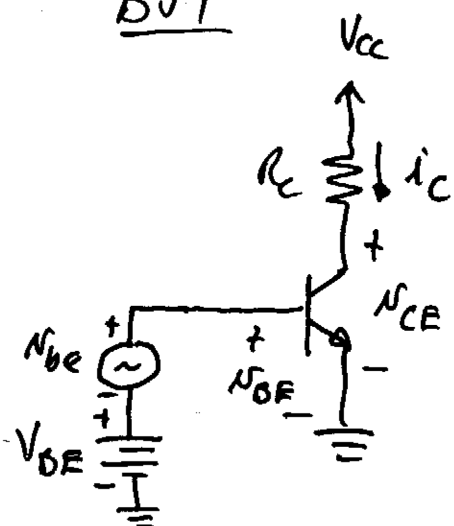
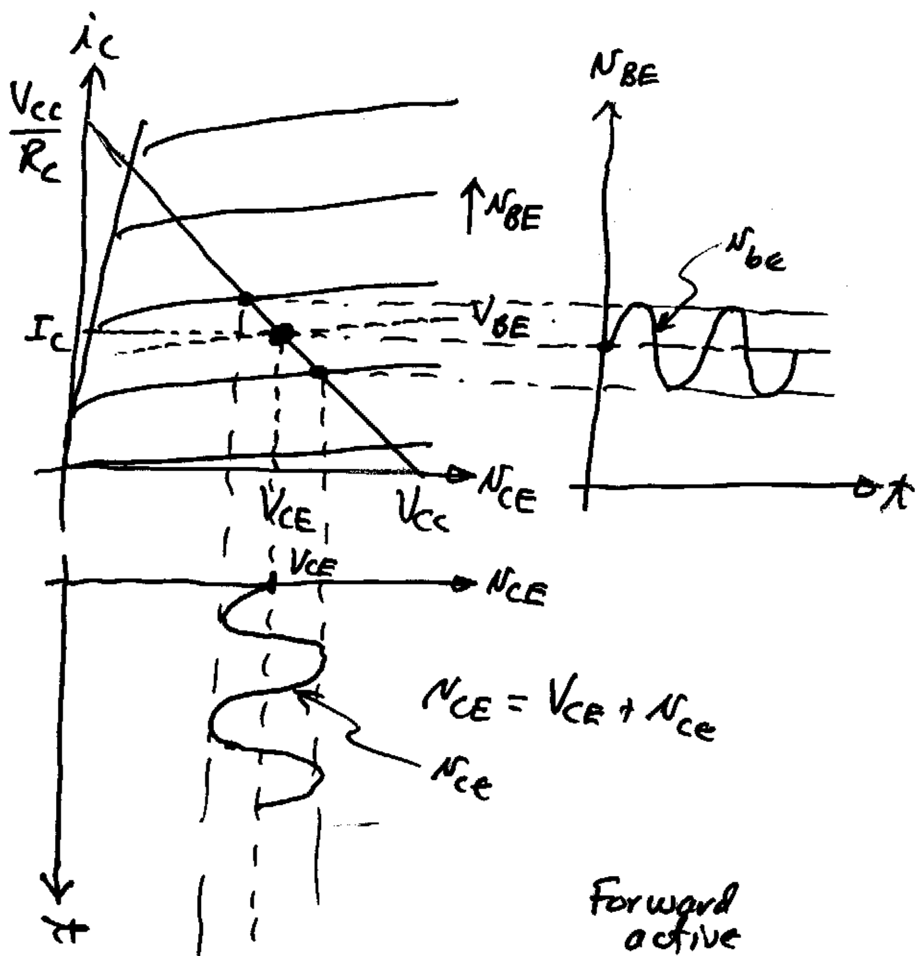
Transistor Amplifiers

BJT





Forward active region

Mathematically,

$$v_{CE} = V_{CC} - R_C i_C = V_{CC} - R_C \left[I_S \exp\left(\frac{v_{BE}}{V_T}\right)\right]$$

$$\left.\frac{\partial v_{CE}}{\partial v_{BE}}\right|_{\substack{v_{BE}=V_{BE} \\ i_C = I_C}} = -\frac{R_C I_S}{V_T} \exp\left(\frac{v_{BE}}{V_T}\right)\Bigg|_Q = -\frac{R_C I_S}{V_T}\exp\left(\frac{V_{BE}}{V_T}\right)$$

~~0.1~~

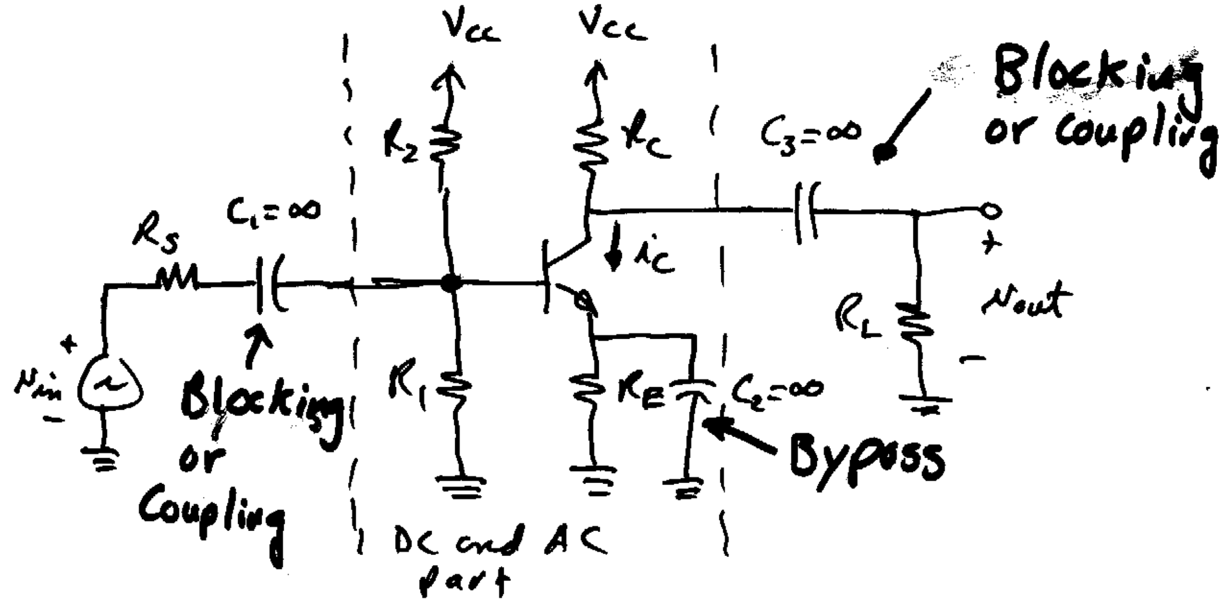
$10^{-4} \cdot 400 = 0.04$

$$= -\frac{R_C I_C}{V_T} = ~~-g_m R_C~~$$

$R_C = 10\,k\Omega$
$I_C = 1\,mA$
$V_T = 25\,mV$

$$\text{Gain} = \frac{\partial v_{CE}}{\partial v_{BE}} = -\frac{R_C I_C}{V_T} = -\frac{10^4 \cdot 10^{-3}}{25 \cdot 10^{-3}} = -\frac{10{,}000}{25} = -400 \text{ V/V}$$

2.) Implementation of the amplifier.



3.) Small-signal model for a diode.

$$i_D = I_S\left[\exp\left(\frac{v_D}{V_T}\right)-1\right]$$

$$i_d + I_D = I_S\left[\exp\left(\frac{v_d+V_D}{V_T}\right)-1\right] = I_S\left[\exp\left(\frac{V_D}{V_T}\right)\exp\left(\frac{v_d}{V_T}\right)-1\right]$$

Perform a series expansion, we get

$$i_d + I_D = I_S\left\{\left[\exp\left(\frac{V_D}{V_T}\right)\right]\left[1+\frac{v_d}{V_T}+\frac{1}{2}\left(\frac{v_d}{V_T}\right)^2+\cdots\right]-1\right\}$$

Assume $\frac{v_d}{V_T} << 1$,

$$i_d + I_D \approx I_S\exp\left(\frac{V_D}{V_T}\right)\left[1+\frac{v_d}{V_T}\right]-I_S$$

$$= \underbrace{I_S\left[\exp\left(\frac{V_D}{V_T}\right)-1\right]}_{I_D} + \left[I_S\exp\left(\frac{V_D}{V_T}\right)\right]\left(\frac{v_d}{V_T}\right)$$

$$i_d + \cancel{I_D} = \cancel{I_D} + \left[I_S\exp\left(\frac{V_D}{V_T}\right)\right]\frac{v_d}{V_T}$$

$$i_d = \underline{I_S\left[\exp\left(\frac{V_D}{V_T}\right)\right]}\frac{v_d}{V_T}$$

Cont'd -

$$I_D = I_S\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right] \rightarrow \underline{I_S \exp\left(\frac{V_D}{V_T}\right)} = I_D + I_S$$

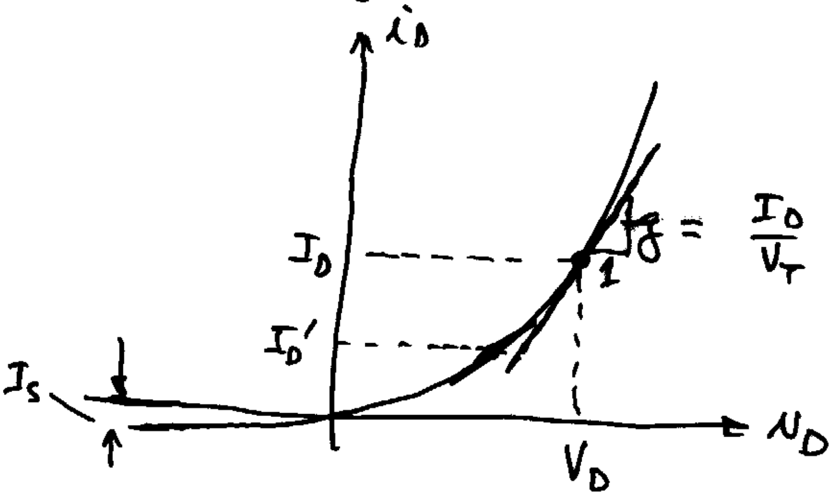
$$i_d = (I_D + I_S)\frac{v_d}{V_T} = g_d\, v_d = \frac{v_d}{r_d}$$

$$\underline{\underline{g_d = \frac{I_D + I_S}{V_T}}} \quad \text{or} \quad \underline{\underline{r_d = \frac{1}{g_d}}}$$

Normally, $I_D \gg I_S$

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

Graphically -



Assume $I_S = 100fA$

$I_D = 1mA \rightarrow g_d = 0.045\,S$

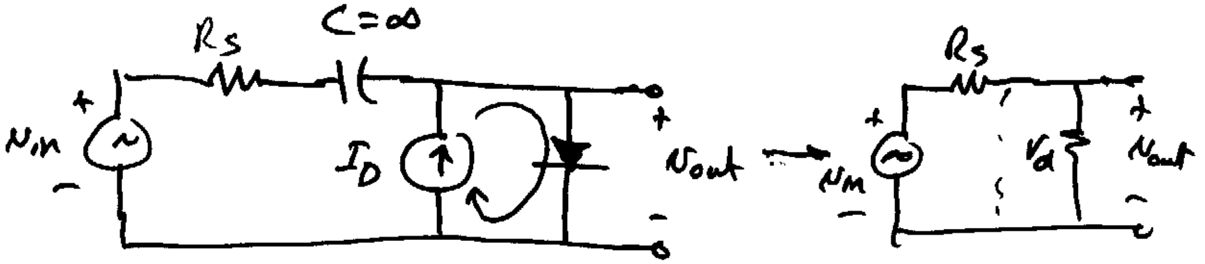
$I_D = 0 \rightarrow g_d = \frac{100fA}{25mV}$

$g_d = 4\times10^{-12}\,S$

$I_D = -I_S$

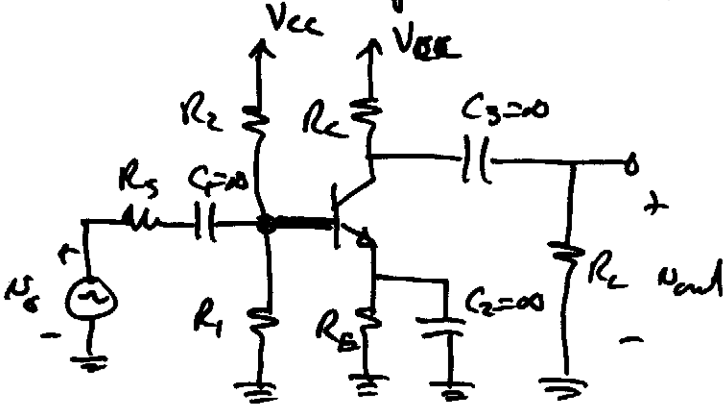
$g_d = \frac{-I_S + I_S}{V_T} = 0$

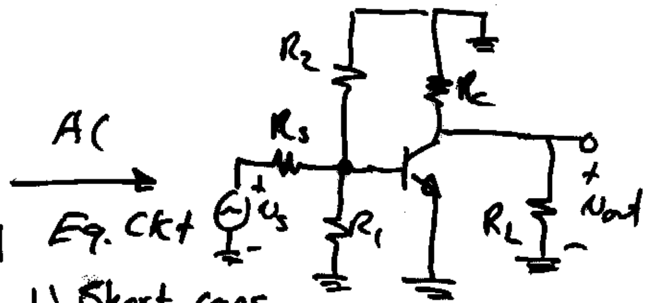
Hmwk P1



$$\frac{v_{out}}{v_{in}} = \frac{r_d}{r_d + R_S} = \frac{1}{1 + \frac{R_S}{r_d}} = \frac{1}{1 + g_d R_S} = \frac{1}{1 + R_S\left[\frac{I_D + I_S}{V_T}\right]}$$

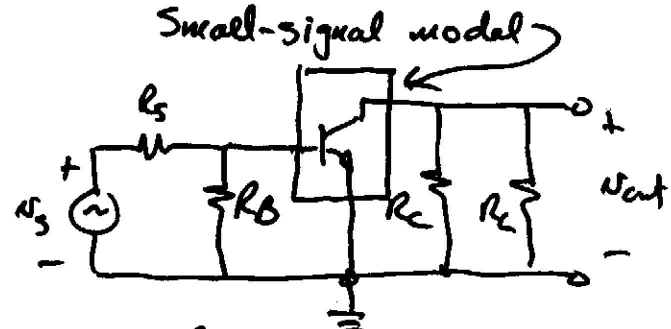
4.) Small signal model for BJT



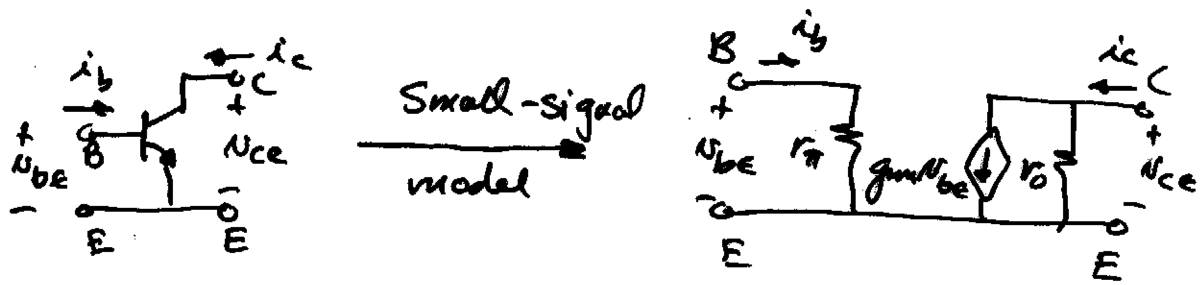


1.) Short caps

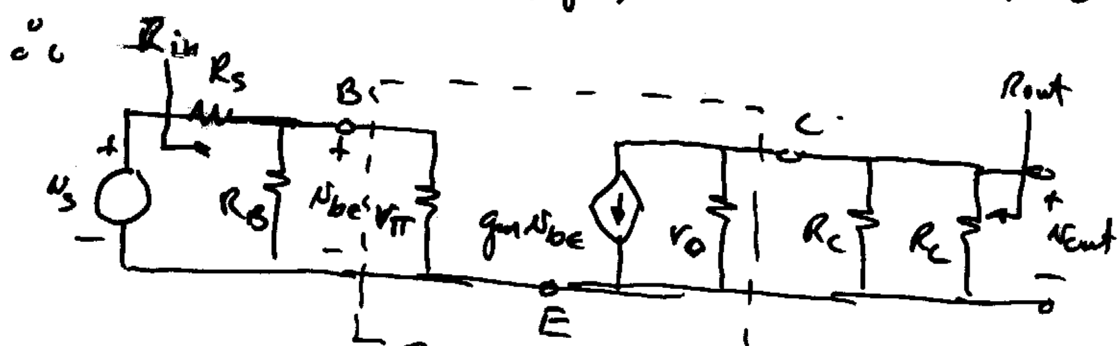
2.) Replace indep. sources with appropriate R.



$R_B = R_1 || R_2$



Remember that r_π, g_m, and r_o are functions of I_C.



Goal is: Find $\frac{v_{out}}{v_s}$, R_{in} and R_{out}

If $R_S = 0$

$$\frac{v_{out}}{v_s} = -g_m (r_o || R_C || R_L)$$

$$R_{in} = R_S + r_\pi || R_B \qquad R_{out} = r_o || R_C || R_L$$