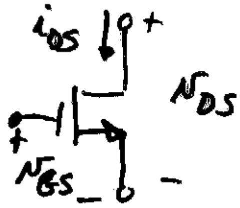
Review - Cont'd

MOSFET:



Cutoff:

$i_{DS} = 0$, $v_{GS} < V_T$

Active (Ohmic - GHLM-sat.):

$v_{DS} < v_{GS} - V_T$, $v_{GS} > V_T$

$$i_{DS} = \frac{K'W}{L}\left[(v_{GS} - V_T) + \frac{v_{DS}}{2}\right] v_{DS}\,(1 + \lambda v_{DS})$$

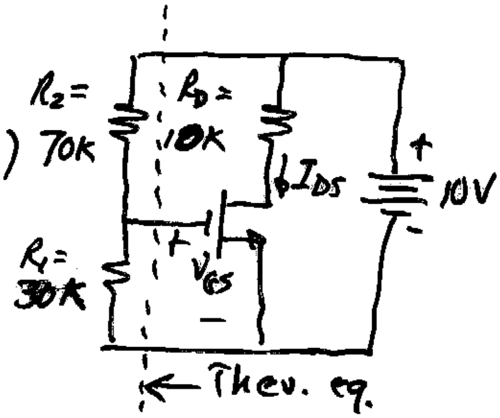
Saturation (GHLM-active):

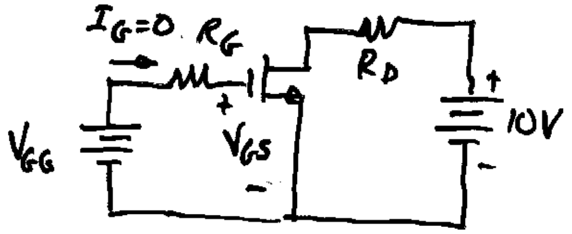
$v_{DS} > v_{GS} - V_T$, $v_{GS} > V_T$

$$i_{DS} = \frac{K'W}{2L}(v_{GS} - V_T)^2 (1 + \lambda v_{DS})$$

Example 1

Find the dc operating point of the NMOS transistor (enh) assuming $K_N' = 25\mu A/V^2$, $W/L = 10$, $V_{TN} = 1V$ and $\lambda = 0$.





$$V_{GG} = \frac{R_1}{R_1 + R_2} 10V = 3V$$

$$R_G = R_1 \| R_2 = 21K$$

Since $I_G = 0$, $V_{GS} = V_{GG} = \underline{3V}$

ASSUME the MOSFET is in saturation,

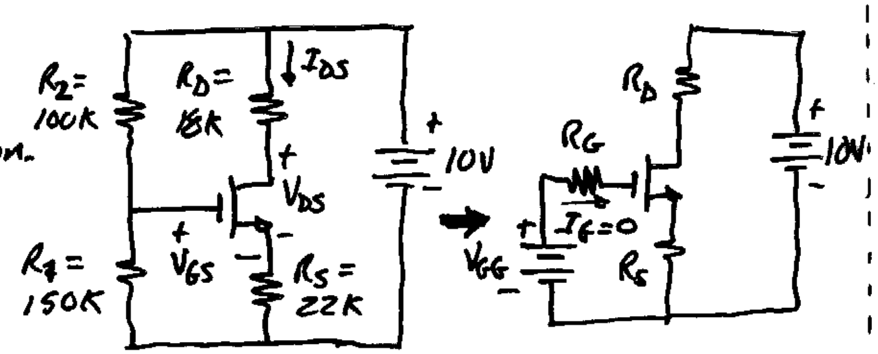
$$\therefore \; I_D = \frac{K_N'}{2}\frac{W}{L}(V_{GS} - V_T)^2 = \frac{25}{2} \cdot 10 (3-1)^2 \mu A = \underline{\underline{500\mu A}}$$

$V_{DS} = 10 - I_D\, 10K = 10 - 5 = \underline{5V}$??

Is $V_{DS} > V_{GS} - V_{TN}$? $\quad 5 \overset{?}{>} 3 - 1 = 2$ Yes.

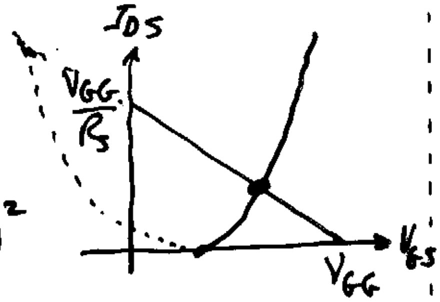
Example 2

Repeat Ex. 1 for the circuit shown.



$$V_{GG} = 10 \frac{R_1}{R_1 + R_2} = 10 \; \frac{150}{250} = 6V$$

$$R_G = R_1 \| R_2 = 60K$$



Gate source loop: $V_{GG} = V_{GS} + I_{DS} R_S$

Saturation eq: $I_{DS} = \frac{K_N'}{2} \frac{W}{L} (V_{GS} - V_{TN})^2$

$I_{DS} = \frac{K_n}{2} (V_{GS} - V_T)^2 \quad \therefore \; K_n = K_N' \frac{W}{L}$

$$V_{GG} = V_{GS} + R_S \frac{K_n}{2} (V_{GS} - V_T)^2 \longrightarrow 6 = V_{GS} + 2.75 (V_{GS} - 1)^2$$

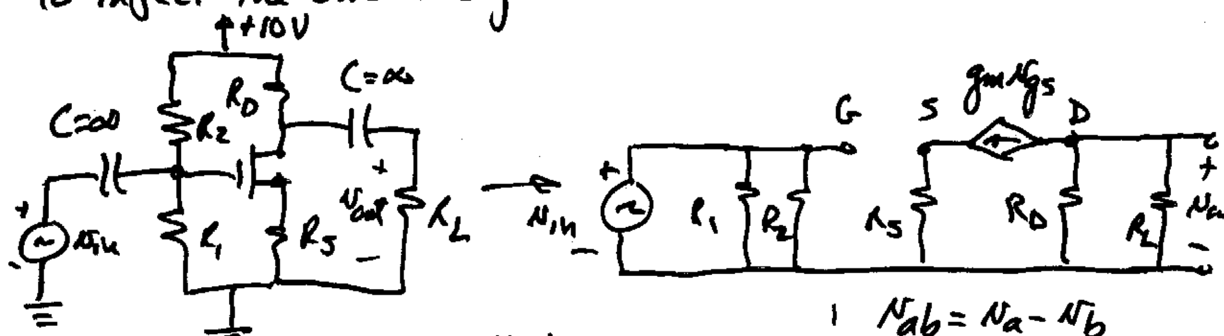
$$V_{GS}^2 - 1.636 V_{GS} - 1.182 = 0 \rightarrow V_{GS} = 0.8182 \pm 1.361$$

$$\therefore V_{GS} = \underline{\underline{2.179V}} \rightarrow I_{DS} = 125 \frac{\mu A}{V^2} (2.179 - 1)^2 = \underline{\underline{174 \mu A}}$$

$$V_{DS} = 10V - I_{DS} (R_D + R_S) = 10V - 174\mu A \cdot 40K = \underline{\underline{3.05V}}$$

$$V_{DS} \overset{?}{\geq} V_{GS} - V_{TN} \rightarrow 3.05V \overset{?}{\geq} 2.179 - 1 = 1.179 \quad \text{Yes}$$

To inject the small signal we modify the circuit as



$$\frac{v_{out}}{v_{in}} = -g_m \frac{R_D \| R_L}{1 + g_m R_S}$$

$v_{ab} = v_a - v_b$

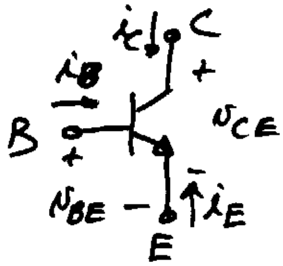
$v_{gs} = v_g - v_s$

$v_{gs} = v_{in} - R_S g_m v_{gs}$

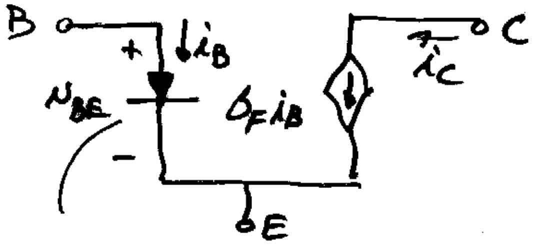
$$\frac{v_{gs}}{v_{in}} = \frac{1}{1 + R_S g_m}$$

BJT – Bipolar Junction Transistors

Schematic:



Forward-Active Region: ($V_{BE}>0$, $V_{BC}<0$)



$$i_B = \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right)-1\right]$$

Key relationships:

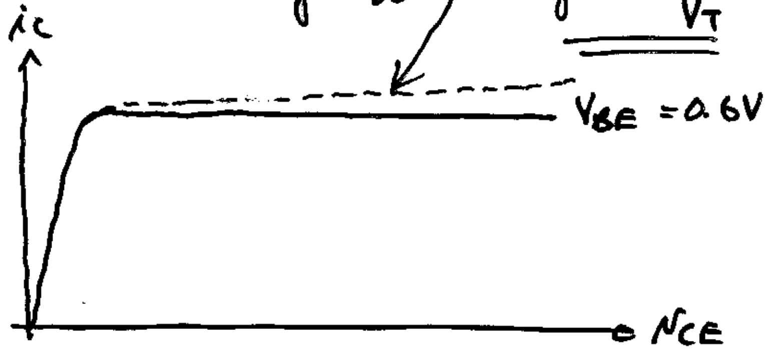
$$i_B = \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right)-1\right] \approx \frac{I_S}{\beta_F}\exp\left(\frac{v_{BE}}{V_T}\right)$$

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

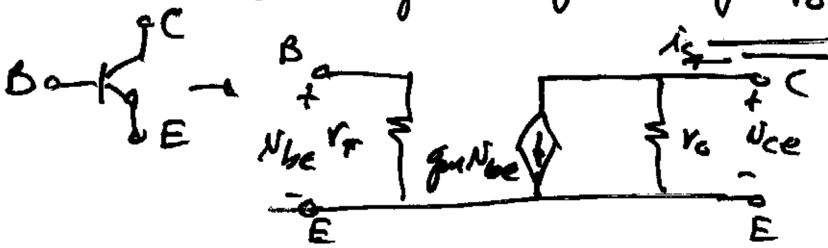
Small signal model:

$$i_b = k_1 v_{be} = g_\pi v_{be} \qquad g_\pi = \frac{1}{r_\pi} = \frac{g_m}{\beta_F}$$

$$i_c = k_2 v_{be} = g_m v_{be} \qquad g_m = \frac{I_C}{V_T}$$

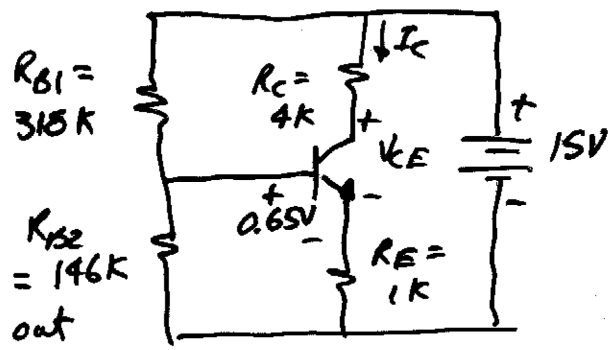


✓ $i_c = k_2 v_{be} + k_3 v_{ce} = g_m v_{be} + g_o v_{ce} \qquad g_o = \frac{1}{r_o} = \frac{I_C}{V_A}$

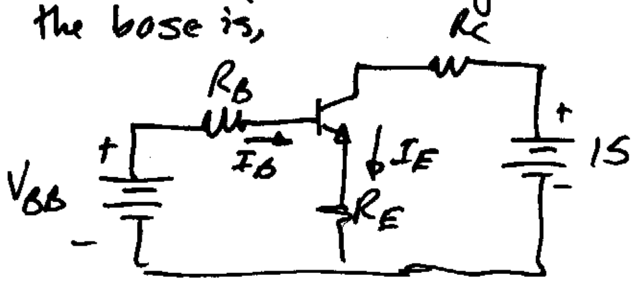


Example 3

Find the Q point if $\beta_F = 100$ and $V_{BEQ} = 0.65V$



Thevenin eq. of looking out the base is,



$V_{BB} = 15 \frac{R_{B2}}{R_{B1}+R_{B2}} = 4.72\ V$

$R_B = R_{B1} \| R_{B2} = 100k\Omega$

~~$I_B = \frac{V_{BB}-0.65}{R_B}$~~ $V_{BB} = I_B R_B + V_{BE} + I_B(1+\beta_F)R_E$

$I_B = \frac{V_{BB}-0.65}{R_B+(1+\beta_F)R_E} = \underline{20\mu A}$ $\quad I_C = \underline{2mA}$

$I_E = I_C + I_B = \underline{2.02mA}$

$V_{CE} = 15 - 2mA(R_C+R_E) = \underline{4.88V}$