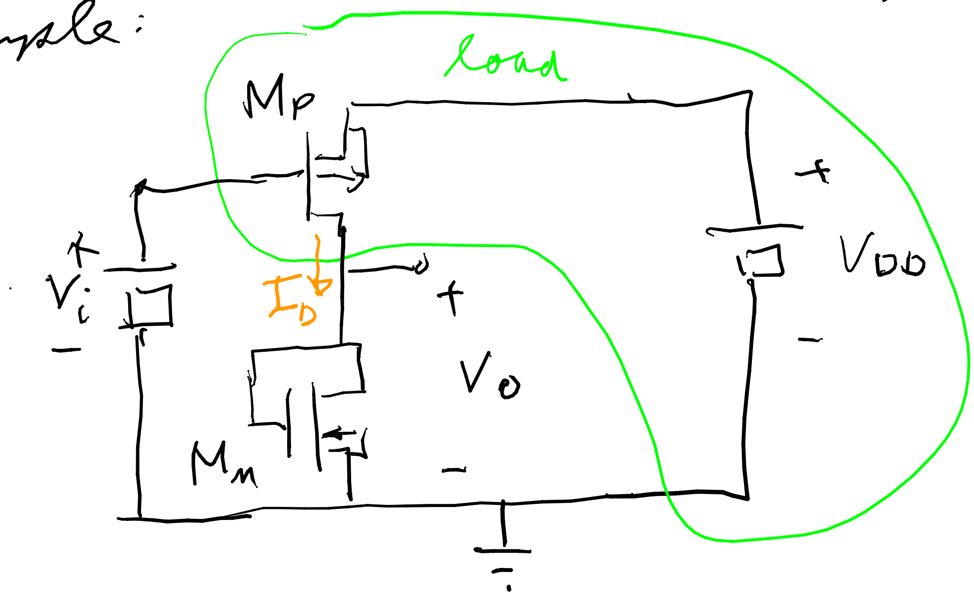
EE 303
03/13/06

Example:

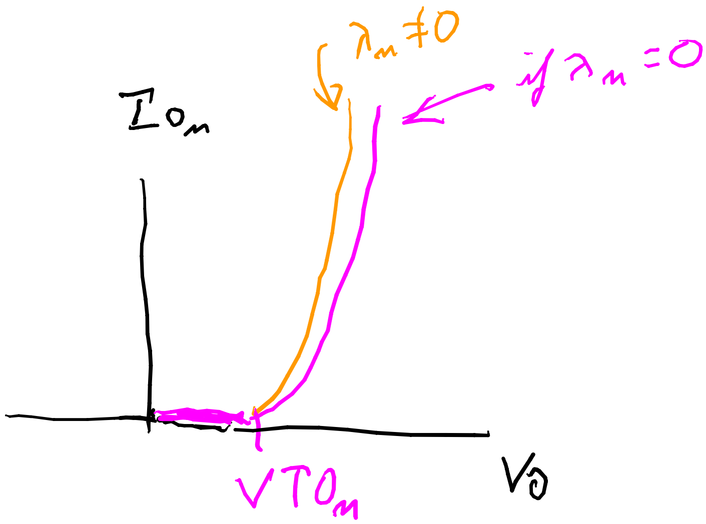


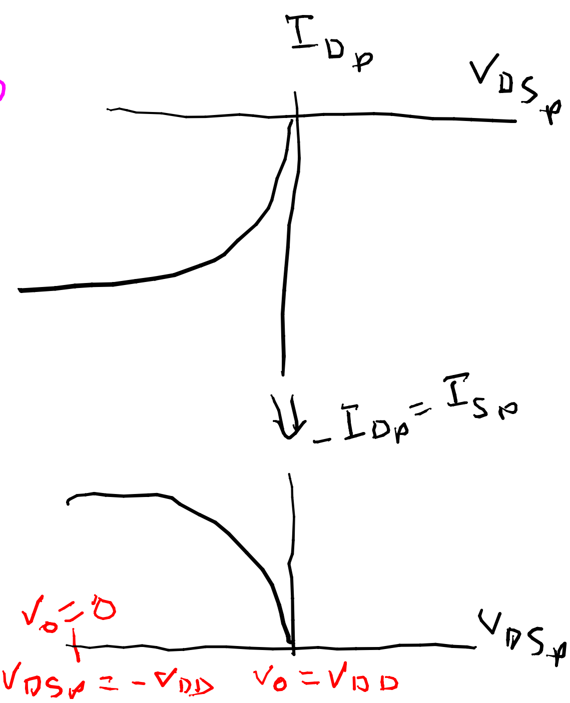
assume $VTO_n > 0$ $\quad$ M_n is in saturation

as $V_{GS_n} - VTO_n = V_{DS_n} - VTO_n < V_{DS_n}$

$$I_{D_n} = \frac{KP_n}{2}\left(\frac{W}{L}\right)_n (V_o - VTO_n)^2 (1 + \lambda_n V_o) \quad \text{if } V_o \geq VTO_n$$

$$= 0 \quad \text{if } V_o \leq VTO_n$$

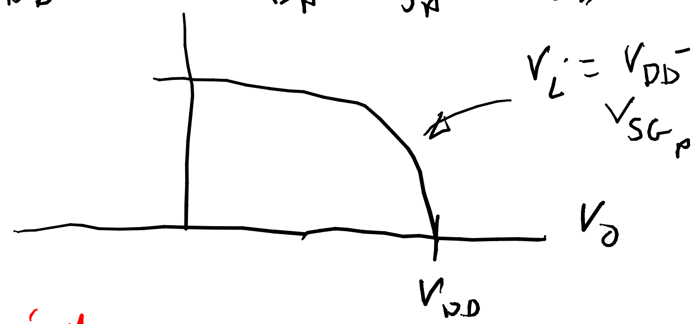


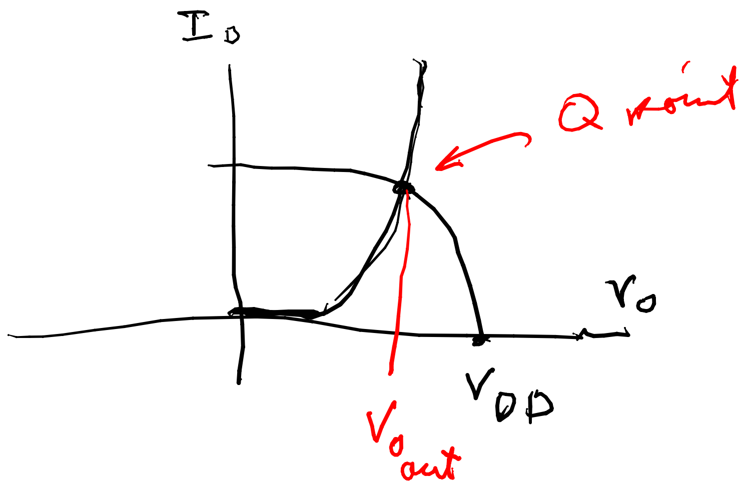


$V_{DS_p} \Rightarrow \quad V_O = V_{DS_p} + V_{DD}$

$-I_{D_p} = I_{S_p} = I_{D_n}$

$V_{SG_p} = V_{DD} - V_i$





$$V_{SG_p} - |VTO_p| \text{ vs } V_{SD_p} \Rightarrow V_O = V_{DS_p} + V_{DD} = -V_{SD_p} + V_{DD}$$

$$\overset{\shortparallel}{V_{DD} - V_i - |VTO_p|} \qquad \Rightarrow V_{SD_p} = V_{DD} - V_O$$

if $\cancel{V_{DD}} - V_i - |VTO_p| < \cancel{V_{DD}} - V_O$ in saturation (M_p)

$\Rightarrow V_O - |VTO_p| < V_i$ saturation

$V_O - |VTO_p| > V_i$ ohmic

} assume $V_{SG_p} > |VTO_p|$ (small enough $|V_i|$)

assume $V_i > V_O - |VTO_p|$; $\underbrace{V_{DD} - V_i > |VTO_p|}_{\text{turned on}}$

$\lambda_n = \lambda_p = 0$

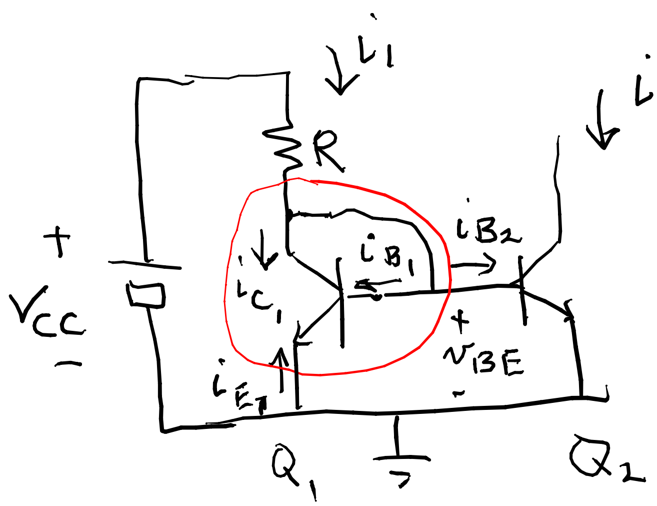
$$I_{D_n} = \frac{KP_n}{2} \frac{W}{L}_n (V_O - |VTO_n|)^2 = +I_{S_p} = \frac{KP_p}{2} \left(\frac{W}{L}\right)_p (V_{DD} - V_O - |VTO_p|)^2$$

$$(V_o - |VTO_n|) = \underbrace{\left(\frac{KP_p}{KP_n}\right)\left(\frac{(W/L)_p}{(W/L)_n}\right)}_{k}\left(V_{DD} - V_o - |VTO_p|\right)$$

$$V_o + kV_o = VTO_n - k\left(V_{DD} + |VTO_p|\right)$$

$$V_o = \frac{1}{1+k}\left(VTO_n + k\left(V_{DD} \cancel{+} - |VTO_p|\right)\right)$$

BJT current source, p. 442



$$\downarrow i_2 = i_{C_2} = \beta_2 i_{B_2}$$

$$-i_{E_2} = A_2 \cdot J_S\, e^{v_{BE}/V_T}$$

$$-i_{E_1} = A_1 \cdot J_S\, e^{v_{BE}/V_T}$$

A_i = emitter area

KCL $\quad i_1 - i_{B_2} + i_{E_1} = 0$

$$\frac{i_{E_2}}{i_{E_1}} = \frac{A_2}{A_1}$$

$$i_c = \beta i_B = -\alpha i_E \Rightarrow i_E = \frac{\beta}{\alpha} i_B = \frac{1}{\alpha - 1} i_B$$

$$\beta = \frac{\alpha}{\alpha - 1}$$

$$i_1 = i_{B_2} - i_{E_1},$$

$$i_2 = i_{C_2} = \alpha_2 i_{E_2}$$

use these to get i_2 vs i_1 as a function of A_2/A_1

$$i_B = (\alpha - 1)\, i_E$$

$$\therefore \quad i_1 = (\alpha_2 - 1)\, i_{E_2} - \frac{A_1}{A_2}\, i_{E_2} = \left[(\alpha_2 - 1) - \frac{A_1}{A_2}\right]\left(\frac{-i_{C_2}}{\alpha_2}\right)$$

$$= \left[\frac{(1-\alpha_2)}{\alpha_2} + \frac{1}{\alpha_2}\frac{A_1}{A_2}\right] i_2$$

or

$$i_2 = \frac{1}{\left[\frac{1}{\beta_2} + \frac{1}{\alpha_2}\frac{A_1}{A_2}\right]}\, i_1$$

To set up i_1 we usually approximate $v_{BE} \approx 0.7$ & use $V_{CC} = v_{BE} + R i_1$ or $i_1 = \frac{V_{CC} - v_{BE}}{R}$

More accurately though we can use the above for $i_1 = i_{B_2} - i_{E_1} = (\alpha_2 - 1)\, i_{E_2} - i_{E_1} = \left[(\alpha_2 - 1)\frac{A_2}{A_1} - 1\right] i_{E_1}$

$$= \left[(\alpha_2 - 1)\frac{A_2}{A_1} - 1\right] \cdot I_{SE_1} e^{v_{BE}/V_T}$$

and solve the equation

$$i_1 = \frac{V_{CC} - v_{BE}}{R} = \left[(\alpha_2 - 1)\frac{A_2}{A_1} - 1\right] I_{SE_1} e^{v_{BE}/V_T}$$

for v_{BE}