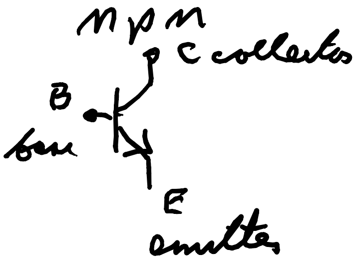
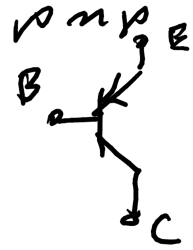
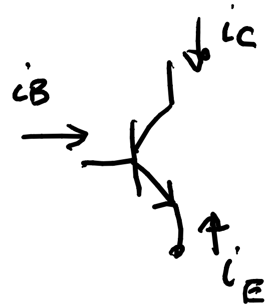
EE 303
02/08/12
modified

BJT = bipolar junction transistor







KCL $i_C + i_B + i_E = 0$

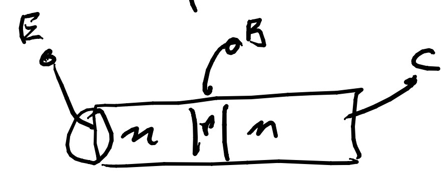
$i_C = -\alpha i_E$ by a small bar $\alpha < \approx 1$

$i_C + i_B - \frac{1}{\alpha} i_C = 0 \Rightarrow (1 - \frac{1}{\alpha}) i_C = -i_B$

$i_C = \frac{-\alpha}{\alpha - 1} \cdot i_B = \frac{\alpha}{1-\alpha} \cdot i_B$

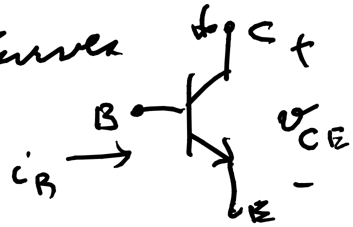
$= \beta i_B$

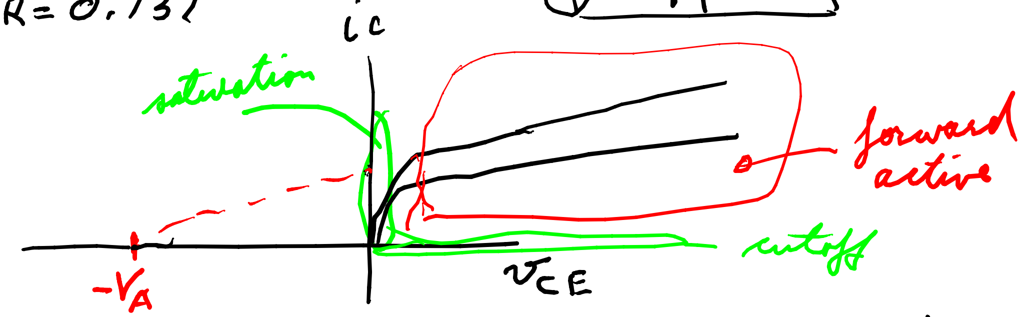
for 2N3904, $\beta = 416.4$ in Spice
$= BF$



i_C but $BR = 0.737$

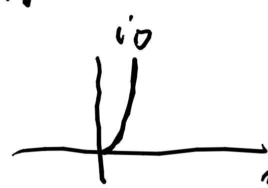
Curves



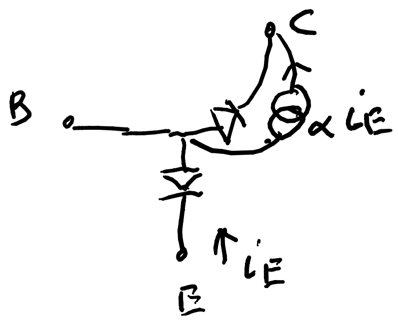


V_A = Early voltage

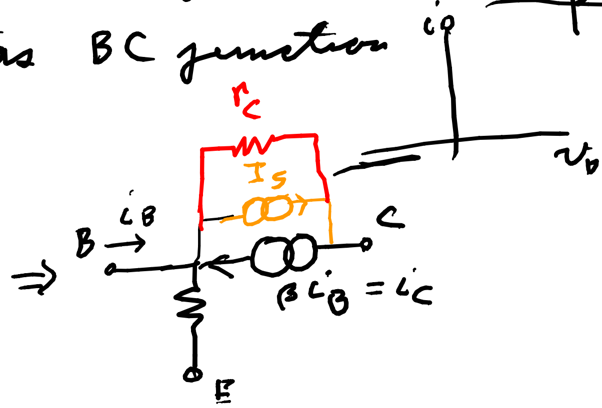
VAF = 74.03 (18.7 for pnp 2N3906)



Normally: forward bias BE junction
back bias BC junction



$\Rightarrow$



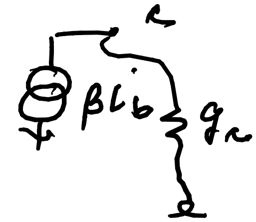
for small signals do a Taylor series expansion

$$i_C(v_{CE}, i_B) = I_C + \underbrace{\left.\frac{\partial i_C}{\partial v_{CE}}\right|_Q (v_{CE} - V_{CE}) + \frac{\partial i_C}{\partial i_B}(i_B - I_B)}_{\text{linear behavior at } C} + \cdots$$

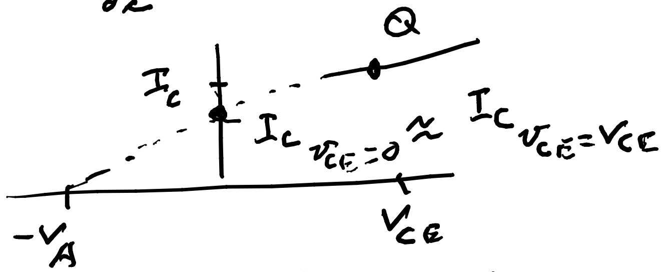
$i_c = i_C - I_C$, $v_{ce} = v_{CE} - V_{CE}$

$i_b = i_B - I_B$

$$i_c = \underset{\substack{\| \\ g_c}}{\frac{\partial i_C}{\partial v_{CE}}} \cdot v_{ce} + \beta \cdot i_b$$

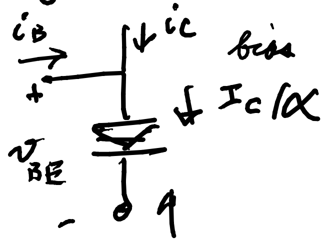


to get g_c

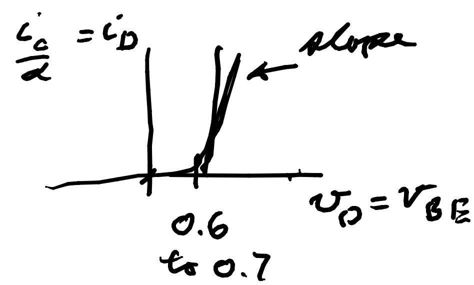


$$g_c = \text{slope of this curve} \approx \frac{I_C}{V_A}$$

look at the emitter in the forward active region (forward bias BE junction



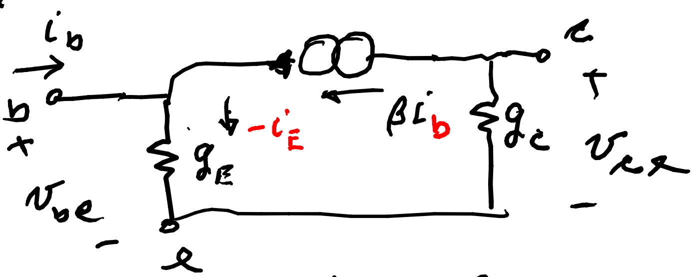
at $i_C = -\alpha i_E$



$$i_D = I_{SE}(e^{v_{BE}/V_T} \cancel{-1})$$

$$g_E = \left.\frac{\partial i_D}{\partial v_{BE}}\right|_Q = \frac{I_{SE}}{V_T} \cdot e^{V_{BE}} = \frac{-I_E}{V_T} = \frac{I_C}{\alpha V_T} = \text{diode conductance}$$

g'_d = conductance



Normal equivalent circuit uses voltage controls & here is a current controlled source, βi_b

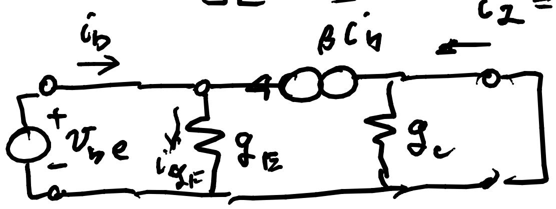
(see p. 421 for Y matrix form;

$$\begin{bmatrix} i_b \\ i_c \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_{be} \\ v_{ce} \end{bmatrix}$$

note $y_{21} \Rightarrow i_c = y_{21} \cdot v_{be}$ if $v_{ce} = 0$

$i_2 = i_c = \beta i_b$

to get y_{21}



$$g_E v_{be} = i_{g_E} \;;\quad i_b = g_E v_{be} - \beta i_b \Rightarrow (1+\beta) i_b = g_E v_{be}$$

$$\beta i_b = \frac{\beta}{1+\beta} \cdot g_E \cdot v_{be} \Rightarrow \quad y_{21} = \frac{\beta}{1+\beta} \cdot g_E = \frac{\beta}{1+\beta} \cdot \frac{I_C}{\alpha V_T} = \frac{I_C}{V_T}$$

since $\dfrac{\beta}{1+\beta} = \alpha$

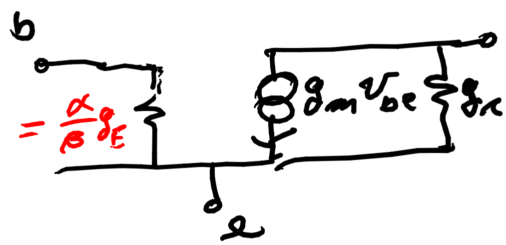
as $\beta = \dfrac{\alpha}{1-\alpha} \Rightarrow \beta - \beta\alpha = \alpha = \beta = \beta\alpha + \alpha = (1+\beta)\alpha \Rightarrow \alpha = \beta/(1+\beta)$

for $y_{12} = \left.\dfrac{i_b}{v_{CE}}\right|_{v_{be}=0} = 0$ as i_b is independent of v_{ce}

$$y_{22} = \left.\frac{i_c}{v_{CE}}\right|_{v_{be}=0} = \frac{\overset{= 0 \text{ if } y_{12}=0}{\text{current in } g_c}}{v_{ce}} = g_c$$

$g_m = y_{21} = \dfrac{I_C}{V_T}$

$$\Rightarrow \quad Y = \begin{bmatrix} \frac{I_C}{\beta V_T} & 0 \\ \frac{I_C}{V_T} & \frac{I_C}{V_A} \end{bmatrix}$$



$$y_{11} = \frac{\text{current } i_b}{v \text{ on the diode}}$$

$$i_b = \frac{i_c}{\beta}$$

$$= \frac{-\alpha/\beta \, i_E}{v_{be}} = \frac{\alpha}{\beta} \cdot g_E = \frac{I_C}{\beta V_T} = \frac{g_m}{\beta}$$

$$\Rightarrow \quad Y = I_C \begin{bmatrix} 1/\beta V_T & 0 \\ 1/V_T & 1/V_A \end{bmatrix} = \begin{bmatrix} g_m/\beta & \\ g_m & g_m \frac{V_T}{V_A} \end{bmatrix} = g_m \begin{bmatrix} 1/\beta & 0 \\ 1 & V_T/V_A \end{bmatrix}$$