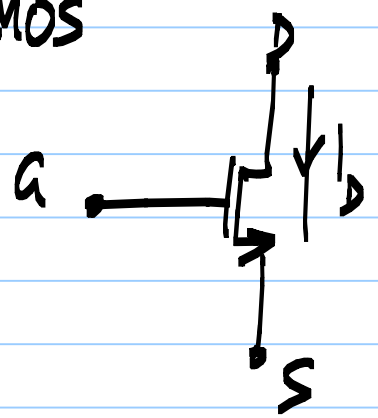
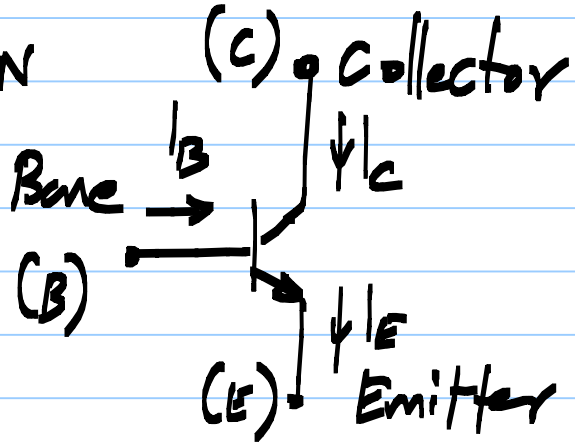
Bipolar junction transistor (BJT)

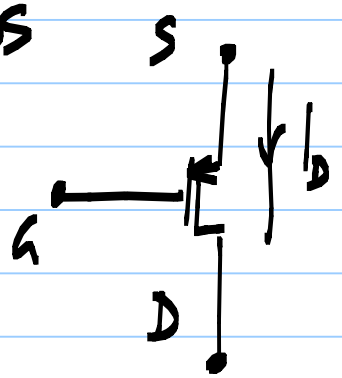
nMOS



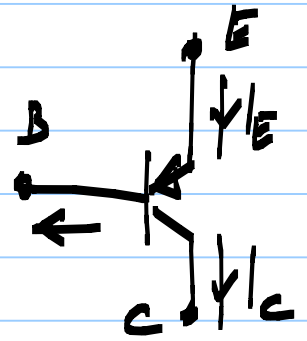
NPN



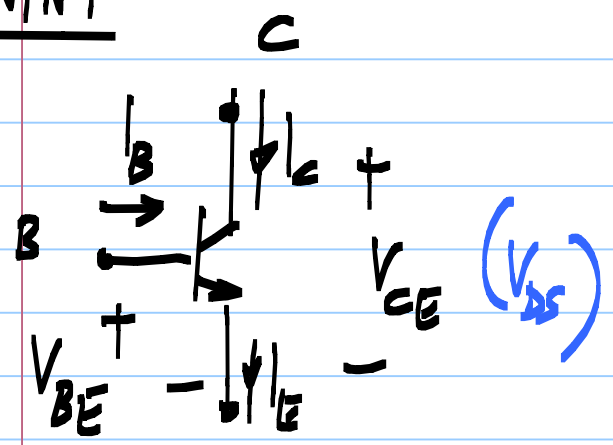
PMOS



PNP



NPN:



$$I_C = I_S \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right) \qquad V_{CE} > V_{CE,SAT}$$

Boltzmann's const. — Absolute temp.

$$V_t = \frac{kT}{q}$$ thermal voltage

Electron charge

$= 25.9\,mV$ @ $300k$

$\simeq 26\,mV$ OR $\simeq 25\,mV$

$$I_E = I_C + I_B$$

$$= (\beta+1) I_B = \left(\frac{\beta+1}{\beta}\right) I_C$$

$$I_B = \frac{I_C}{\beta} \;;\Rightarrow\; I_C = \beta \cdot I_B$$

$$I_C = \frac{\beta}{\beta+1} \cdot I_E = \alpha \cdot I_E$$

NPN: $I_C = I_S \exp\left(\frac{V_{BE}}{\eta}\right) \cdot \left(1 + \frac{V_{CE}}{V_A}\right)$

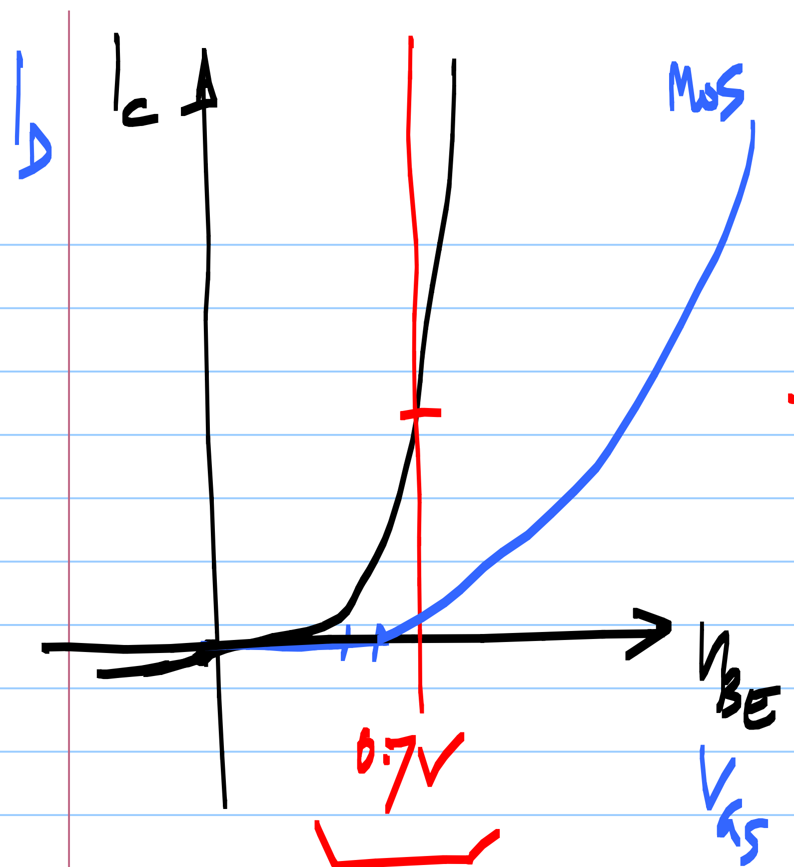
Early effect

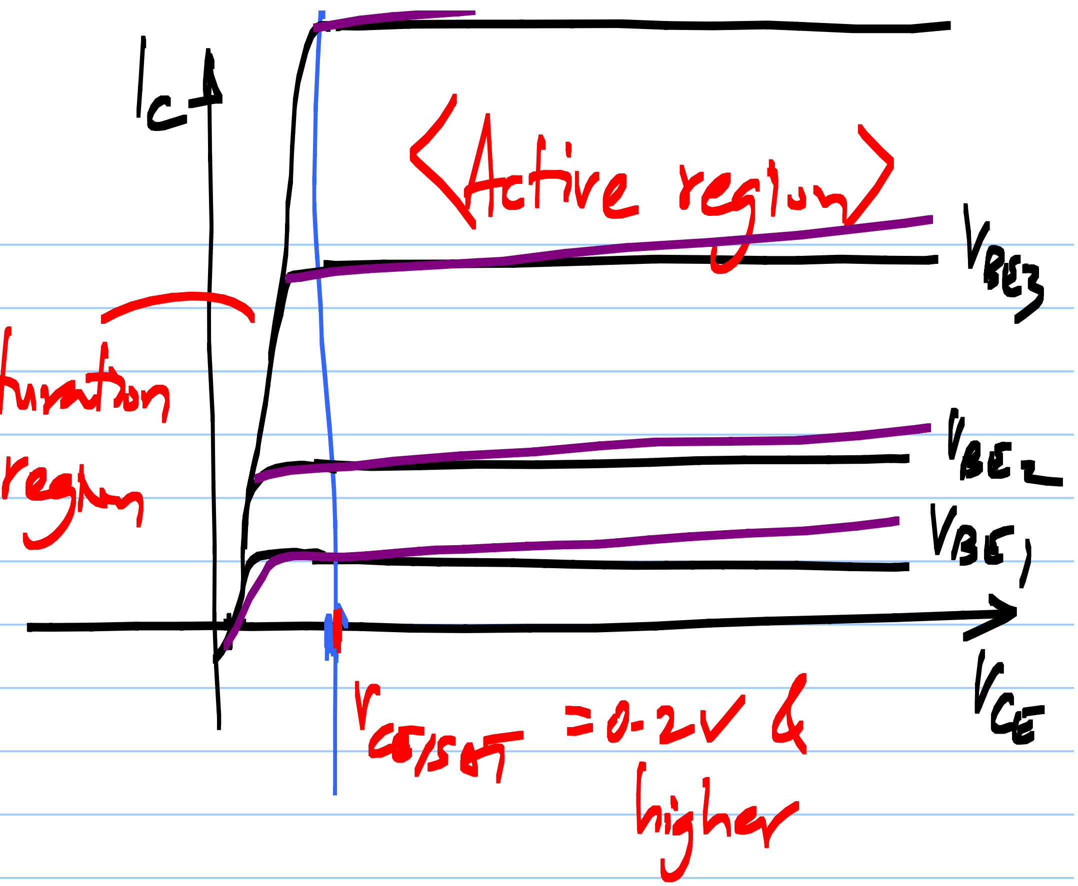
$\lambda \cong \frac{1}{V_A}$

Reverse saturation current

Early voltage

nMOS: $I_D = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$

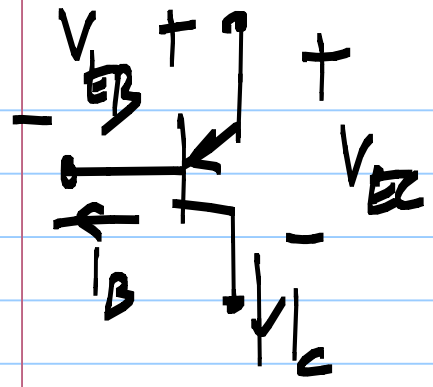




$V_{BE,QUIESCENT}$ of an "ON" transistor

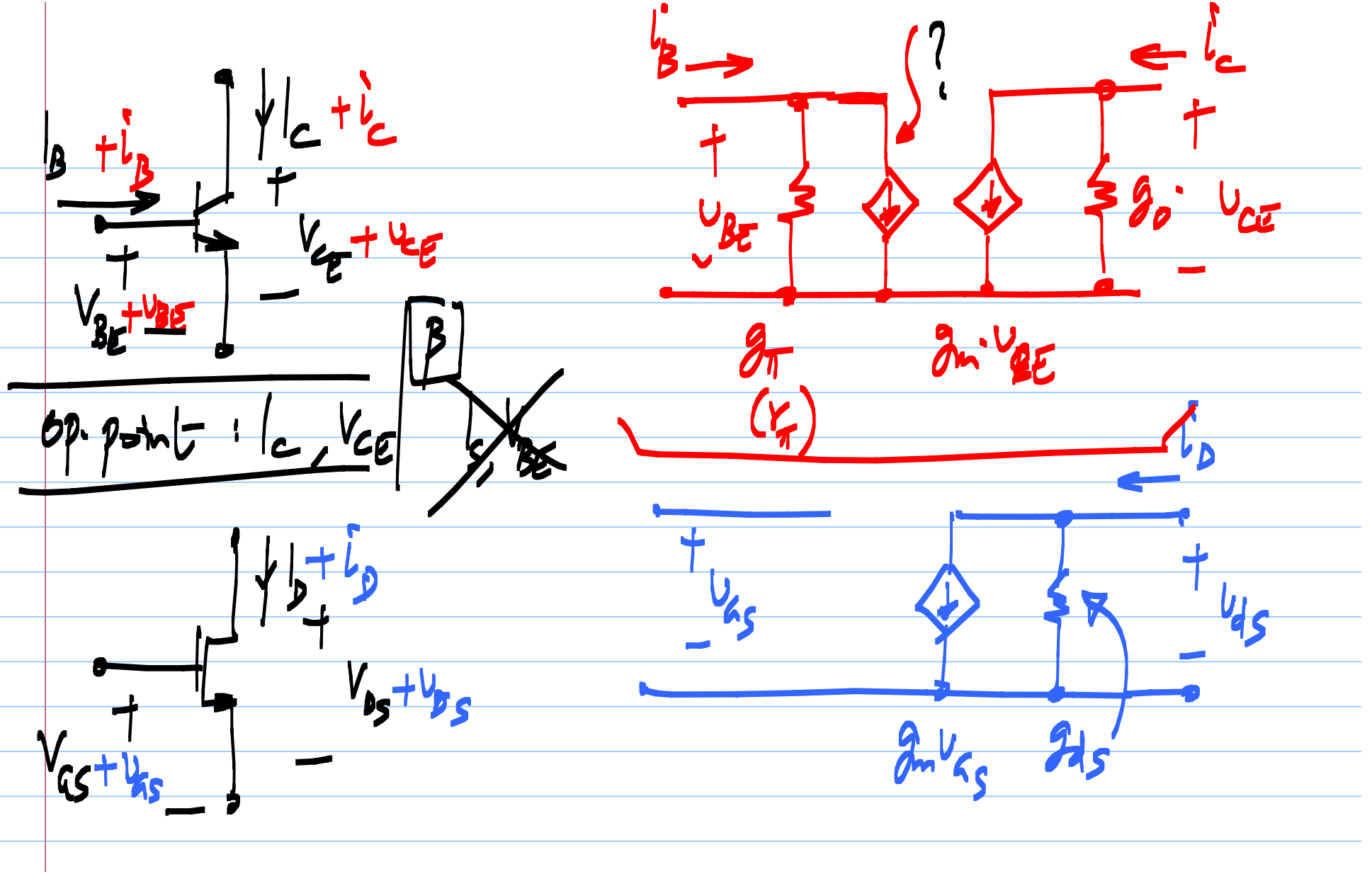
$V_{CE,SAT} = V_{BE,ON} = 0.7V$

PNP:



$$I_C = I_{SP} \exp\left(\frac{V_{EB}}{V_t}\right) \cdot \left(1 + \frac{V_{EC}}{V_{AP}}\right)$$

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


$I_B + i_B$
$I_C + i_C$
$V_{CE} + v_{CE}$
$V_{BE} + v_{BE}$
B
C
E
Op. point : I_C, V_{CE}
$I_D + i_D$
$V_{DS} + v_{DS}$
$V_{GS} + v_{GS}$
i_B
i_C
?
v_{BE}
$g_O \cdot v_{CE}$
g_π (r_π)
$g_m \cdot v_{BE}$
i_D
v_{GS}
v_{DS}
$g_m v_{GS}$
g_{DS}

$$I_c = I_s \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$g_m = \frac{\partial I_c}{\partial V_{BE}} = \frac{1}{V_t} \cdot I_c$$

$$g_o = \frac{\partial I_c}{\partial V_{CE}} = \frac{I_c}{V_A} \cdot \frac{1}{\left(1 + \frac{V_{CE}}{V_A}\right)}$$

$$I_s \exp\left(\frac{V_{BE}}{V_t}\right) \cdot \frac{1}{V_A}$$

$$\frac{I_c}{1 + \frac{V_{CE}}{V_A}} \simeq I_c$$

$$\simeq \frac{I_c}{V_A}$$

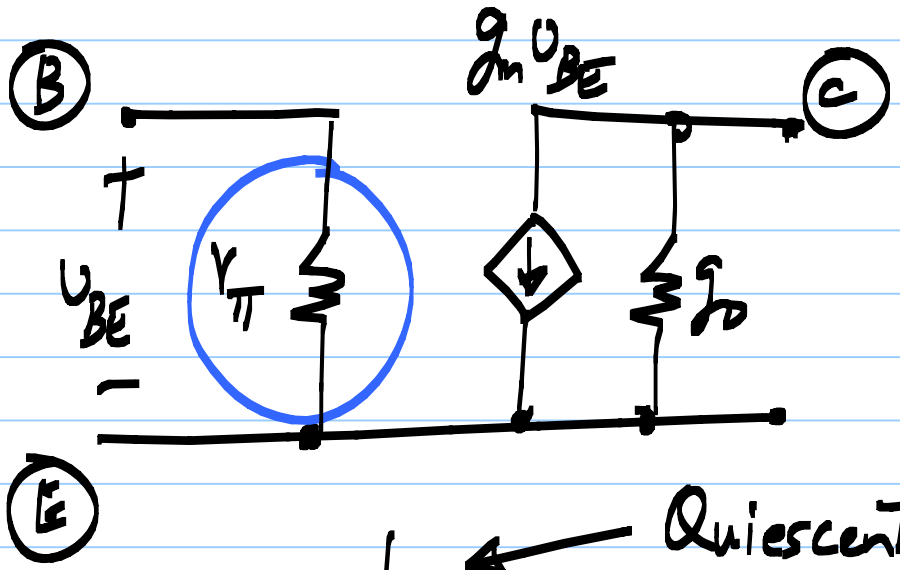
$1/\beta$

$$\frac{\partial I_B}{\partial V_{BE}}$$

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

$$g_r = g_o/\beta \rightarrow \text{neglect}$$

Small signal model of a bijolar transistor



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

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

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

$$g_m = \frac{I_C}{V_t}$$ ← Quiescent current

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

$$g_{m,MOS} = \frac{I_D}{(V_{GS} - V_T)/2}$$