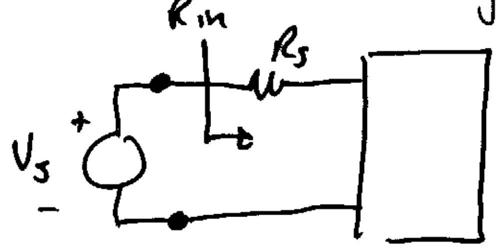
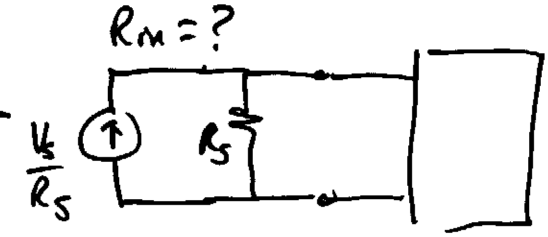
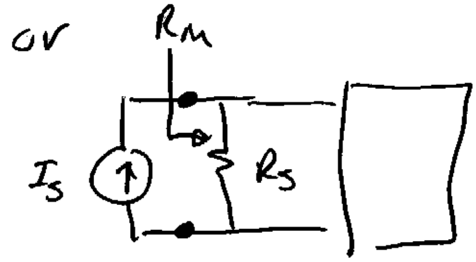
Watch out when using Thevenin - Norton transformation -



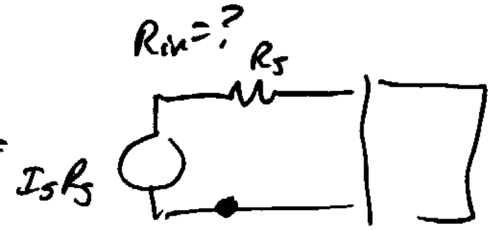
$\longrightarrow$



or

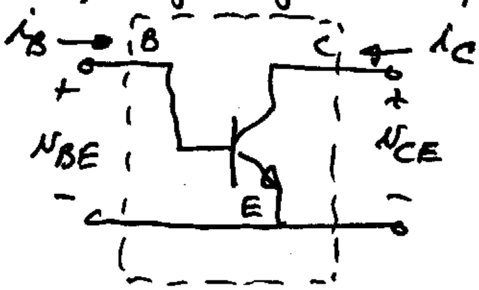


$\longrightarrow$



1.) BJT small signal model

a.) Large Signal Viewpoint



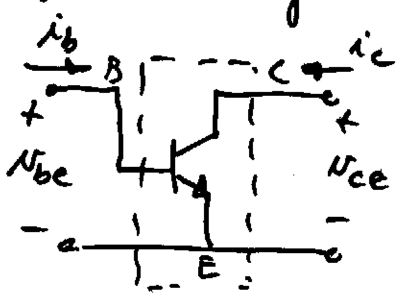
$\xrightarrow[\text{Model}]{\text{Mathematical}}$

Forward active region:

$$i_C = I_S\left[\exp\left(\frac{v_{BE}}{V_T}\right)\right]\left(1 + \frac{v_{CE}}{V_A}\right)$$

$$i_B = \frac{i_C}{\beta_F} = \frac{I_S}{\beta_F}\exp\left(\frac{v_{BE}}{V_T}\right)$$

b.) Small-signal model (linear)



$\xrightarrow[\text{Model}]{\text{Mathematical}}$

$$i_c = k_1 v_{be} + k_2 v_{ce}$$

$$i_b = k_3 v_{be}$$

$$k_1 = \left.\frac{i_c}{v_{be}}\right|_{v_{ce}=0} = \left.\frac{\Delta i_C}{\Delta v_{BE}}\right|_Q = \left.\frac{\partial i_C}{\partial v_{BE}}\right|_Q = \frac{I_S}{V_T}\exp\left(\frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$k_1 = \boxed{\frac{I_C}{V_T} = g_m}$$

NOTE: This V_T should not be here.

$$k_2 = \left.\frac{i_c}{v_{ce}}\right|_{v_{be}=0} = \left.\frac{\partial i_C}{\partial v_{CE}}\right|_Q = \frac{I_S}{V_T}\exp\left(\frac{V_{BE}}{V_T}\right)\left(\frac{1}{V_A}\right) = \frac{I_C}{V_A + V_{CE}} \approx \frac{I_C}{V_A}$$

$$k_2 = \boxed{g_o = \frac{1}{r_o} = \frac{I_C}{V_A}}$$

Cont'd

$$h_3 = \frac{i_b}{v_{be}} = \frac{\partial i_B}{\partial v_{BE}}\Big|_Q = \frac{I_C}{\beta_F V_T} = \boxed{\frac{g_m}{\beta_F} = \frac{1}{r_\pi}}$$

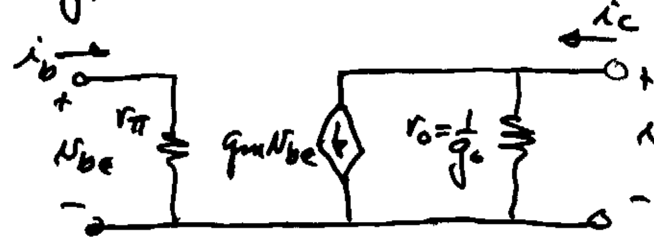
$$\boxed{r_\pi = \frac{1}{g_\pi} = \frac{\beta_F}{g_m} = \frac{\beta_F V_T}{I_C}}$$

Note that $\beta_F = g_m r_\pi$

oc

$i_c = g_m v_{be} + g_o v_{ce}$

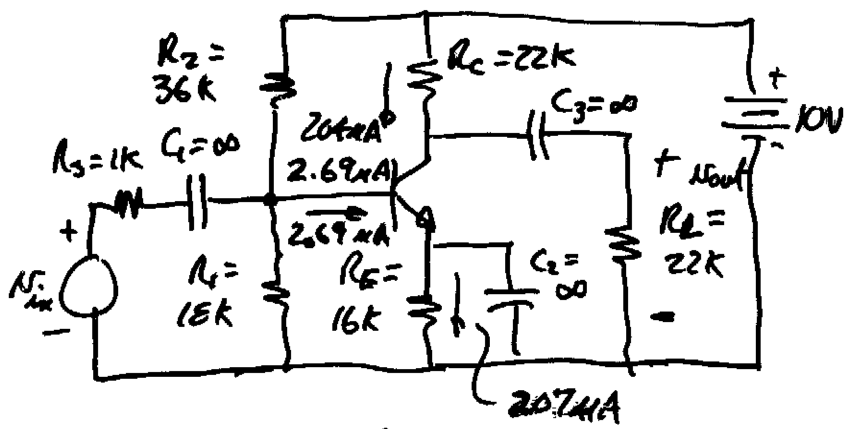
$i_b = g_\pi v_{be}$



NPN or PNP

$g_m = \frac{I_C}{V_T}$, $r_\pi = \frac{\beta_F}{g_m}$, and $r_o \hat{=} \frac{V_A}{I_C}$

Example

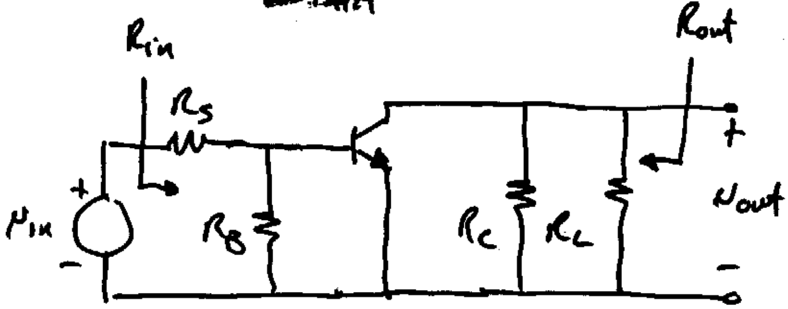


$\beta_F = \beta_o = 100$ & $V_T = 25$ mV

Find $\frac{v_{out}}{v_{in}}$, R_{in}, & R_{out}

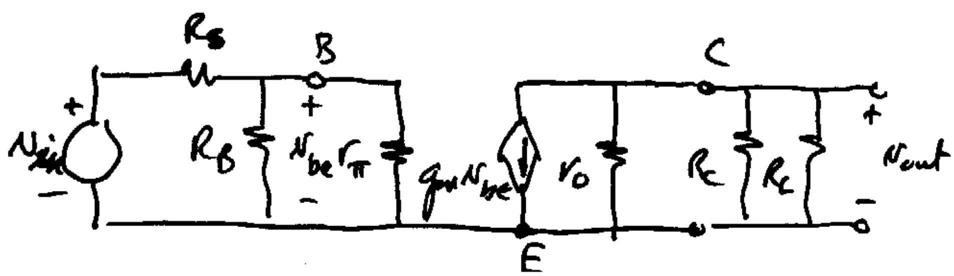
$V_A = \infty$

1.)



$R_B = R_1 || R_2$

2.)



$$g_m = \frac{I_C}{V_T} = \frac{204\,\mu A}{25\,mV} = 8.16\,mS \qquad r_\pi = \frac{\beta_o}{g_m} = 9.19\,k\Omega$$

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

3.) Analysis

$$R_{in} = R_S + R_B \| r_\pi = \underline{\underline{6.205\,k\Omega}}$$

$$R_{out} = R_C \| R_L = \underline{\underline{11\,k\Omega}}$$

Wrong

$$\frac{v_{out}}{v_{in}} = \frac{v_{out}}{v_{be}} \times \frac{v_{be}}{v_{in}} = \left(-g_m R_{out}\right)\left(\frac{R_{in}}{R_S + R_{in}}\right) = \underline{\underline{-75.3\,V/V}}$$

More detail (not included in class lecture)

$$\frac{v_{out}}{v_{be}} = -g_m (R_L \| R_C) = -g_m R_{out}$$

$$\frac{v_{be}}{v_{in}} = \frac{R_B \| r_\pi}{R_S + R_B \| r_\pi} = \frac{R_B \| r_\pi}{R_{in}}$$

$$\therefore \frac{v_{out}}{v_{in}} = \left(-g_m R_{out}\right)\left(\frac{R_B \| r_\pi}{R_{in}}\right) = \left(-8.16 \cdot 11\right)\left(\frac{5.205}{6.205}\right)$$

$$\frac{v_{out}}{v_{in}} = -75.3\,V/V$$