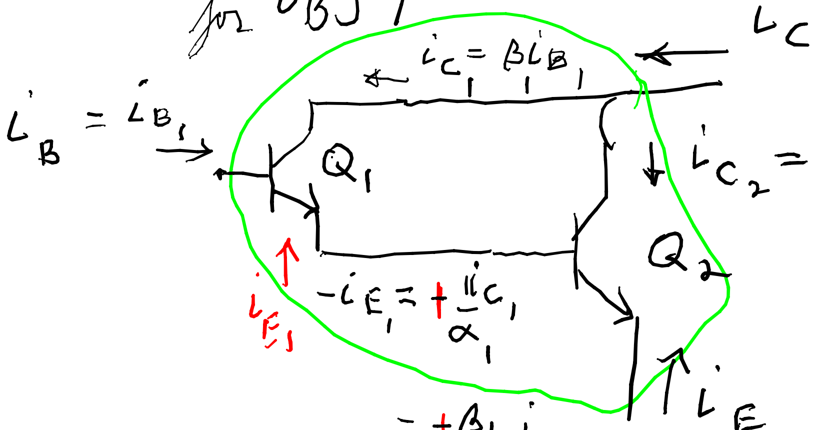
Darlington pair p. 645 for BJT

EE302
02/15/05



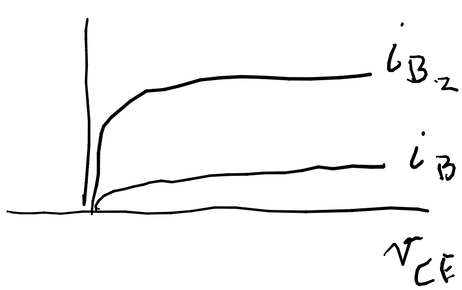
$= +\frac{\beta_1}{\alpha_1} i_{B_1}$

$= i_{B_2}$

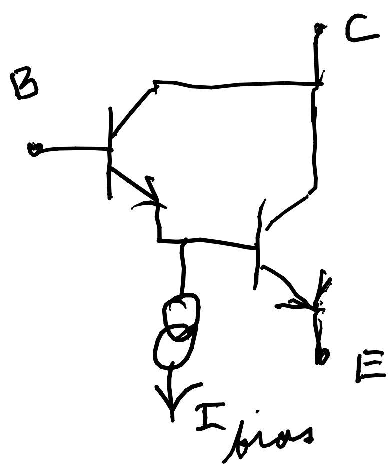
$$i_{C_2} = \beta_2 i_{B_2} = \beta_2 \left(\frac{\beta_1}{\alpha_1}\right) i_{B_1} \approx \beta_2 \beta_1 i_{B_1}$$

$$i_C = \left(\frac{\beta_2 \beta_1}{\alpha_1} + \beta_1\right) i_B$$

$= \beta_{equiv} \cdot i_B$



to bias Q_1 as $i_{B_1} < i_{B_2}$ we force a bias current on i_{E_1}



gives very large β for signals

$\beta_{eq} \approx \beta^2$

Ex if $\beta = 100$, $\beta^2 = 10^4$

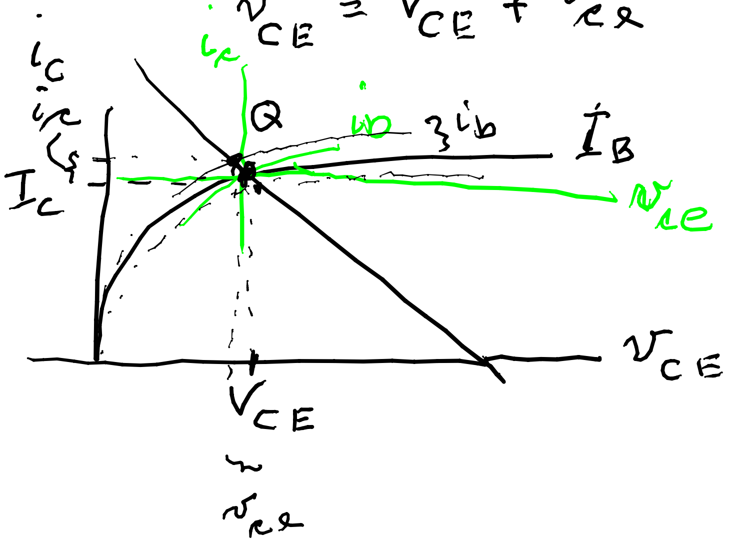
Using a BJT for signals:

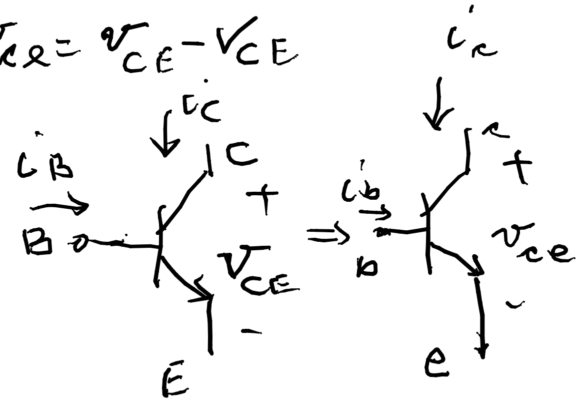
convention for designating v, i

i_B = total, I_B = bias, i_b = signal

$$i_B = I_B + i_b \quad \Rightarrow i_b = i_B - I_B$$

$$v_{CE} = V_{CE} + v_{ce} \qquad v_{ce} = v_{CE} - V_{CE}$$



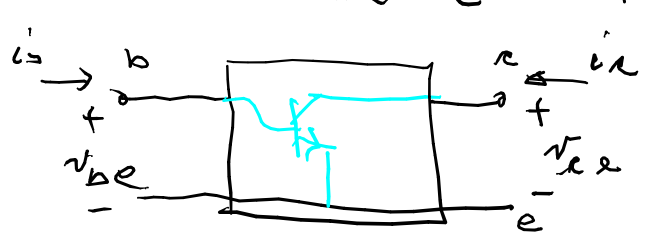


$$i_C = f(i_B, v_{CE}) = f(I_B, V_{CE}) + \frac{\partial f}{\partial i_B}\Bigg|_{Q \; \substack{i_B = I_B \\ v_{CE} = V_{CE}}} (i_B - I_B) +$$

$$\frac{\partial f}{\partial v_{CE}}\Bigg|_Q (v_{CE} - V_{CE}) + \frac{\partial^2}{\partial i_B \partial v_{CE}} + \dots$$

$$\approx f(I_B, V_{CE}) + \beta i_b + \overset{g}{\cancel{r}}_{ce} \cdot v_{ce}$$

$$= I_C + \beta i_b + \overset{g}{\cancel{r}}_{ce} v_{ce} \Rightarrow i_c = \beta i_b + \overset{g}{\cancel{r}}_{ce} v_{ce}$$



$$i_c = \beta i_b + g_{ce} v_{ce}$$

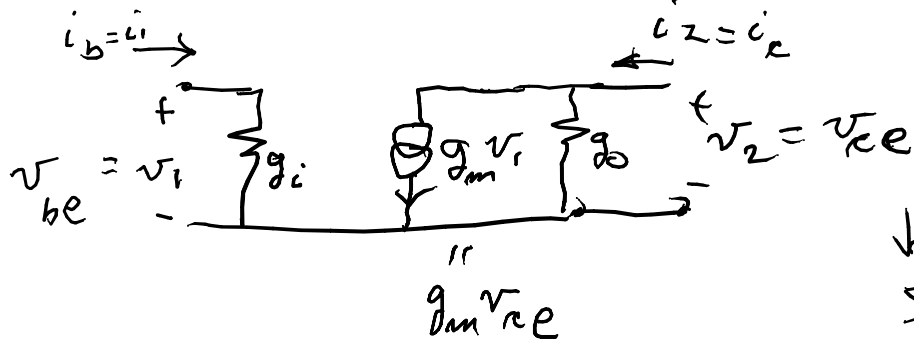
admittance matrix of a 2-port

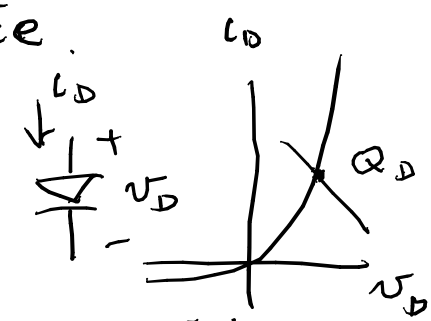
$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = Y \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \; ; \rightarrow \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} i_b \\ i_c \end{bmatrix} ; \begin{bmatrix} v_{be} \\ v_{ce} \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

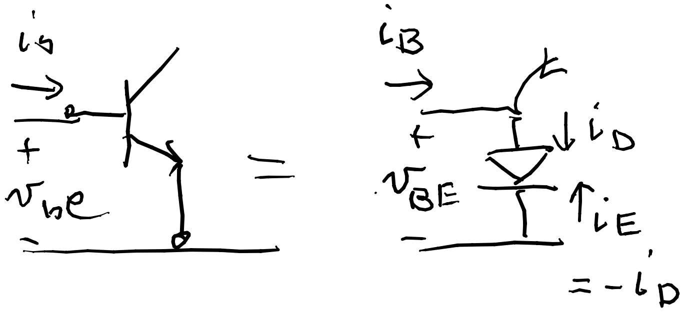
$$= \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$ gives a π equivalent circuit see p. 448 for BJT

here $y_{12} = 0$ for the BJT for low frequencies

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & 0 \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} g_i & 0 \\ g_m & g_o \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$







$$i_D = I_S\left(e^{v_D/V_T} - 1\right)$$

V_T = Thermal voltage

$= \frac{kT}{|q|} \approx 0.026\,v$ @ room T

$$i_D = I_D + \frac{\partial i_D}{\partial v_D} \cdot (v_D - V_D) + \cdots$$

$$i_d = i_D - I_D = \frac{I_S}{V_T} e^{V_D/V_T} v_d + \cdots$$ assume ≈ 0 by small changes around Q_D point

$$= \frac{I_D}{V_T} v_d = g_d \cdot v_d$$

for our transistor $i_e = -i_d = -g_d \cdot v_{be} = -\frac{I_E}{V_T} \cdot v_{be}$

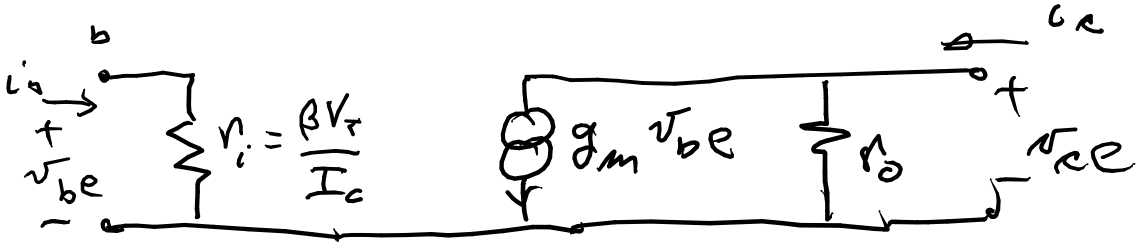
$i_c = \beta i_b$, $i_e = \frac{-1}{\alpha} i_c$

$I_c = \beta I_B$, $I_E = \frac{-1}{\alpha} I_c$

$$i_e = -\frac{1}{\alpha} i_c = -\frac{\beta}{\alpha} i_b = -\frac{I_E}{V_T} v_{be}$$

$$\Rightarrow i_b = \frac{\alpha}{\beta} \frac{I_E}{V_T} \cdot v_{be} = \frac{|-I_c|}{\beta V_T} v_{BE}$$

$$i_b = \frac{I_c}{\beta V_T} \cdot v_{be} = g_i v_{be}, \quad g_i = \frac{I_c}{\beta V_T}$$



$$g_m = \left.\frac{\partial i_c}{\partial v_{BE}}\right|_Q \quad ; \quad -i_c = \alpha i_E$$

$$-i_E = I_{S_E} e^{v_{BE}/V_T}$$

$$\left.\frac{\partial i_E}{\partial v_{BE}}\right|_Q = -\frac{I_S}{V_T} e^{v_{BE}/V_T} = -\frac{I_E}{V_T}$$

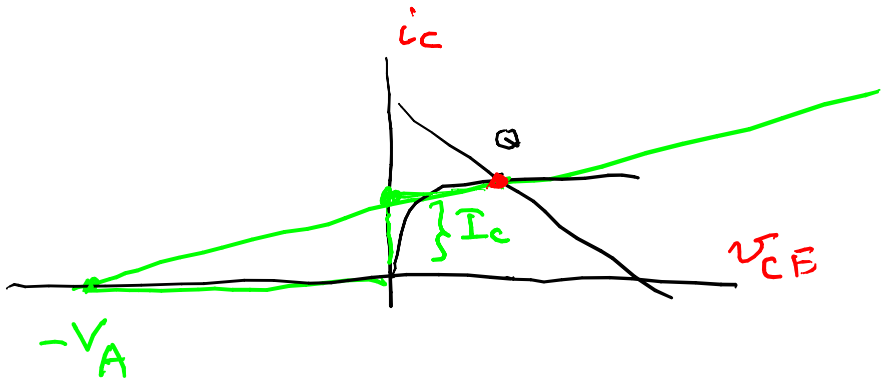
$$\left.\frac{\partial i_c}{\partial v_{BE}}\right|_Q = -\alpha\left(-\frac{I_E}{V_T}\right) = \frac{I_c}{V_T} \quad ; \quad g_m = \frac{I_c}{V_T} \quad ; \quad g_i = \frac{I_c}{\beta V_T} = \frac{g_m}{\beta}$$

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

$g_o = g_m \cdot \frac{V_T}{V_A}$

assumes $y_{12} = 0$

small signal equivalent circuit for a grounded emitter



npn transistor

$$\text{slope} = \frac{I_C}{V_A} = \frac{I_C}{V_T} \cdot \frac{V_T}{V_A}$$

$$\frac{\partial i_C}{\partial v_{CE}} = g_m \cdot \eta_A$$

$\frac{\partial i_C}{\partial v_{CE}} = g_o$

V_A = Early Voltage > 0

Same equivalent circuit for a pnp if $I_C \Rightarrow |I_C|$