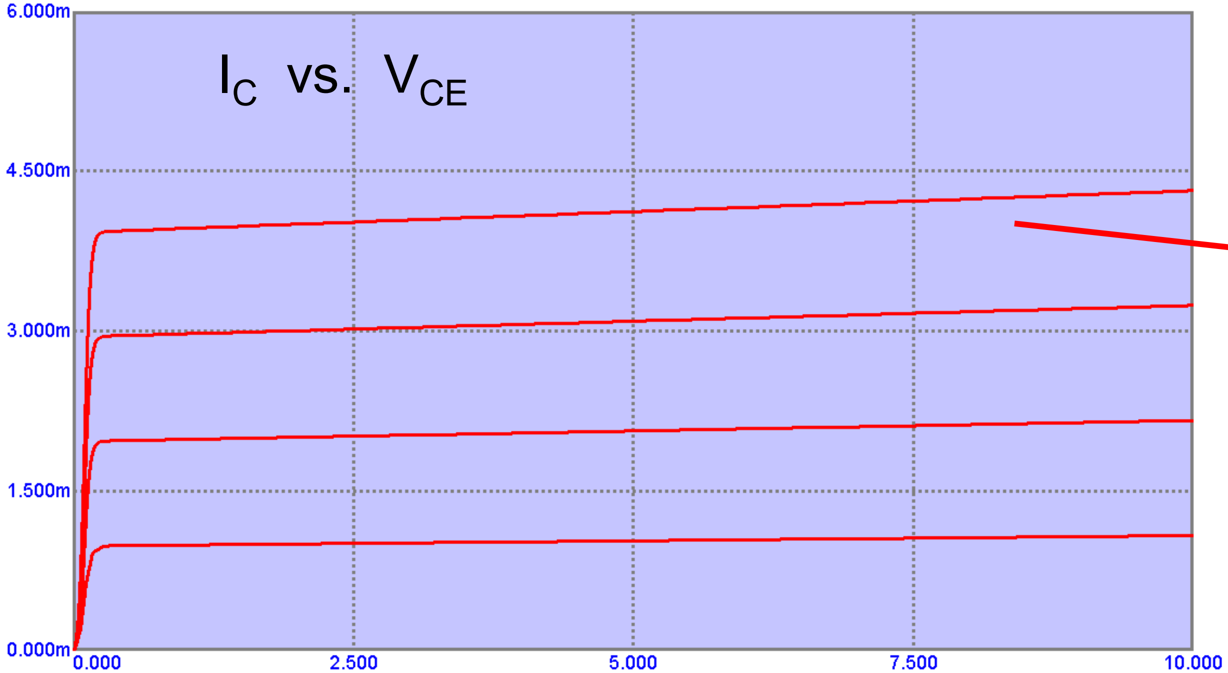

V_{BC}
Reverse Active
(R,F)
Saturation
(F,F)
V_{BE}
Cut Off
(R,R)
Forward Active
(F,R)
Amplifier

Forward Active Mode: Early Voltage



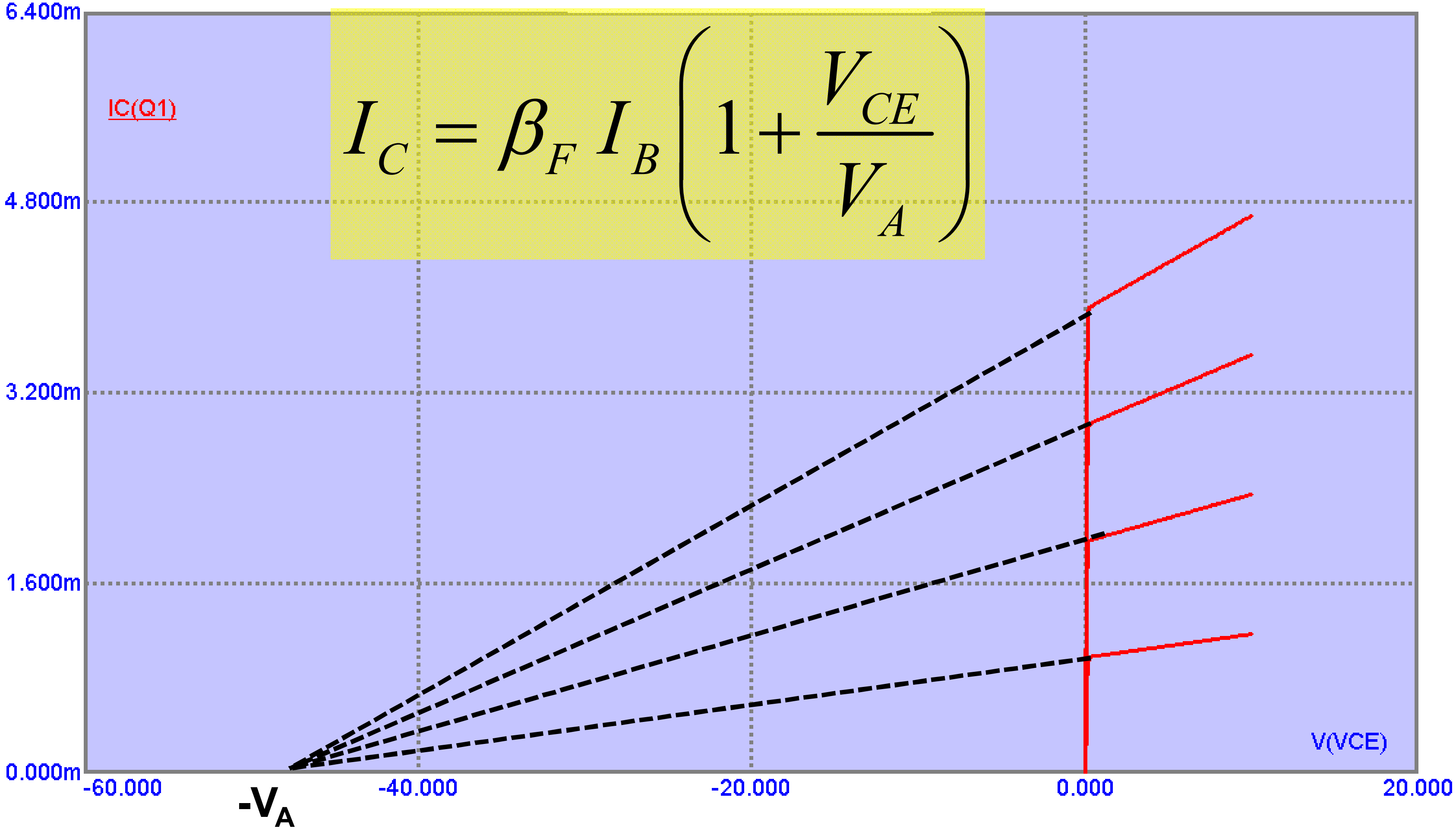
$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)$$

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



Current does increase with collector voltage through the increase is usually small

Early Voltage

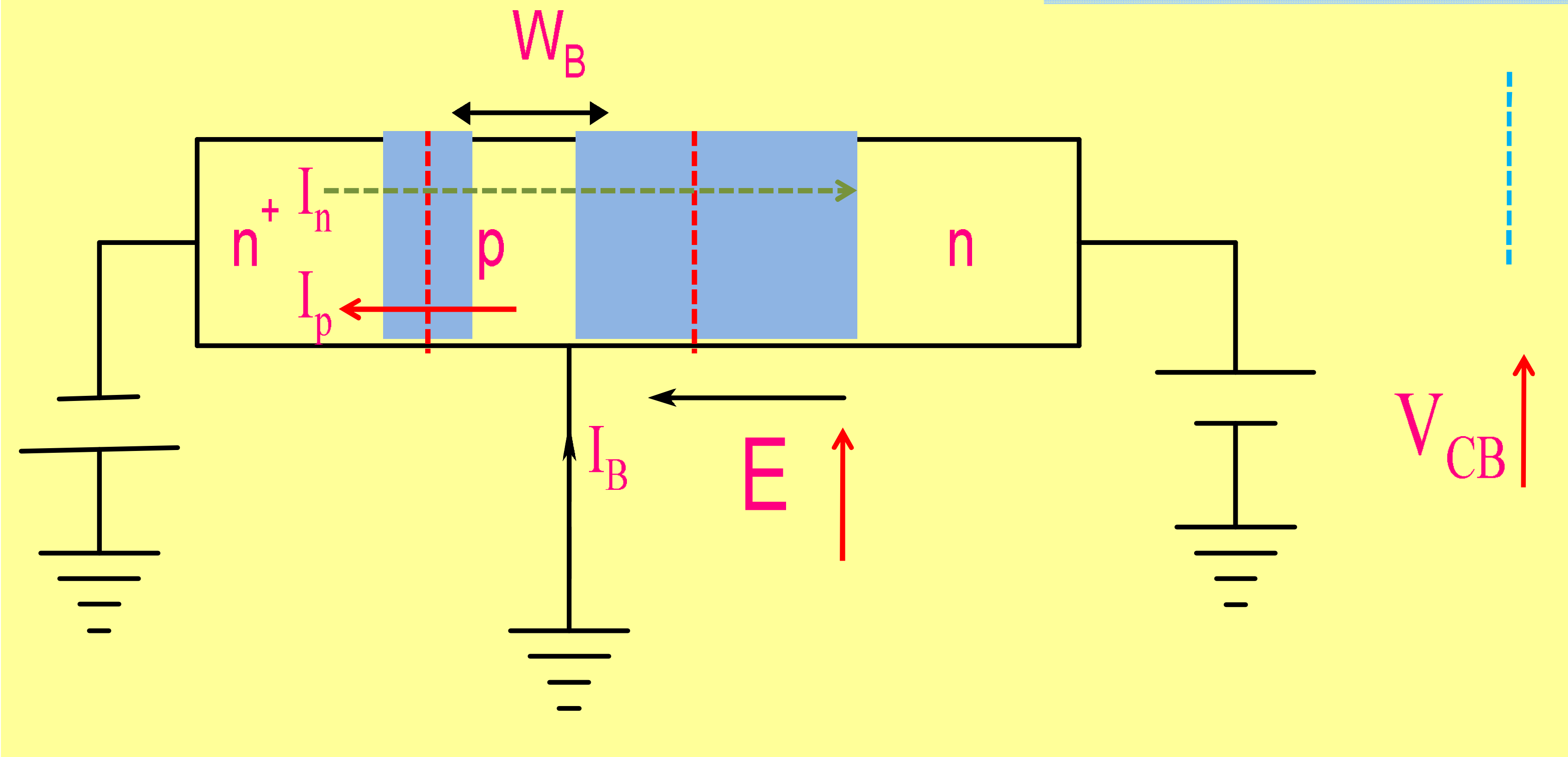


$$I_C = \beta_F\, I_B \left(1 + \frac{V_{CE}}{V_A}\right)$$

Early Voltage

Base Width Modulation

$$I_N = qD_n \frac{dn}{dx} \cong qD_n \times \frac{n(0)}{W_B}$$



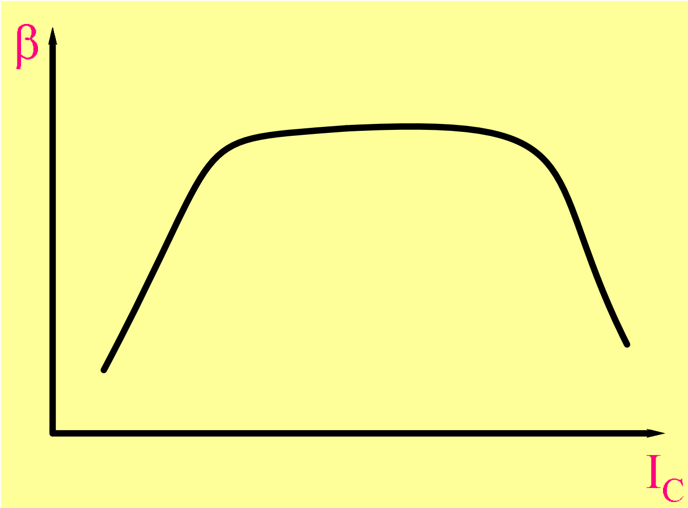
Decrease in effective base width causes an increase in collector current !

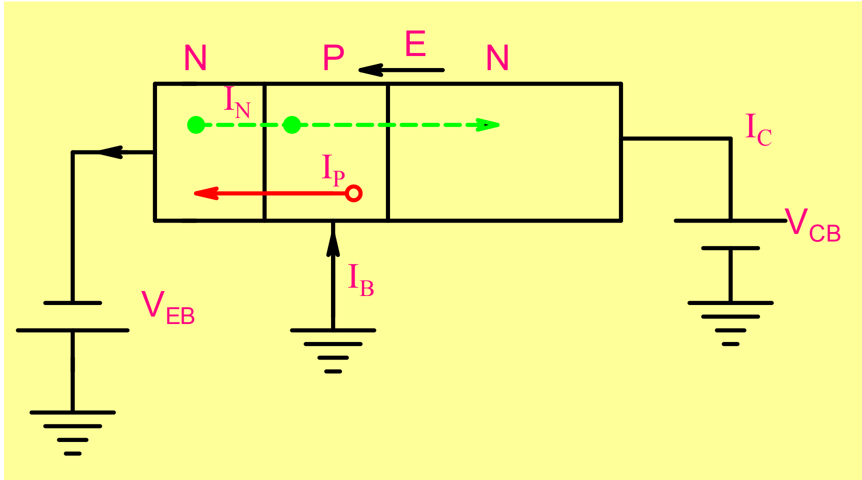
$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

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

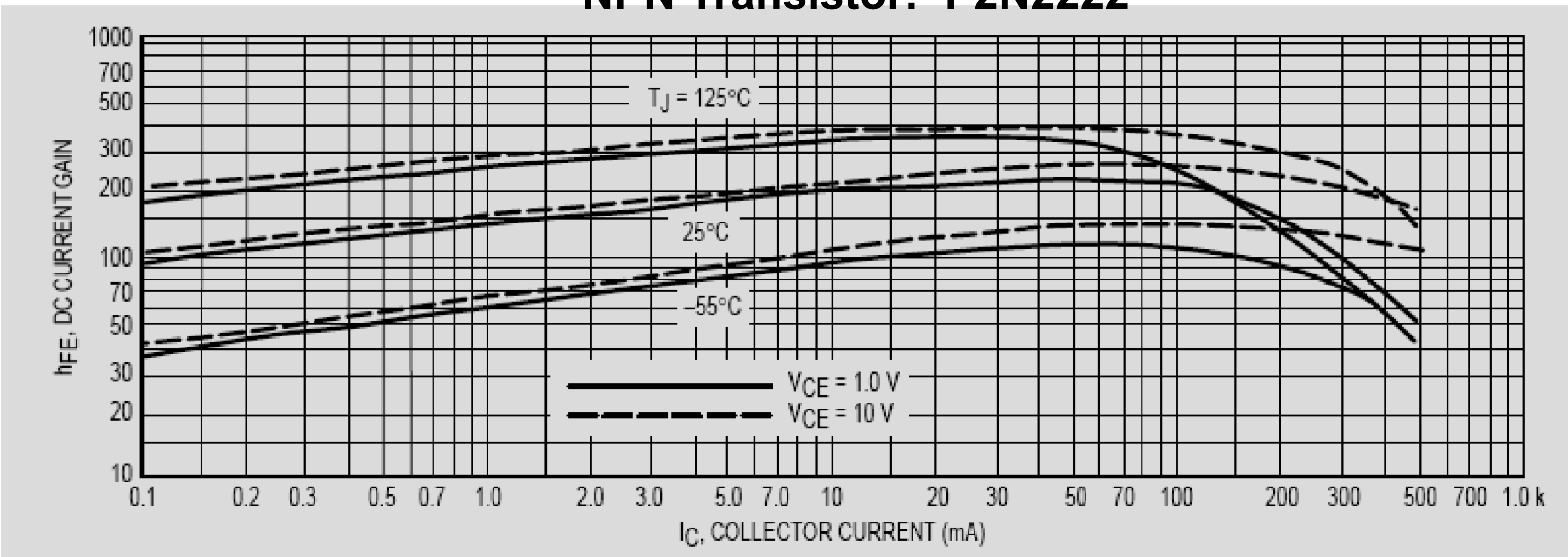
$$I_C = \beta_F\, I_B\left(1 + \frac{V_{CE}}{V_A}\right)$$

Variation of current gain with Current



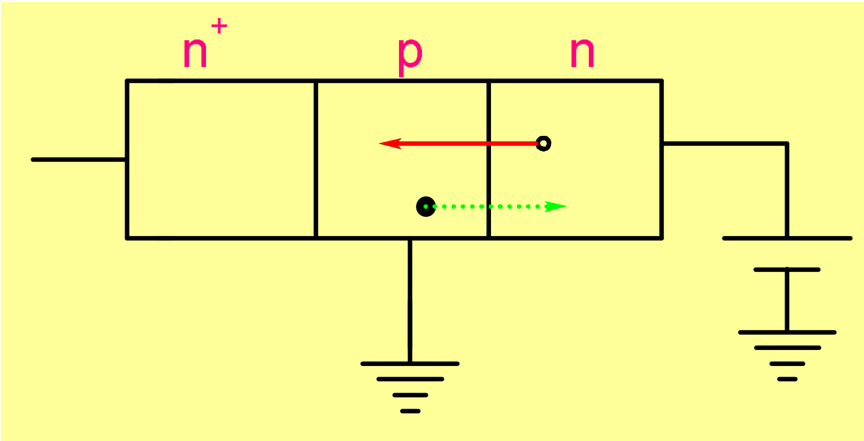


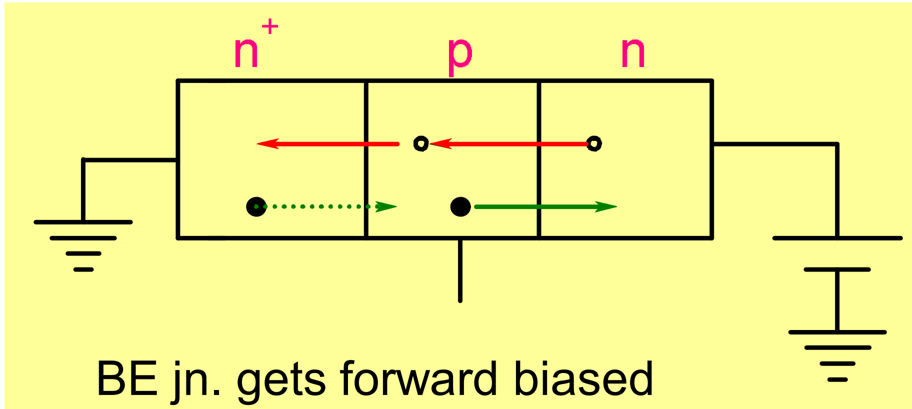
NPN Transistor: P2N2222



Breakdown

Collector-Base junction Breakdown





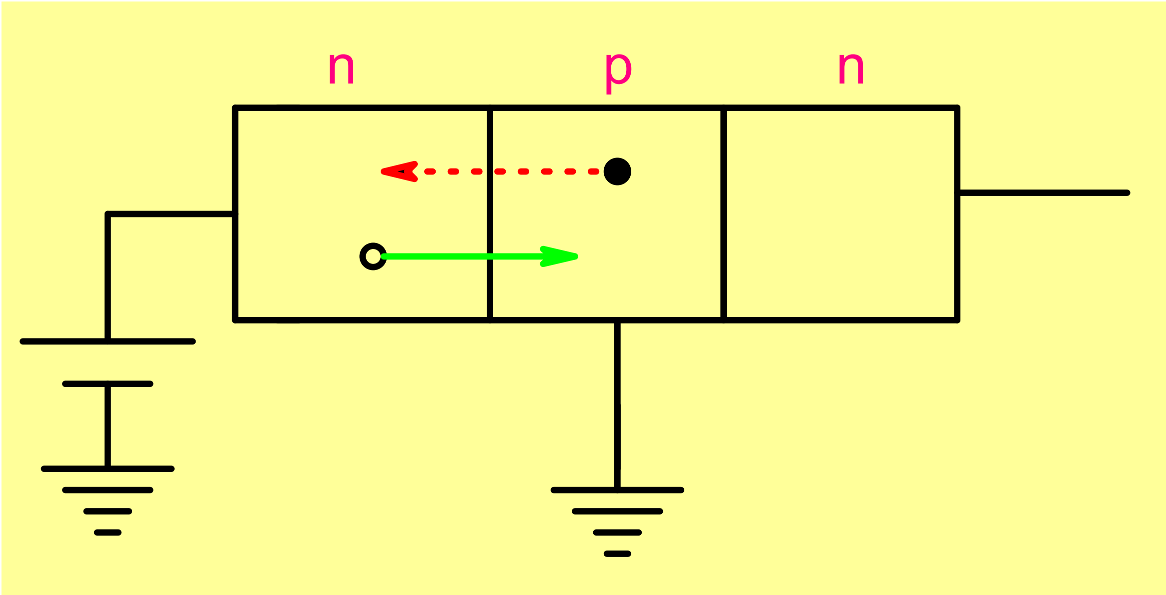
BV_{CBO}: Breakdown voltage with emitter open

BV_{CEO}: Breakdown voltage with base Open.

Example: P2N2222: BV_{CBO} ~75V while BV_{CEO} ~40V

Breakdown

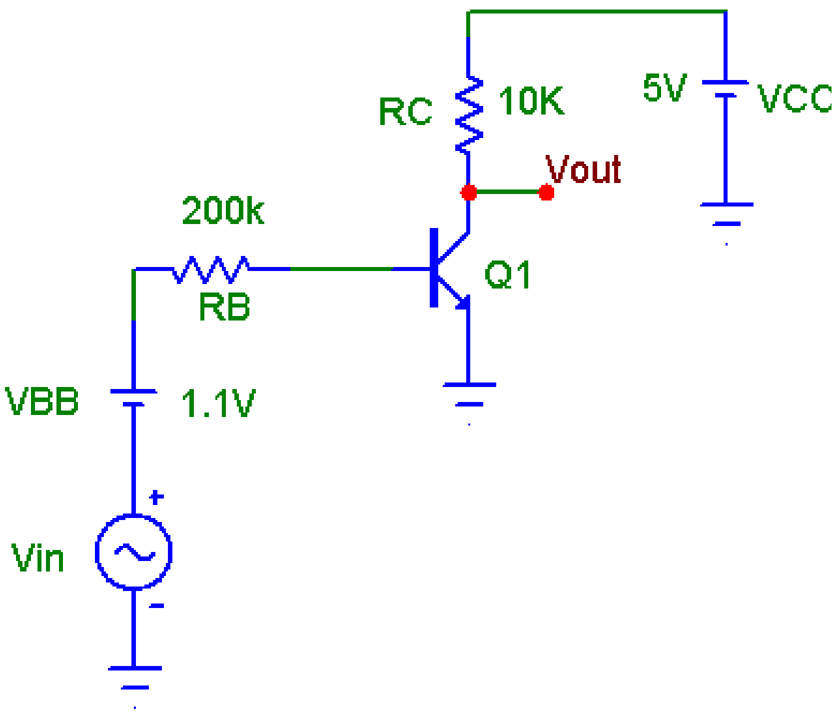
Emitter-Base junction Breakdown

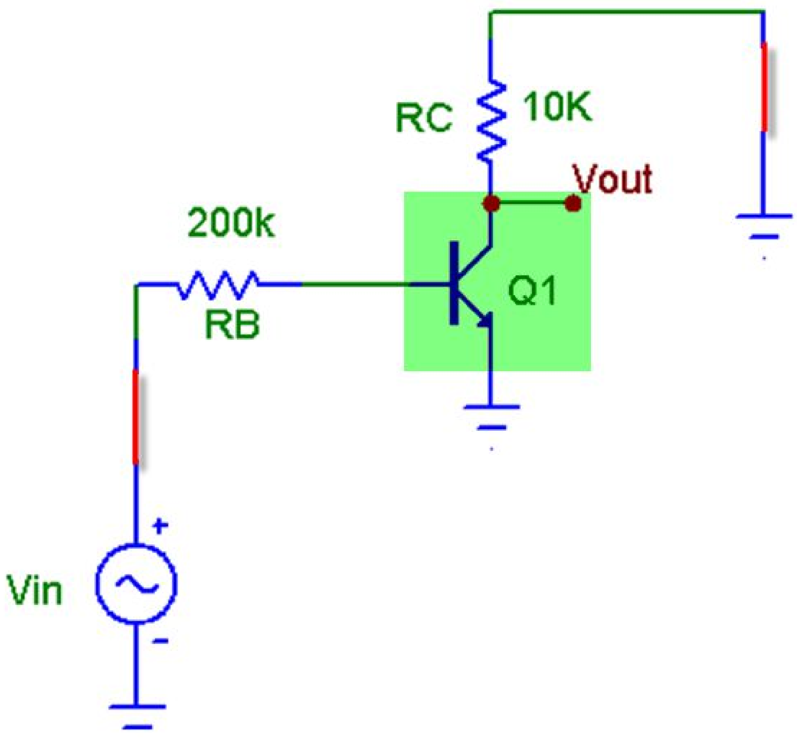


BV_{EBO}: Breakdown voltage with collector open

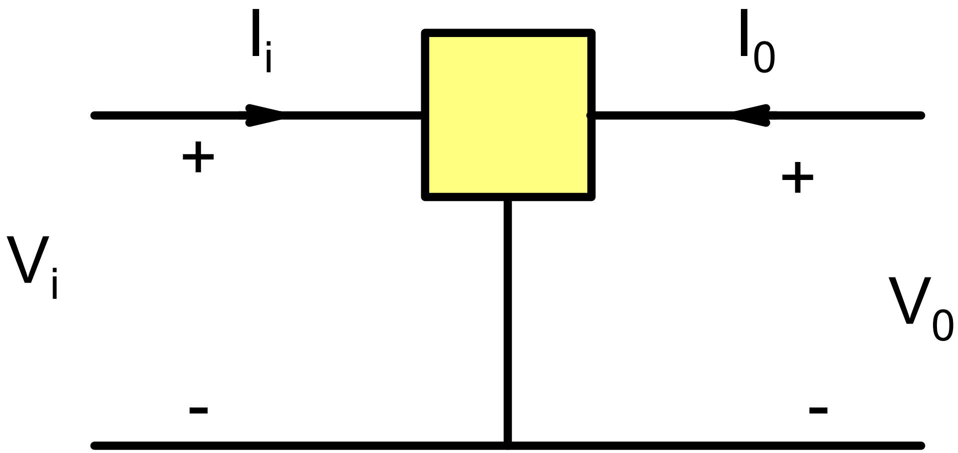
Example: P2N2222: BV_{EBO} ~6V (much smaller due to heavy doping)

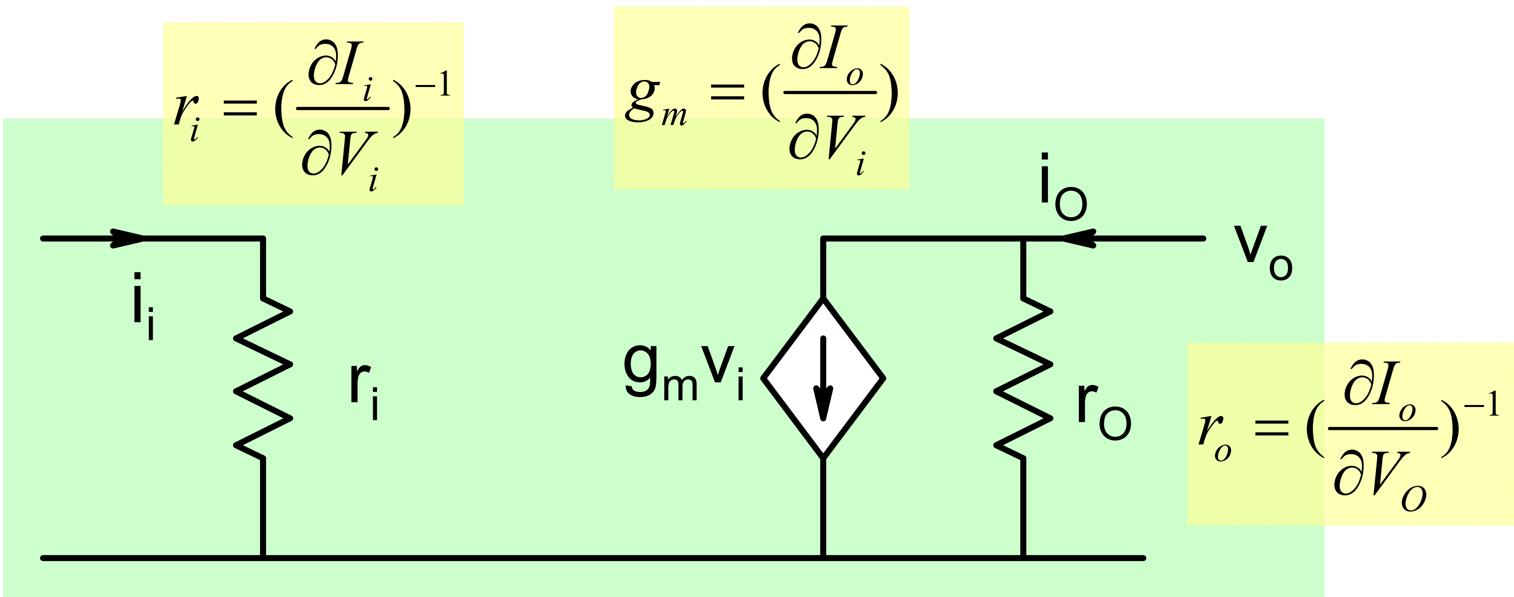
BJT : Small Signal Model



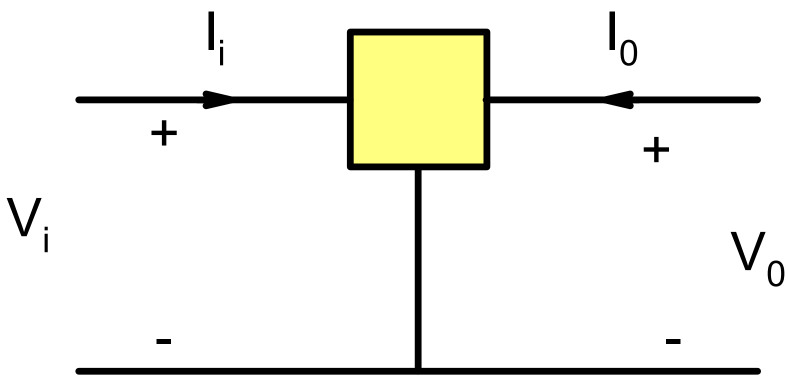


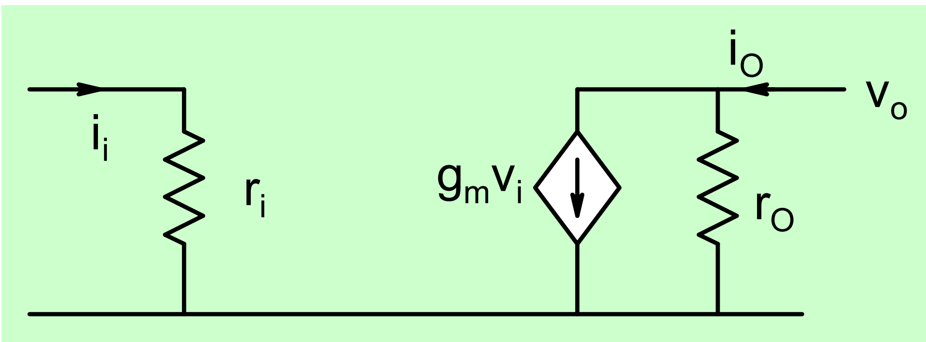
Complete small signal model (dc) for a 3-terminal unilateral device.





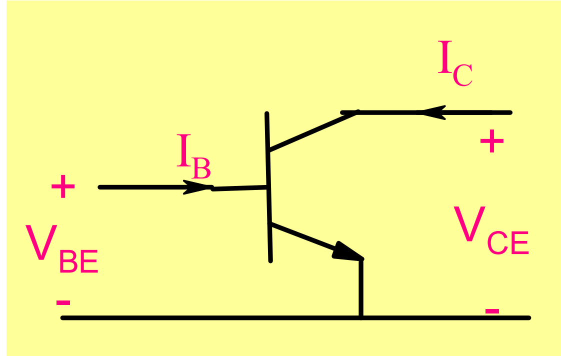
Complete small signal model (dc) for a 3-terminal unilateral device.

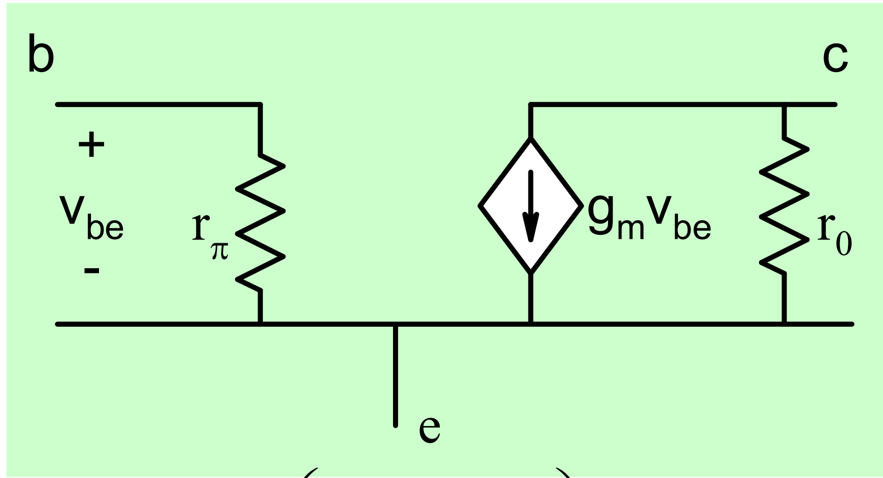




$$r_i = \left(\frac{\partial I_i}{\partial V_i}\right)^{-1} \qquad g_m = \left(\frac{\partial I_o}{\partial V_i}\right)$$

$$r_o = \left(\frac{\partial I_o}{\partial V_O}\right)^{-1}$$



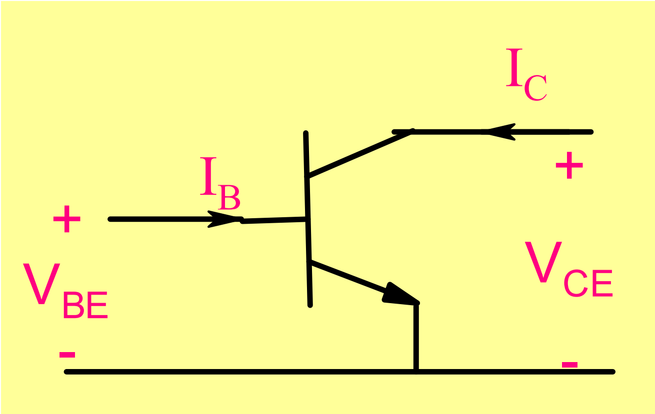


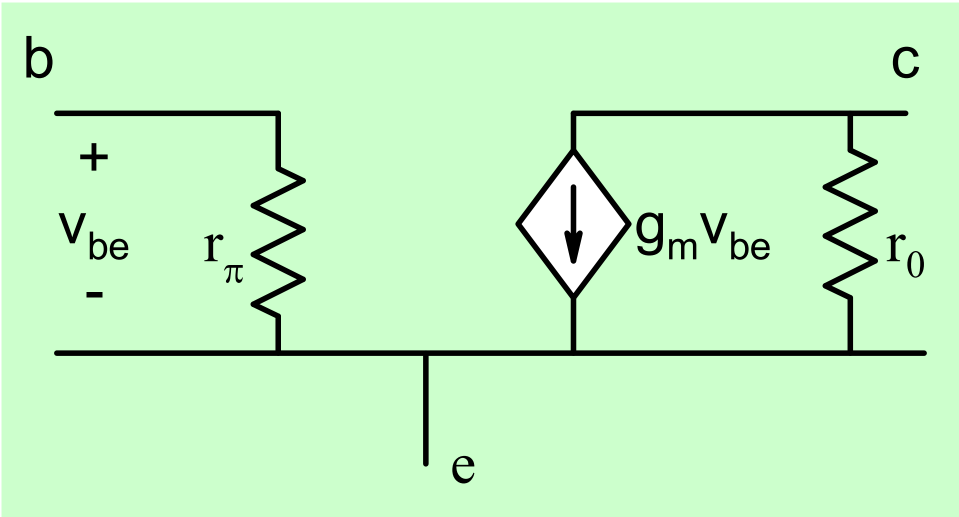
$$I_b = \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{be}}{V_T}\right) - 1\right)$$

$$r_\pi^{-1} = \left.\frac{\partial I_b}{\partial V_{be}}\right|_{I_B} \cong \frac{I_B}{V_T}$$

$$r_\pi = \frac{V_T}{I_B} = \frac{V_T}{I_C}\cdot\beta\ ; \quad r_\pi = r_E\cdot\beta$$

G-Number



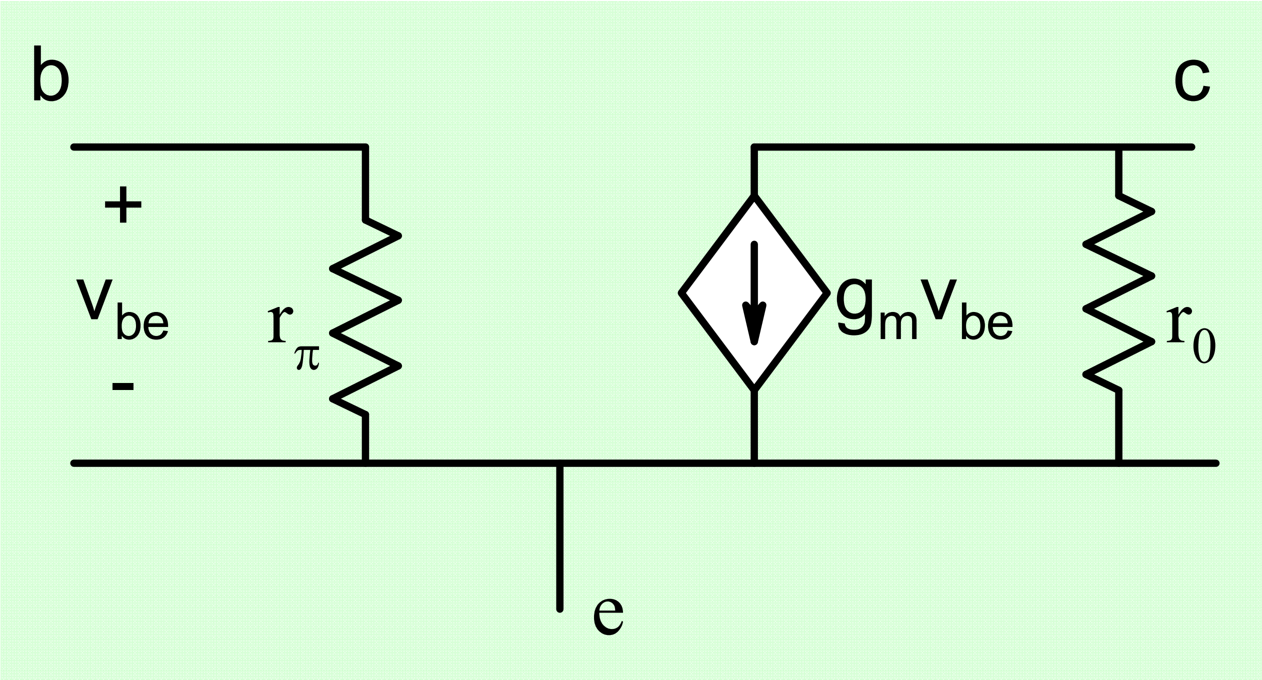


$$I_c = I_S \left(\exp(\frac{V_{be}}{V_T}) - 1 \right) \left(1 + \frac{V_{ce}}{V_A} \right)$$

$$g_m = \left. \frac{\partial I_c}{\partial V_{be}} \right|_{V_{CE}} \cong \frac{I_C}{V_T}$$

$$r_0^{-1} = \left. \frac{\partial I_c}{\partial V_{ce}} \right|_{V_{BE}} = \frac{I_C}{V_{CE} + V_A} \approx \frac{I_C}{V_A}$$

Hybrid-pi Small Signal Model : low frequency



$$r_\pi = \frac{V_T}{I_B} = \frac{V_T}{I_C} \cdot \beta$$

$$g_m = \frac{I_C}{V_T} \; ; \; r_0 = \frac{V_A}{I_C}$$

$$I_b = \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{be}}{V_T}\right) - 1\right) \qquad I_c = I_S\left(\exp\left(\frac{V_{be}}{V_T}\right) - 1\right)\left(1 + \frac{V_{ce}}{V_A}\right)$$

Validity : $v_{be} << V_T$