JOINT INSTITUTE

交大密西根学院

BJT and BJT Circuit

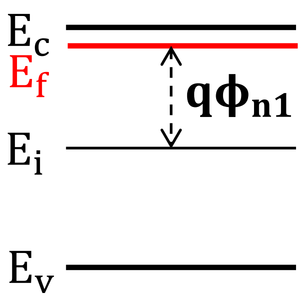
Ve311 Electronic Circuits (Fall 2021)

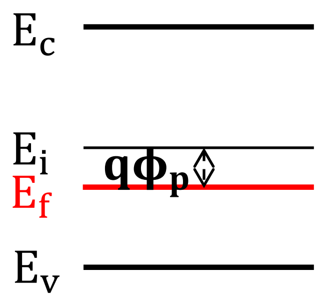
Dr. Chang-Ching Tu

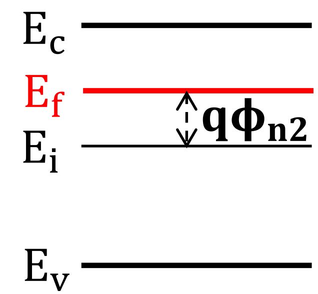
Last Updated on **October 7, 2021**

BJT (Before Contact)

Emitter	**Base**	**Collector**
n-type	p-type	n-type







$$n \cong N_{d1} = n_i e^{\frac{q\phi_{n1}}{kT}}$$

$$p \cong \frac{n_i^{\,2}}{N_{d1}} = n_i e^{\frac{-q\phi_{n1}}{kT}}$$

$$p \cong N_a = n_i e^{\frac{q\phi_p}{kT}}$$

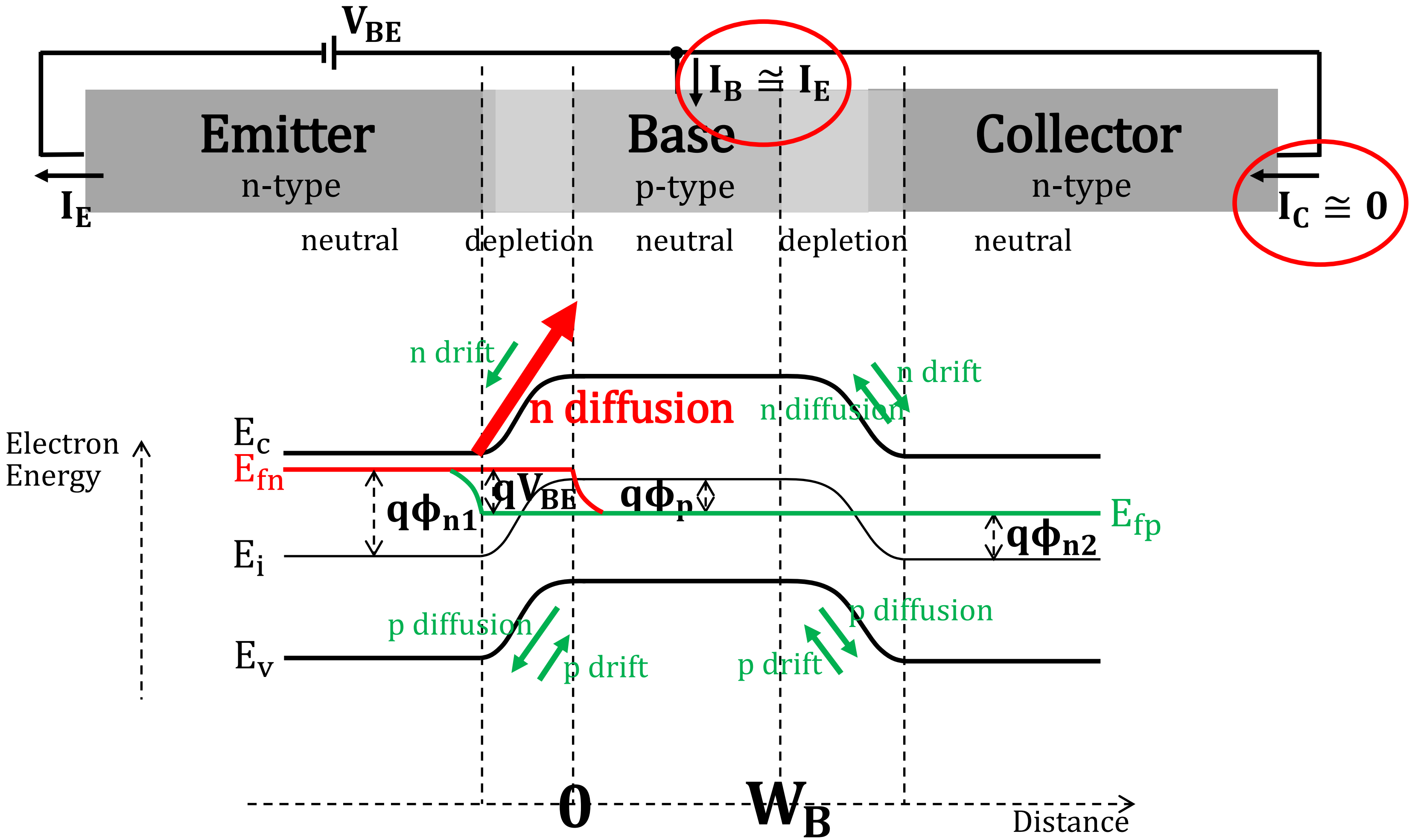
$$n \cong \frac{n_i^{\,2}}{N_a} = n_i e^{\frac{-q\phi_p}{kT}}$$

$$n \cong N_{d2} = n_i e^{\frac{q\phi_{n2}}{kT}}$$

$$p \cong \frac{n_i^{\,2}}{N_{d2}} = n_i e^{\frac{-q\phi_{n2}}{kT}}$$

$$\boxed{N_{d1} \gg N_a}$$

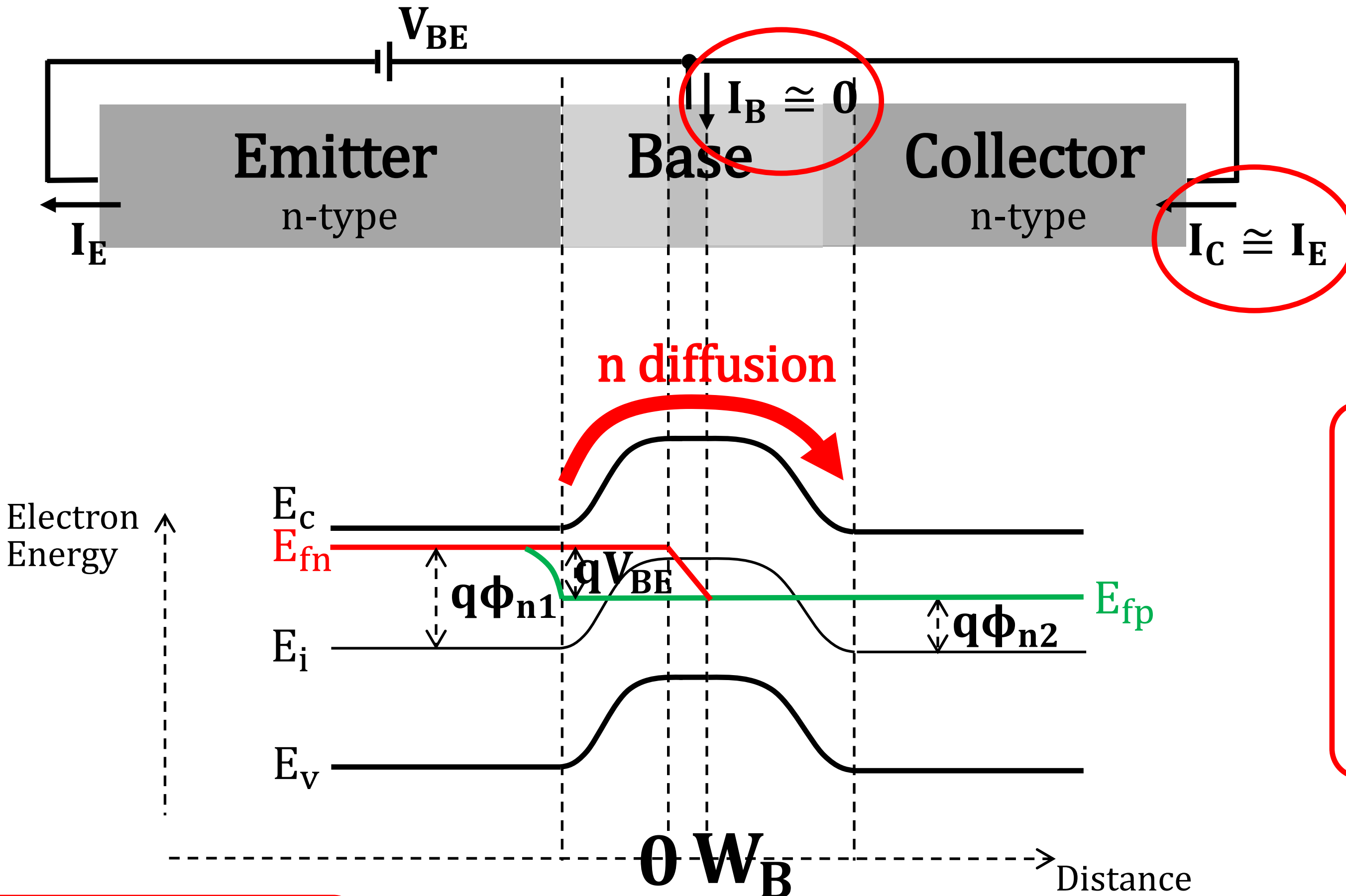
$V_{BE} > 0$ and $V_{CB} = 0$ (W_B long)



$N_{d1} \gg N_a$

The n (electron) diffusion is much larger than the p (hole) diffusion at the Base-Emitter junction.

$V_{BE} > 0$ and $V_{CB} = 0$ (W_B very short)



$$I_E = I_C + I_B$$

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

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

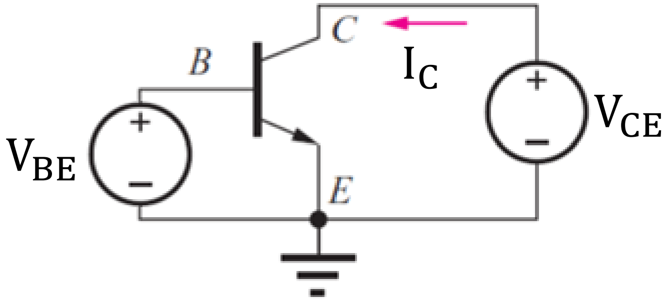
$N_{d1} \gg N_a$

The n (electron) diffusion is much larger than the p (hole) diffusion at the Base-Emitter junction.

W_B very short

Nearly all the n (electron) diffusion from the Base-Emitter junction pass through the Base, enter into the depletion region of the Base-Collector junction, and are swept to the Collector side by the built-in electric field.

Summary



$$V_{CE} \geq V_{BE}$$
$$\Rightarrow \textbf{Forward}-\textbf{Active}$$

Ideal case

$$\mathbf{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)}$$

$$\boldsymbol{\alpha} = \frac{\mathbf{I_C}}{\mathbf{I_E}} \cong \mathbf{1}$$

$$\boldsymbol{\beta} = \frac{\mathbf{I_C}}{\mathbf{I_B}} = \frac{\boldsymbol{\alpha}}{\mathbf{1}-\boldsymbol{\alpha}}$$

$$\mathbf{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)}$$

$$\boldsymbol{\alpha} = \frac{\mathbf{I_C}}{\mathbf{I_E}} = \mathbf{1}$$

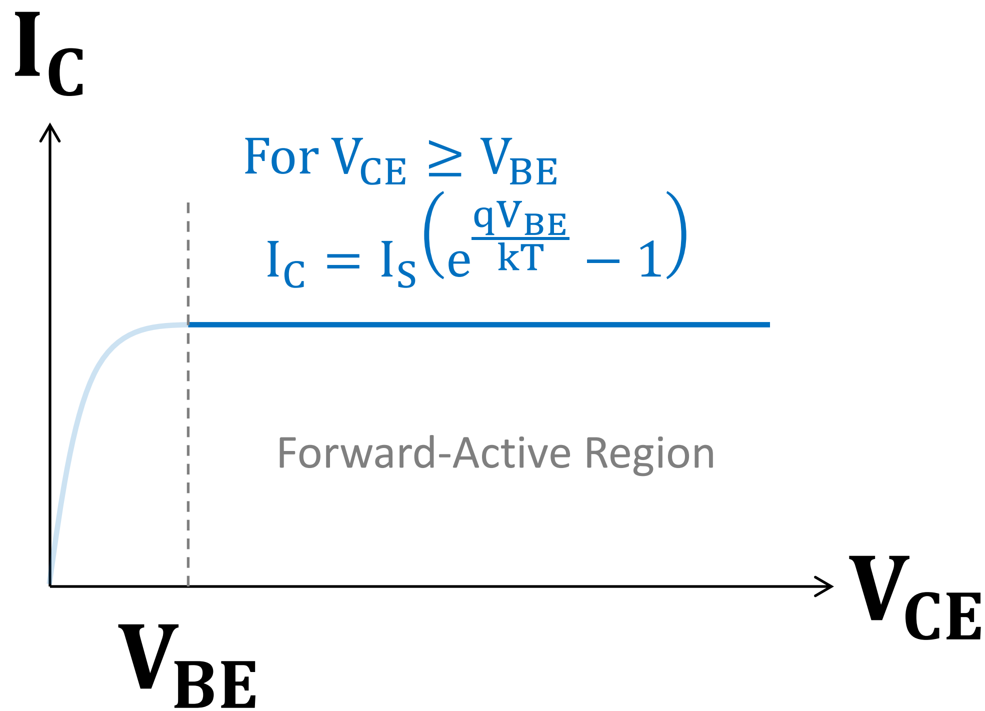
$$\boldsymbol{\beta} = \frac{\mathbf{I_C}}{\mathbf{I_B}} = \infty$$

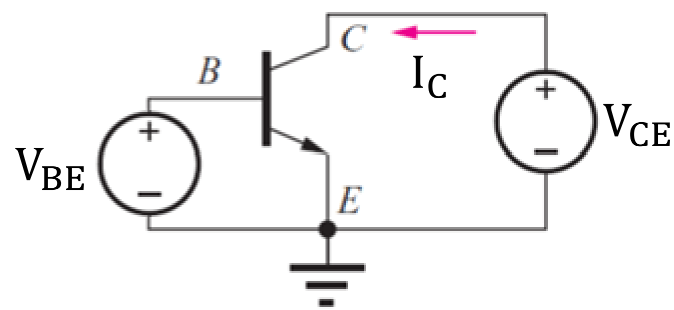
I_S is a constant in the spice model.

I_C vs V_{CE} and I_C vs V_{BE} in Forward-Active Region

I_C vs V_{CE} (not considering Early Effect)

At given V_{BE}, DC sweep V_{CE}



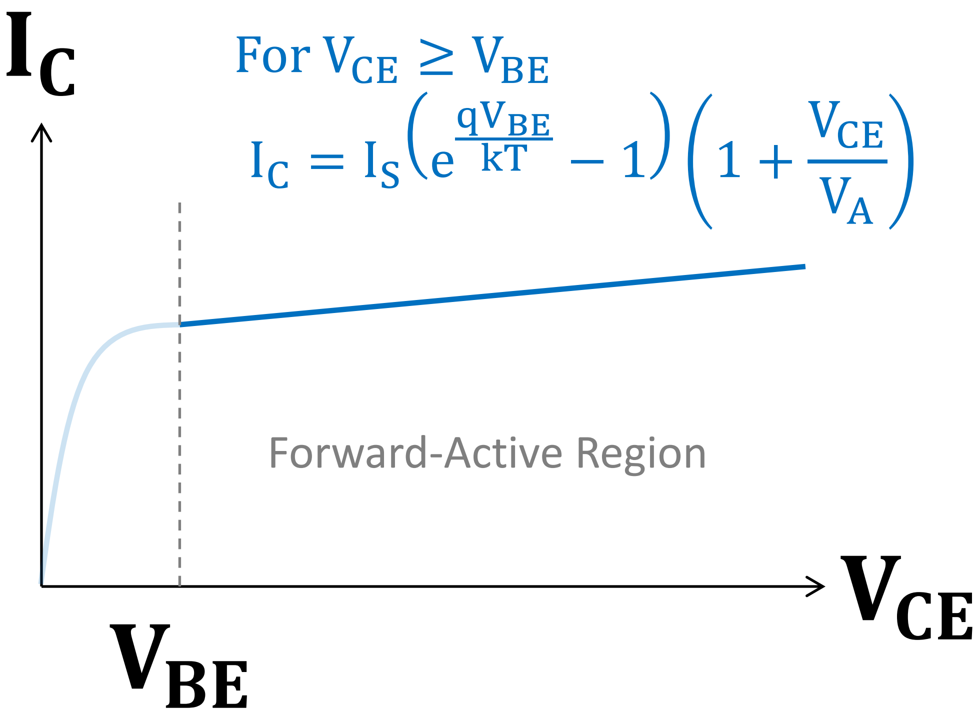


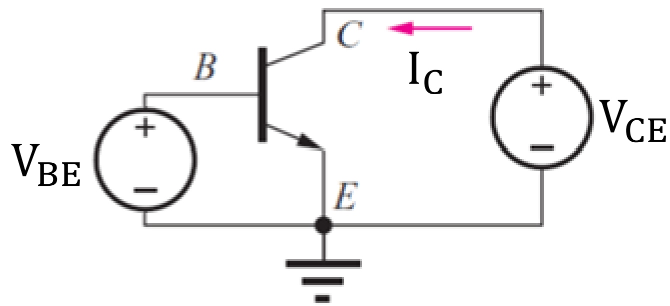
I_C vs V_{CE} (considering Early Effect)

At given V_{BE}, DC sweep V_{CE}

For $V_{CE} \geq V_{BE}$

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$





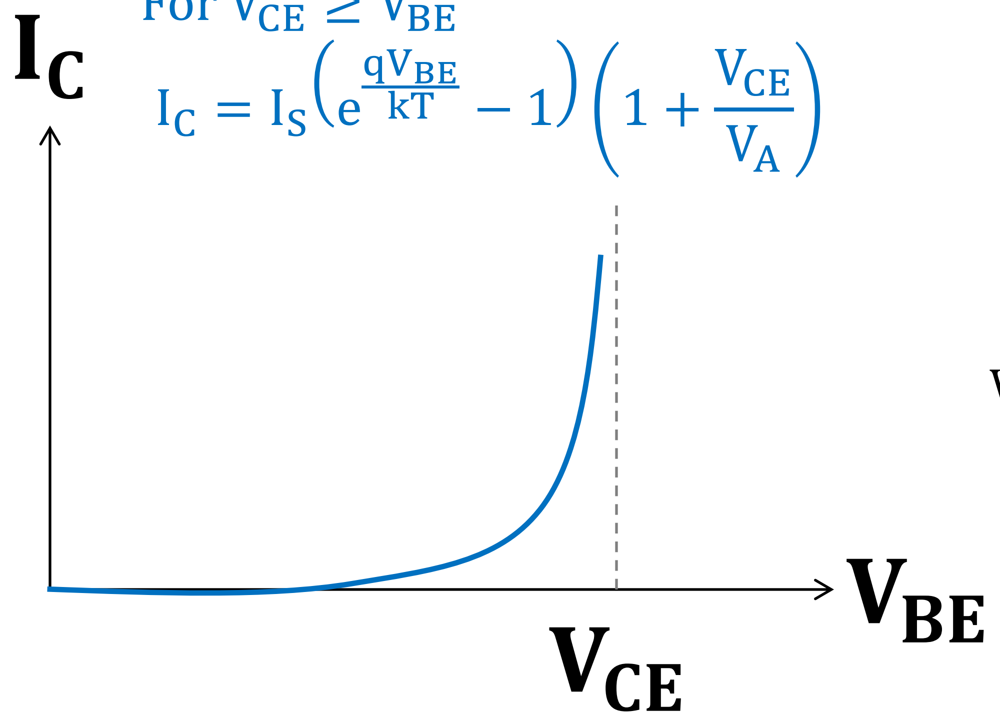
V_A is a constant in the spice model.

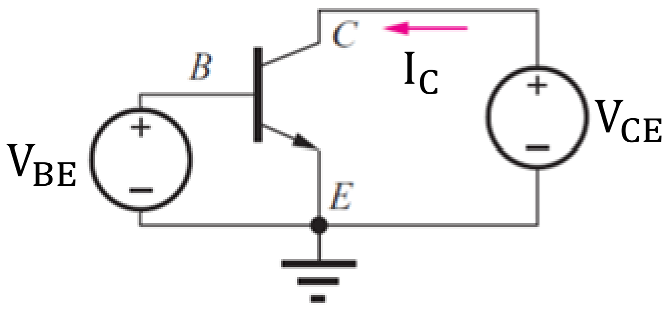
I_C vs V_{BE}

At given V_{CE}, DC sweep V_{BE}

For $V_{CE} \geq V_{BE}$

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

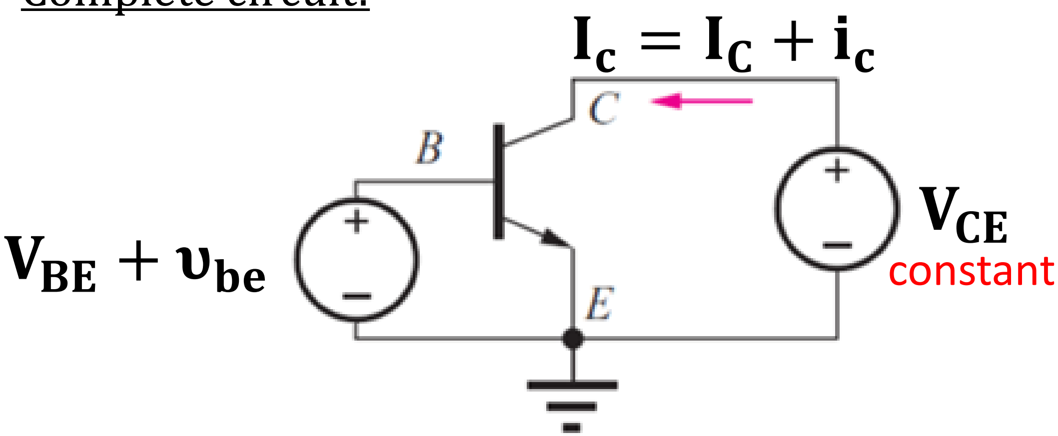




Small-Signal Model

Hybrid-π Model (how to get gm and r_π)

Complete circuit:

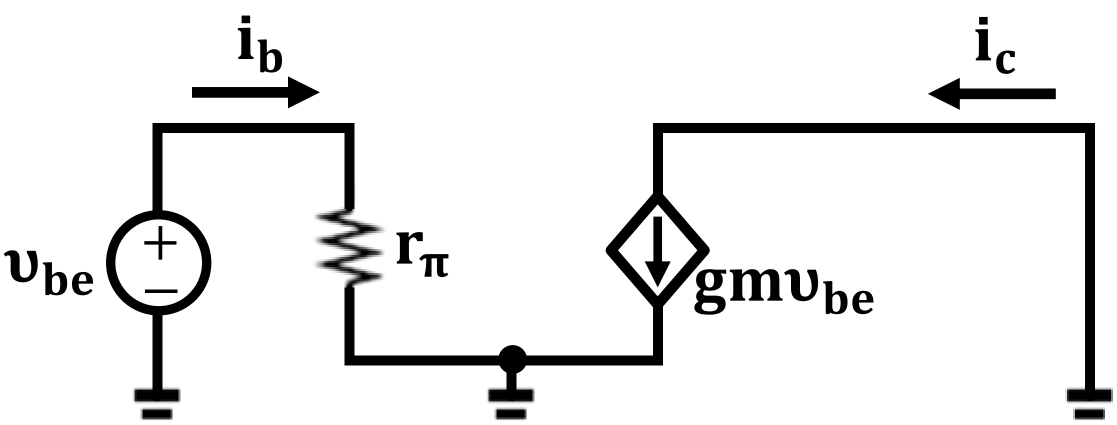


$V_{CE} \geq V_{BE}$

$\Rightarrow$ Forward – Active

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

Small-signal circuit:

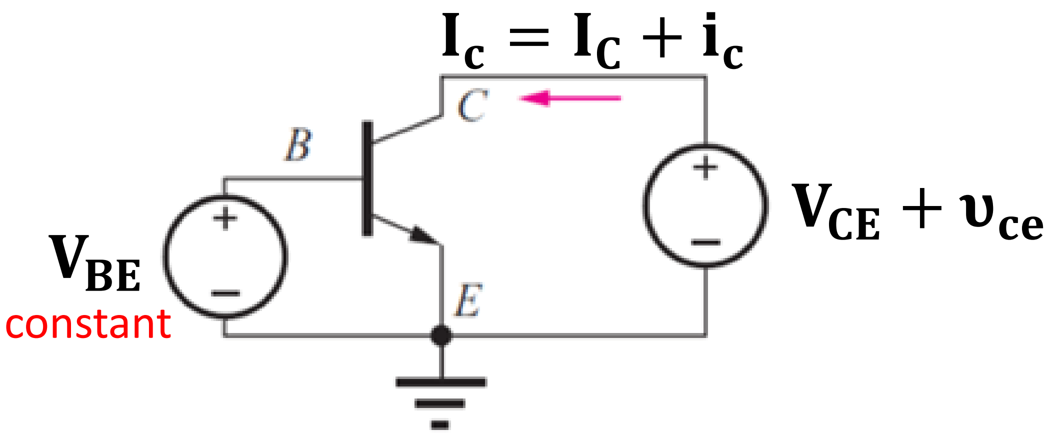


$$r_\pi = \frac{dV_{BE}}{dI_B} = \frac{1}{\frac{dI_C}{\beta dV_{BE}}} = \frac{1}{\frac{gm}{\beta}} = \frac{\beta}{gm}$$

$$gm = \frac{dI_C}{dV_{BE}} \cong \frac{I_C}{kT/q}$$

Hybrid-π Model (how to get r_o)

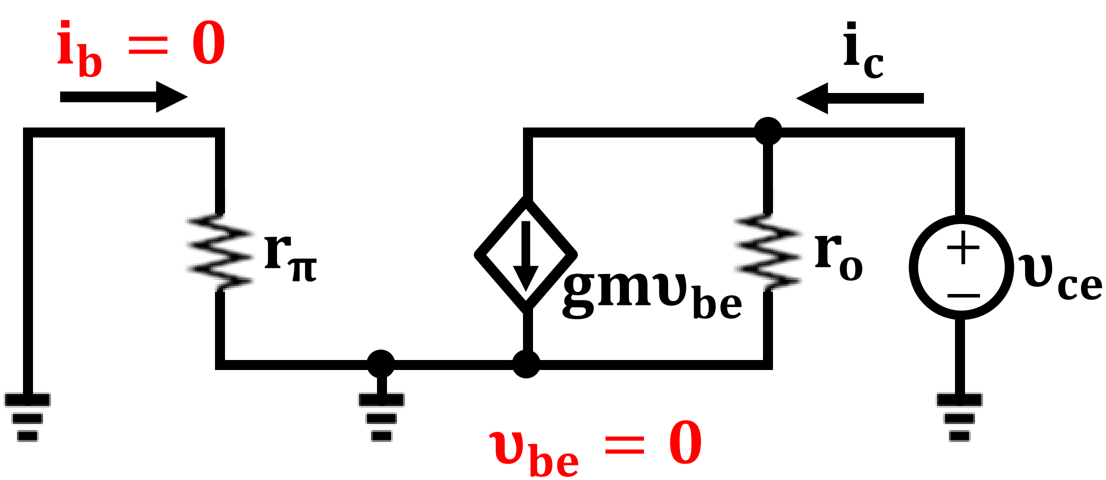
Complete circuit:



$$V_{CE} \geq V_{BE}$$
$\Rightarrow$ Forward – Active

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

Small-signal circuit:



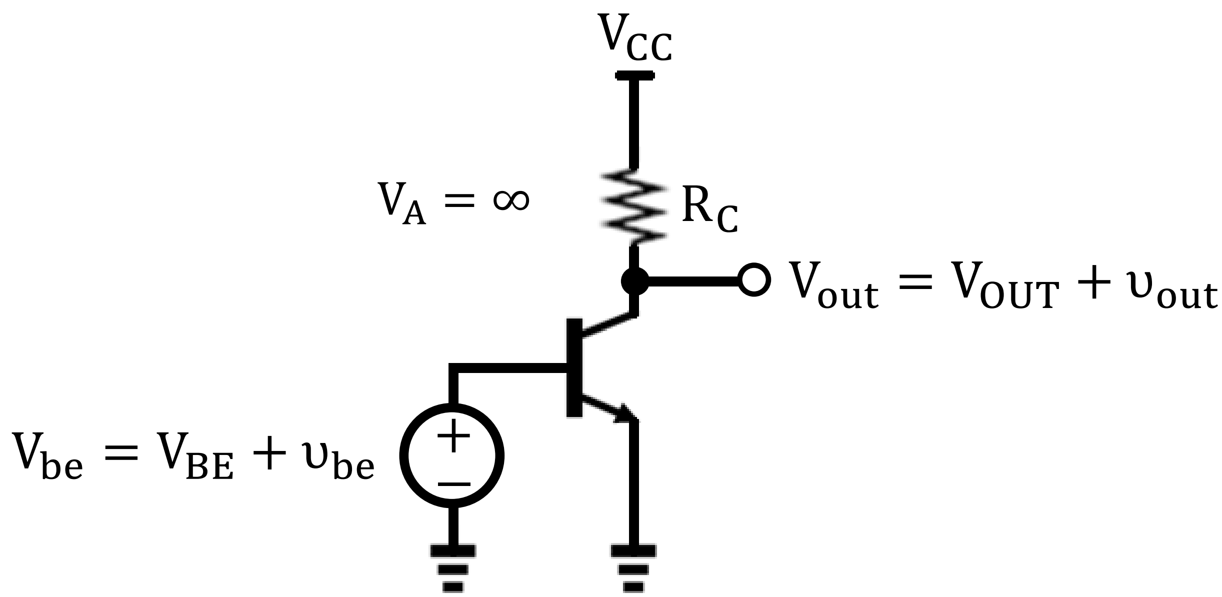
$$r_\pi = \frac{1}{\frac{dI_B}{dV_{BE}}} = \frac{1}{\frac{dI_C}{\beta dV_{BE}}} = \frac{1}{\frac{gm}{\beta}} = \frac{\beta}{gm}$$

$$gm = \frac{dI_C}{dV_{BE}} \cong \frac{I_C}{kT/q}$$

$$r_o = \frac{1}{\frac{dI_C}{dV_{CE}}} \cong \frac{V_A}{I_C}$$

Common-Emitter Amplifier

Common-Emitter Amplifier ($V_A = \infty$)

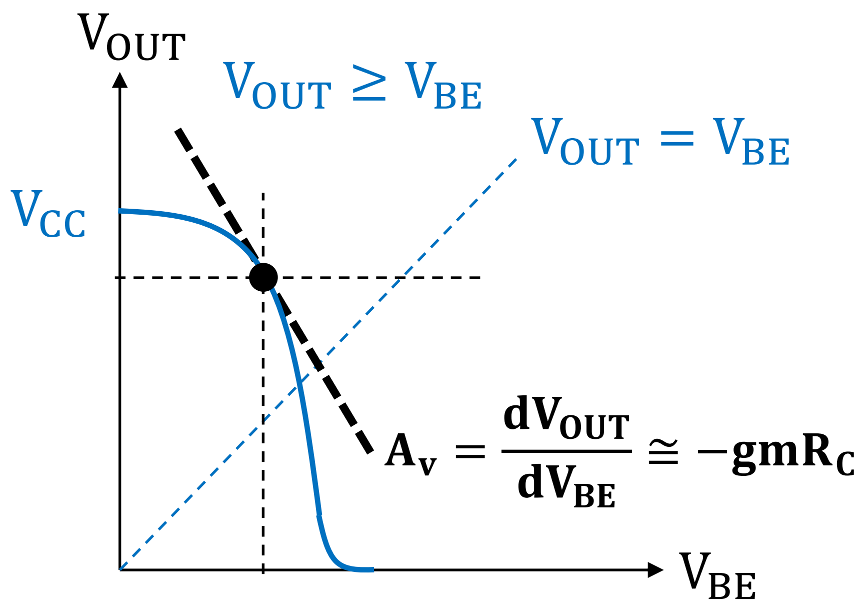


- **DC Analysis**

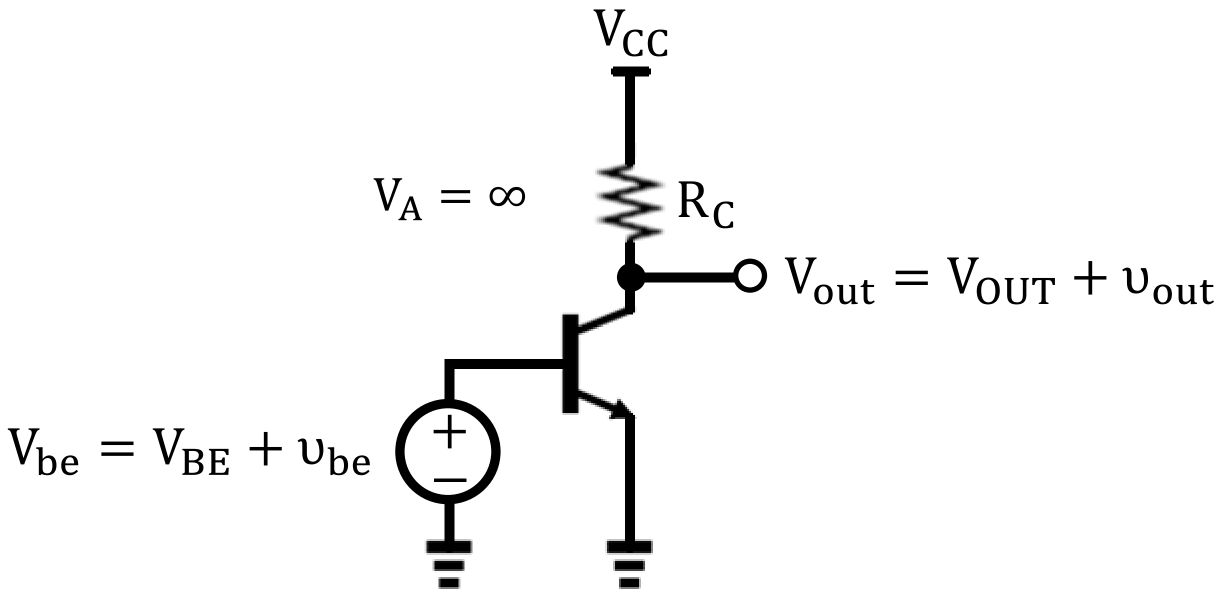
$$V_{OUT} = V_{CC} - I_C R_C$$

$$= V_{CC} - \frac{AqD_n n_i^2}{N_a W_B}\left(e^{\frac{qV_{BE}}{kT}} - 1\right)R_C$$

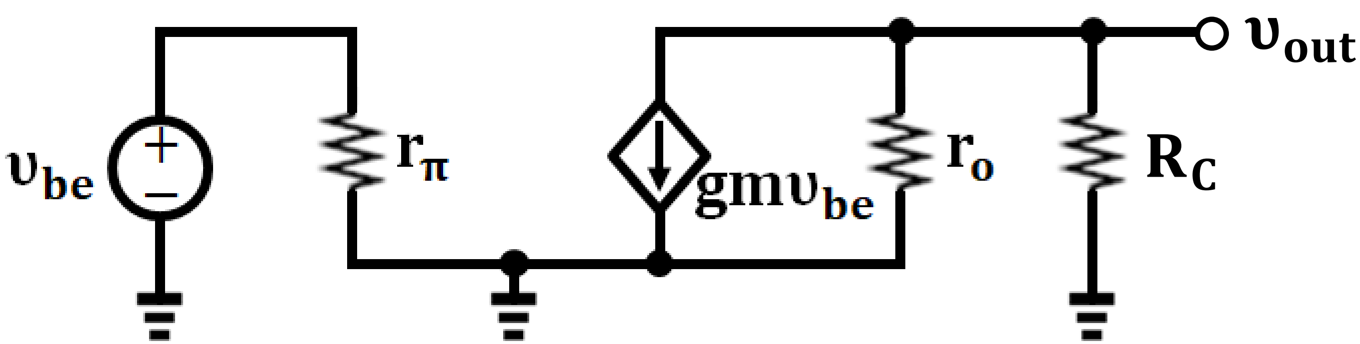
$$\boxed{A_v = \frac{dV_{OUT}}{dV_{BE}} \cong -\frac{I_C}{kT/q}R_C = -gmR_C}$$



Common-Emitter Amplifier ($V_A = \infty$)

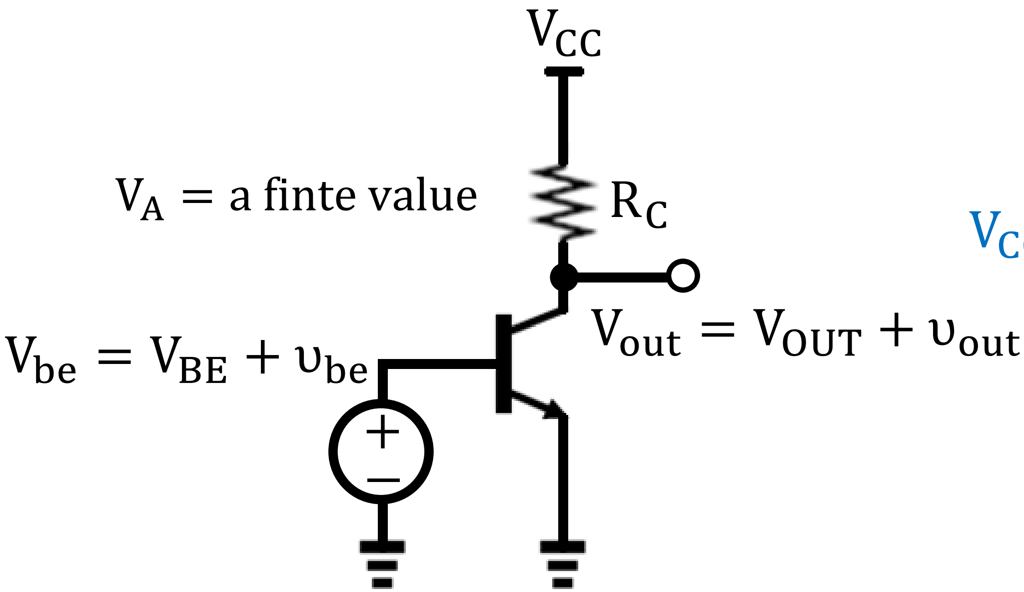


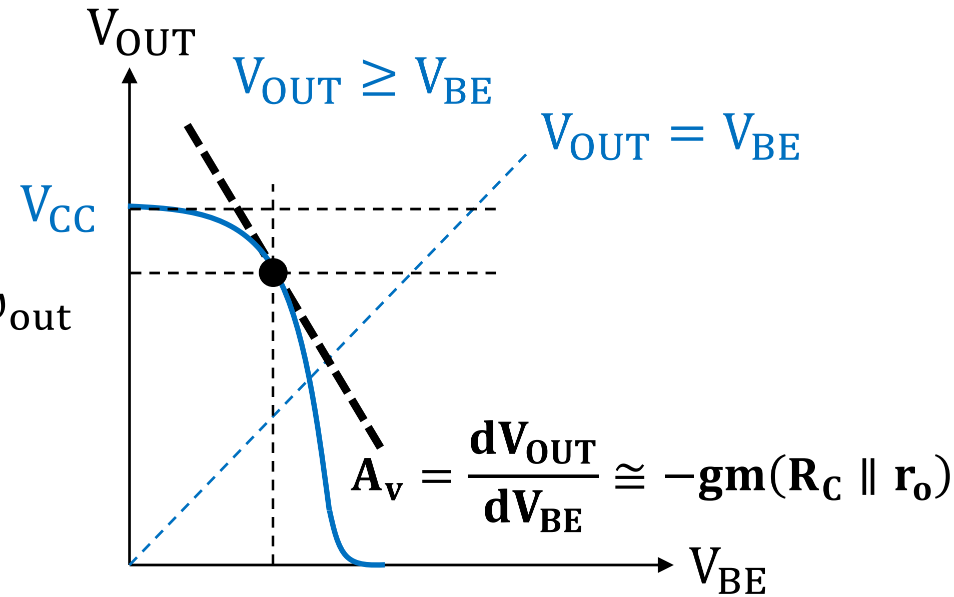
- **Small-Signal Analysis**



$$\boxed{A_v = \frac{\upsilon_{out}}{\upsilon_{be}} = -gm(R_C \parallel r_o) = -gmR_C} \quad (\text{since } r_o = \infty)$$

Common-Emitter Amplifier (V_A = a finite value)





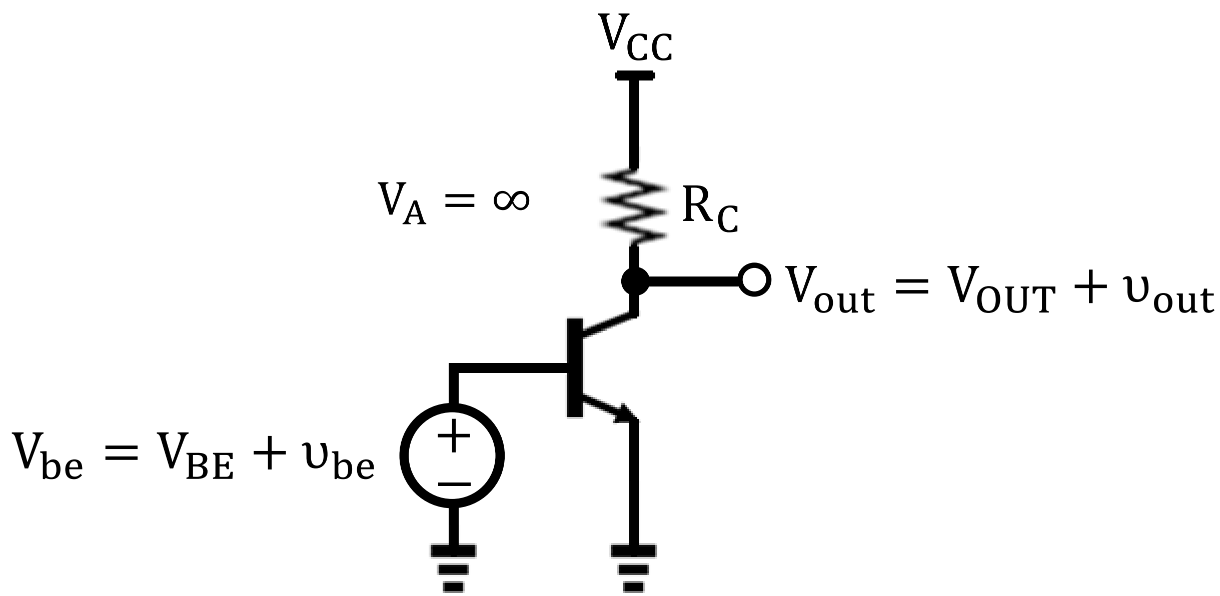
- **DC Analysis**

$$V_{OUT} = V_{CC} - I_C R_C = V_{CC} - I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{OUT}}{V_A}\right) R_C$$

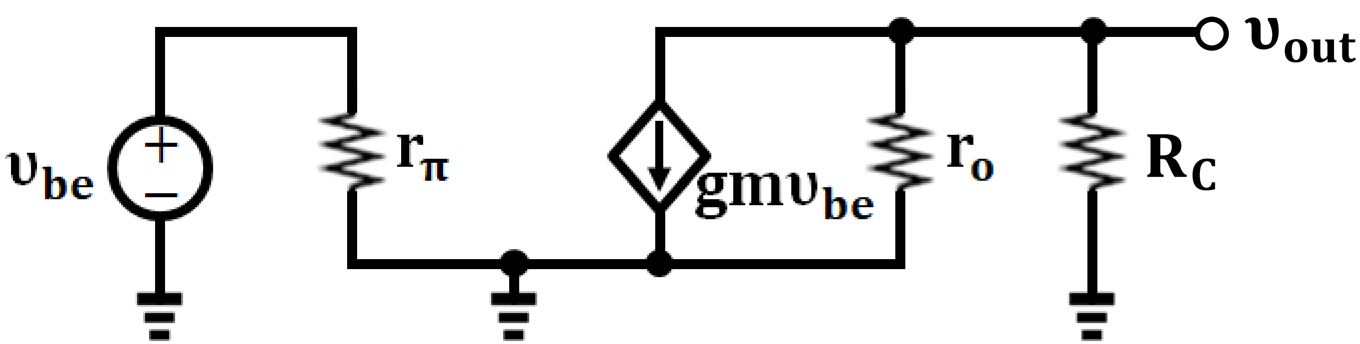
$$\frac{dV_{OUT}}{dV_{BE}} = -\frac{q}{kT} I_S e^{\frac{qV_{BE}}{kT}}\left(1 + \frac{V_{OUT}}{V_A}\right) R_C - I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\frac{1}{V_A}\frac{dV_{OUT}}{dV_{BE}} R_C \cong -gmR_C - \frac{1}{r_o}\frac{dV_{OUT}}{dV_{BE}} R_C$$

$$\boxed{A_v = \frac{dV_{OUT}}{dV_{BE}} \cong -gm(R_C \parallel r_o)}$$

Common-Emitter Amplifier (V_A = a finite value)



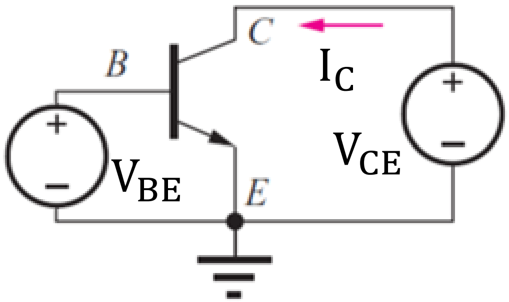
- **Small-Signal Analysis**

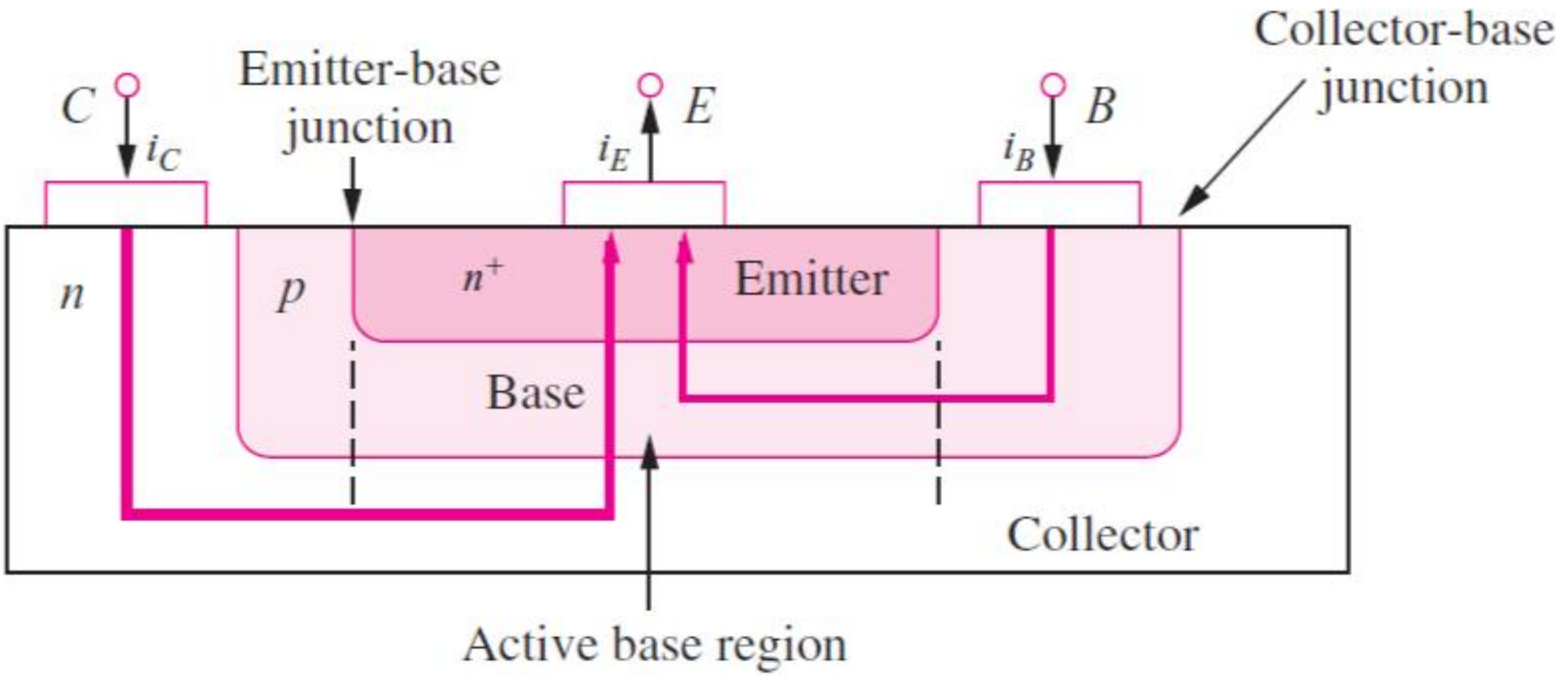


$$\boxed{A_v = \frac{\upsilon_{out}}{\upsilon_{be}} = -gm(R_C \parallel r_o)}$$

BJT Structure and Pspice Model

npn BJT Cross Section





npn BJT Pspice Model

.model Qbreakn NPN IS=1e-18 BF=100 VAF=100

$$I_C = \mathbf{IS}\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{\mathbf{VAF}}\right)$$

$$\mathbf{BF} = \frac{I_C}{I_B} \qquad I_E = I_C + I_B$$

$$gm \cong \frac{I_C}{kT/q} \qquad r_\pi = \frac{\mathbf{BF}}{gm} \qquad r_o \cong \frac{\mathbf{VAF}}{I_C}$$