# ECE 310 – Lecture 30.

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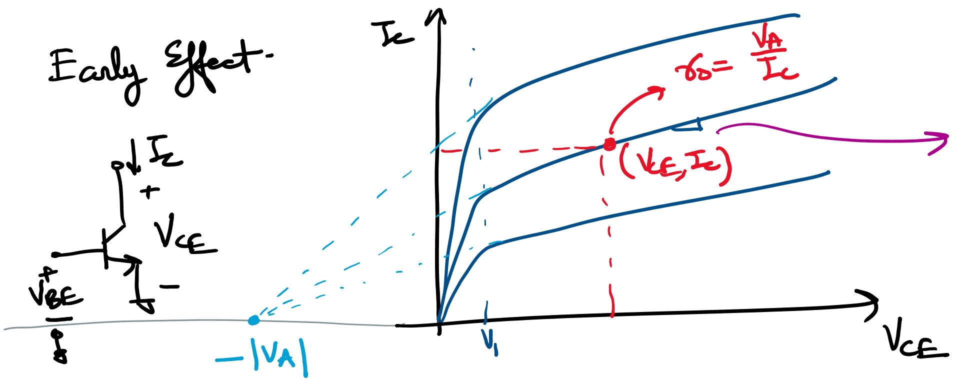
Early Effect.




$$I_C \simeq I_S\, e^{\frac{v_{BE}}{V_T}} \left(1 + \boxed{\frac{V_{CE}}{V_A}}\right)$$

$\frac{v_{BE}}{nV_T}$ → $n = 1$ from our Book

$$r_o = \left(\frac{\partial i_C}{\partial v_{CE}}\right)^{-1}\Bigg|_{(V_{CE}, I_C)} = \boxed{\frac{V_A}{I_C}}$$

# BJT Small-signal Model

$\boxed{r_o = \frac{I_C}{V_A}}$ : BJT

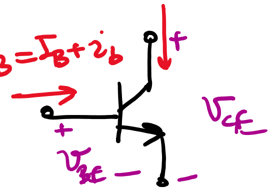
$\rightarrow \frac{1}{\lambda I_D}$ for MOSFETs

$$g_m = \left(\frac{\partial i_C}{\partial v_{BE}}\right)\Bigg|_{(V_{BE},\, I_C)} = \frac{\partial}{\partial v_{BE}}\left(I_S\, e^{\frac{v_{BE}}{v_T}}\right) = \frac{\underbrace{I_S \cdot e^{v_{BE}/v_T}}_{I_C}}{v_T}$$

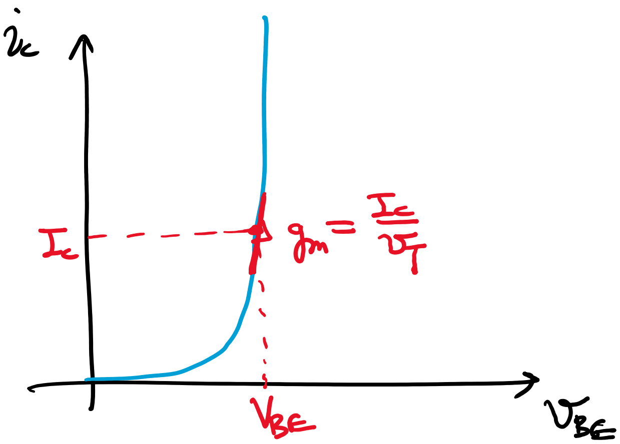
$$\Rightarrow \boxed{g_m = \frac{I_C}{v_T}}$$

$i_C = I_C + i_c$

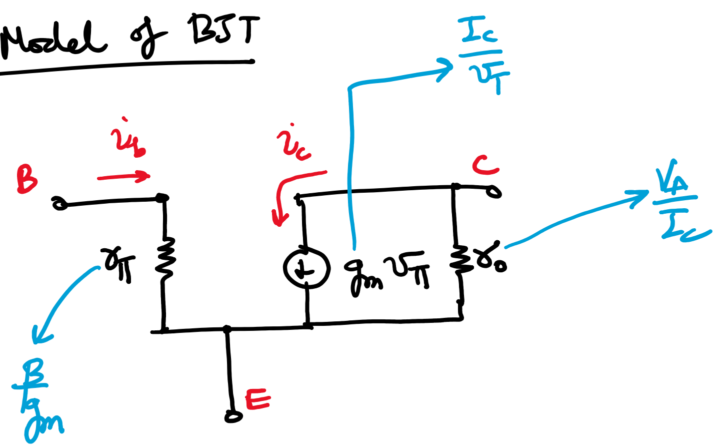
$i_B = I_B + i_b$




$i_c = \beta\, i_B$




## π-Model of BJT




$$i_b = \frac{i_c}{\beta} = \frac{g_m v_\pi}{\beta}$$

$$\Rightarrow i_b = \underbrace{\left(\frac{g_m}{\beta}\right)}_{r_\pi^{-1}} v_\pi$$

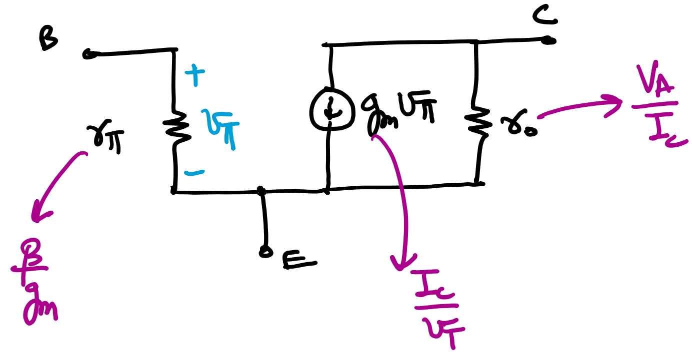
$$\Rightarrow i_b = \frac{v_\pi}{r_\pi}$$

$$\boxed{r_\pi = \frac{\beta}{g_m}}$$

## Small signal BJT Model

## Small signal BJT Model

### π-Model :




$r_\pi = \frac{\beta}{g_m}$

$g_m = \frac{I_c}{V_T}$

$r_o = \frac{V_A}{I_c}$

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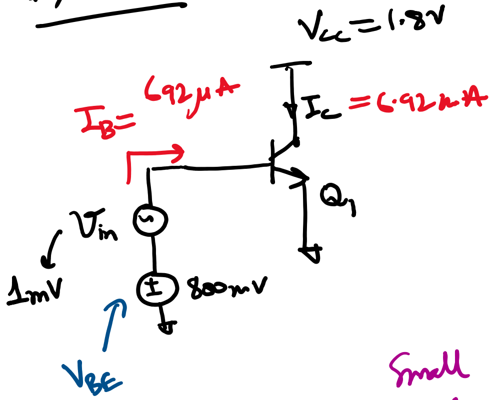
$I_S = 3\times10^{-16}\,A$, $\beta = 100$, $V_A = \infty$ $\qquad \underline{V_T = 26\,mV}$

<u>Ex 4.10</u>:

Find small-signal (Ac) circuit




$$I_c = I_s e^{V_{BE}/V_T} = 3\times10^{-16}\exp\left(\frac{0.8}{0.026}\right)$$

$$\Rightarrow \boxed{I_c = 6.92\,mA} \text{ for } V_{BE} = 0.8V$$

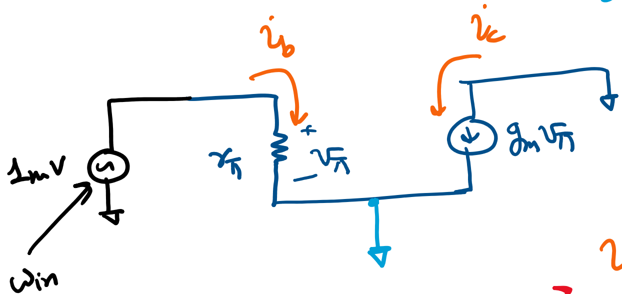
Small signal parameter

$$g_m = \frac{I_c}{V_T} = \frac{6.92\,mA}{26\,mV} = \frac{1}{3.75\,\Omega}$$

$$r_\pi = \frac{\beta}{g_m} = 375\,\Omega$$

$$r_o = \frac{V_A}{I_c} = \infty$$

$V_A \to \infty \Rightarrow r_o \to \infty$




Small signal currents

$$i_c = g_m v_\pi = g_m v_{in} = 267\,\mu A$$

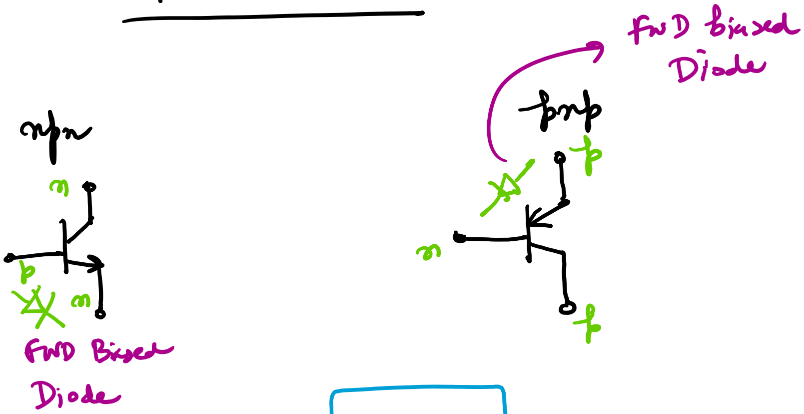
$$i_b = \begin{cases} \dfrac{i_c}{\beta} \\ \dfrac{v_\pi}{r_\pi} = \dfrac{1mV}{375\Omega} = 2.67\,\mu A \end{cases}$$

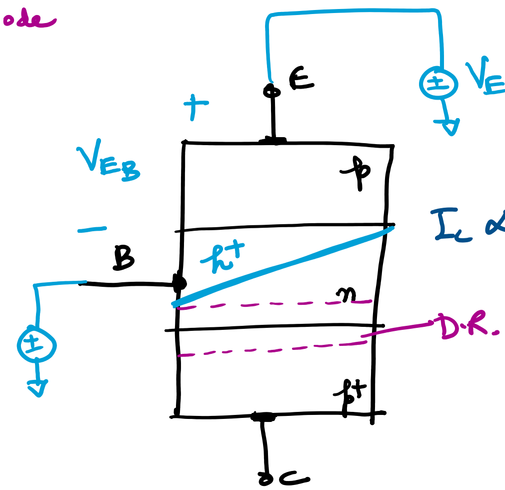
total current $\Rightarrow$

$$i_c = I_c + i_c \cdot \sin(\omega_{in} t)$$

$$i_B = I_B + i_b \sin(\omega_{in} t).$$

# PNP BJT




$I_C \propto \frac{dp}{dx}$

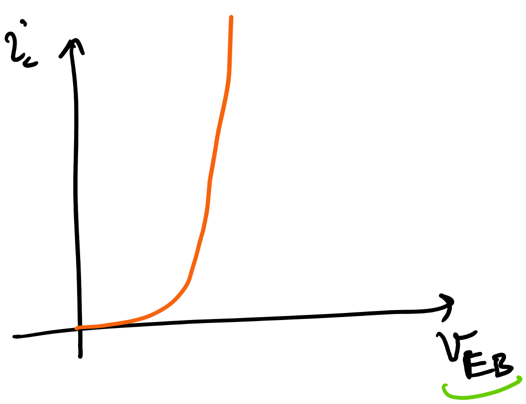
$$I_C = I_S e^{V_{EB}/V_T}$$

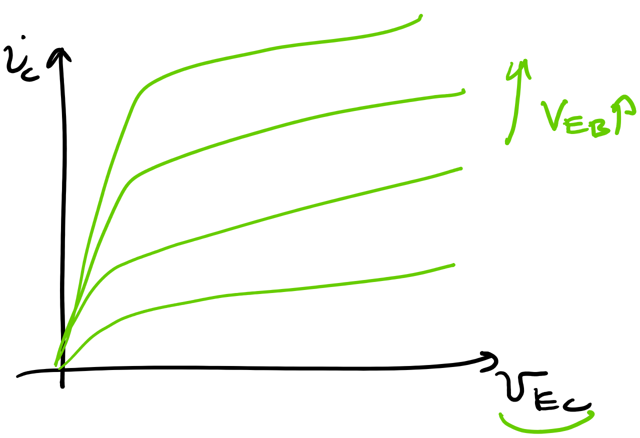
$$I_B = \frac{I_C}{\beta}$$

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

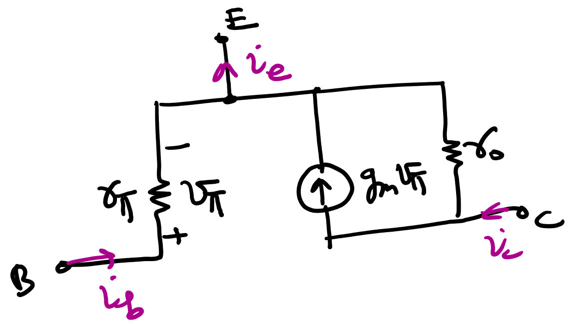
With Early Effect:

$$I_C = I_S e^{(V_{EB}/V_T)}\left(1 + \frac{V_{EC}}{V_A}\right)$$



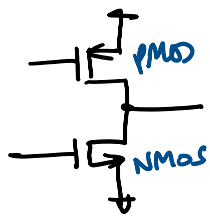

PNP Small-signal Model



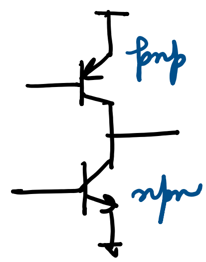

Read Section 4.6.3 in the Textbook

NMOS $\longrightarrow$ npn BJT

PMOS $\longrightarrow$ pnp BJT




CMOS




BJTs

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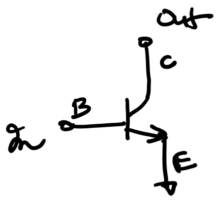
# Chapter 5: Bipolar Amplifiers

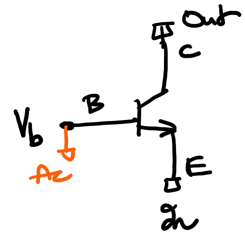
CS

CG

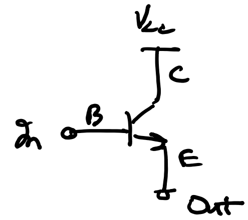
CD/SF




Common-Emitter
(CE)




Common Base
(CB)




Common Collector (CC) Circuit

Emitter follower

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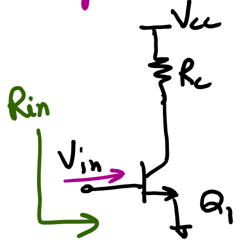
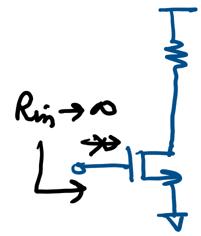
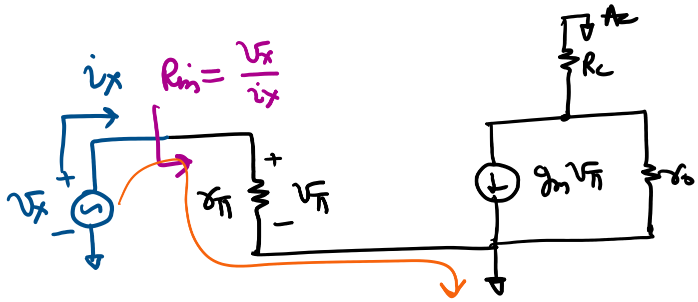
Input resistance looking into the Base



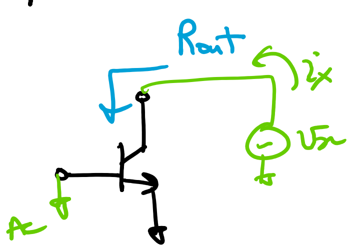



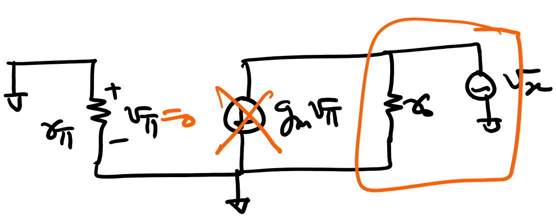

KVL: $v_x = i_x r_\pi \Rightarrow R_{in} = \frac{v_x}{i_x} = r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C}$

$\boxed{R_{in} = \frac{\beta}{g_m}}$ for a large $R_{in} \Rightarrow \beta\uparrow$ or $I_C\downarrow$

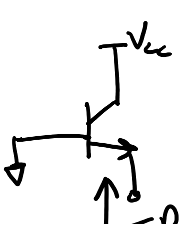
* Output resistance looking into the collector

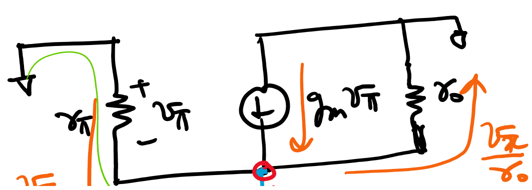


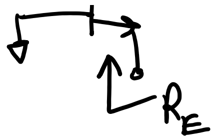

$\boxed{R_{out} = r_o = \frac{V_A}{I_C}}$

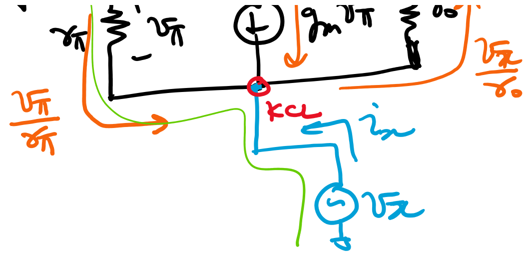



* Resistance looking into the emitter






$v_\pi + v_x = 0$

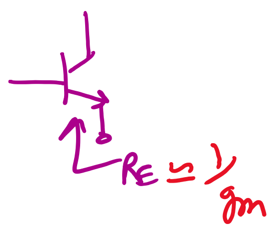
$\Rightarrow v_x = -v_\pi$

KCL:

$$i_x + \frac{v_\pi}{r_\pi} + g_m v_\pi - \frac{v_x}{r_o} = 0$$

$$i_x = v_x\left[\frac{1}{r_\pi} + g_m + \frac{1}{r_o}\right]$$

$$\Rightarrow R_E = \frac{v_x}{i_x} = \frac{1}{g_m + 1/r_\pi + 1/r_o}$$




$$\boxed{R_E = \frac{1}{g_m + r_\pi^{-1} + r_o^{-1}} \simeq \frac{1}{g_m}}$$

Since $r_\pi = \frac{\beta}{g_m} >> \frac{1}{g_m}$ $\because \beta >> 1$

also $r_o >> 1/g_m$