BJT As An Amplifier

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Label Convention:

I_A, V_A	DC values
I_a, V_a	Complex values
i_A, v_A	Instantaneous values
i_a, v_a	Small signal values

Model: $i_C = I_C + i_c$

- i_C: instantaneous current
- I_C: DC current
- i_c: small signal current

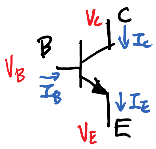
Transistor act as amplifier in its ACTIVE REGION

↳ EBJ is forward biased: $V_{BE} \approx 0.7V$

↳ CBJ is reverse biased: $V_{CB} > -0.7V$

DC Relationship:

NPN BJT Transistor:



$I_C = \alpha I_E$ ← common base current gain factor

$I_C = \beta I_B$ ← common emmiter current gain factor

$I_C = I_S e^{\frac{V_{BE}}{V_T}}$ ← V_T: thermal equivalence of voltage; I_S: reverse saturation current

Relationships b/w α & β:

$$\alpha = \frac{\beta}{\beta+1}, \quad \beta = \frac{\alpha}{1-\alpha}$$

Collector Current

Given $I_C = I_S e^{\frac{V_{BE}}{V_T}}$, and $v_{BE} = V_{BE} + v_{be}$

$$i_C = I_S e^{\frac{v_{BE}}{V_T}}$$

$$= I_S e^{\frac{V_{BE}+v_{be}}{V_T}}$$

$$= \underbrace{I_S e^{\frac{V_{BE}}{V_T}}}_{I_C} \cdot e^{\frac{v_{be}}{V_T}}$$

instantaneous collector current:

$$i_C = I_C \cdot e^{\frac{v_{be}}{V_T}}$$

using Taylor's series expansion

$$i_C = \underbrace{I_C}_{\text{DC}} + \underbrace{\frac{I_C}{V_T} v_{be}}_{\text{Small Signal}} \quad \left(i_c = \frac{I_C}{V_T} v_{be} \right)$$

Small signal collector current $i_c = \frac{I_C}{V_T} v_{be} = g_m \cdot v_{be}$

Small signal collector current $i_c = \frac{I_c}{V_T} v_{be} = g_m v_{be}$

↑ transconductance

Base Current

Instantaneous current $i_B = I_B + i_b$,

$$i_B = \frac{i_C}{\beta} \leftarrow i_C = I_C + i_c$$

$$i_B = \frac{I_C}{\beta} + \frac{i_c}{\beta} \leftarrow i_c = g_m v_{be}$$

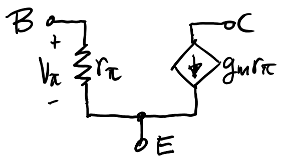
$$i_B = \frac{I_C}{\beta} + \underbrace{\frac{g_m}{\beta} v_{be}}_{\text{small signal}}$$

→ thus $i_c = \frac{g_m v_{be}}{\beta}$

Small Signal Input Resistance

$$r_\pi \equiv \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \beta \frac{V_T}{I_C} = \frac{V_T}{I_B}$$

So far our model is:



⚠ THIS IS STILL NOT COMPLETE MODLE

missing components:- EBJ junction capacitances
- CBJ junction capacitances

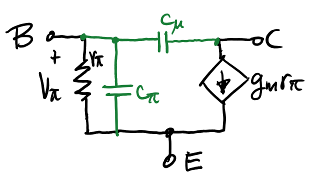
EBJ Capacitance (Diffuse Capacitance)

- capacitance based on "change in the minority carrier concentrations on either side of the junction"
- can be approximately modelled <u>linearly</u>

Reverse Biased CBJ Capacitance (Space-Charge Capacitance)

- based on "change in exposed charge on either side of the depletion region"
- can also be modelled <u>linearly</u>

Now our model is:



⚠ THIS IS STILL NOT COMPLETE MODLE

missing components:- Voltage controlled current source output impedence

Output Impedence is given as the inverse of the change in i_C as a function of V_{CE} at constant v_{BE}

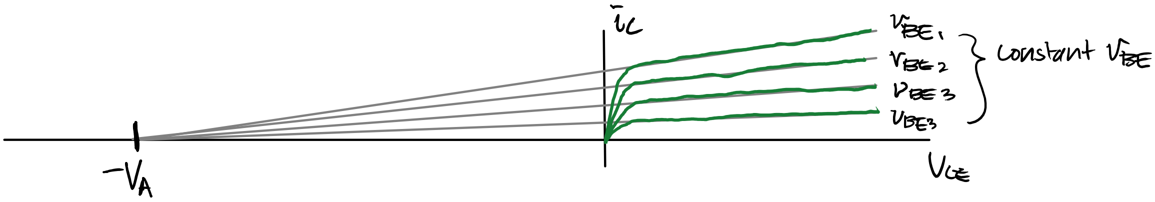
$$\rightarrow r_o = \left[\left(\frac{\partial i_C}{\partial v_{CE}}\right)\Bigg|_{v_{BE}\text{ is constant}}\right]^{-1}$$

* this can be approximated as

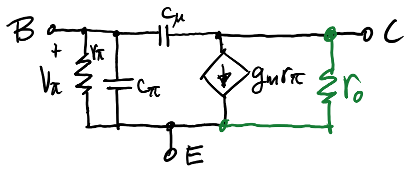
$$r_o \approx \frac{V_A}{I_C}$$

V_A ← Early voltage

I_C ← Bias current



Updated Model:



✓ Model is good enough