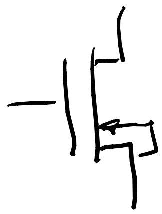
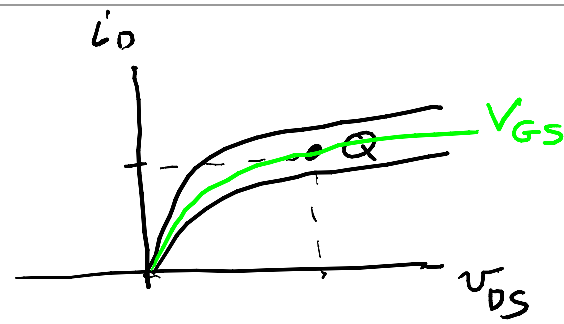
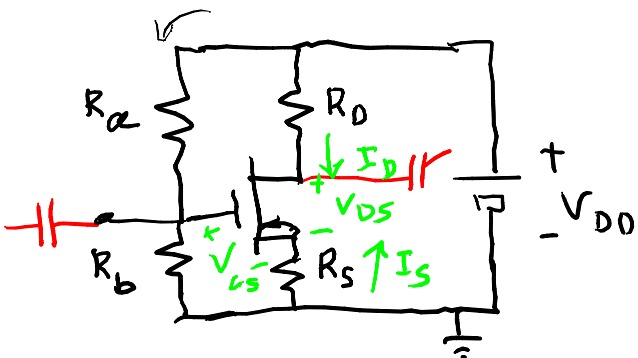
Biasing MOS





$Q \Rightarrow I_D, V_{GS}, V_{DS}$ (VTO, KP, λ



$$V_{GS} = R_S I_D + \frac{R_b}{R_a + R_b} V_{DD}$$

$$V_{DS} = V_{DD} - R_D I_D - R_S I_D$$
$$= V_{DD} - (R_D + R_S) I_D$$

normally bias in saturation

$V_{DS} > V_{GS} - VTO$

also usually given $A_v = -g_m R_L$

$= -g_m R_D$

Ex: $I_D = 2$ ma, $V_{GS} = 4$V, $VTO = 1$; $V_{DD} = 9$

choose $R_S = 1\,K\Omega \Rightarrow$, $V_S = R_S I_D = 1\times10^{+3} \times 2\times10^{-3} = 2$V

$\therefore$ V at top of $R_b = 6$V; $\frac{R_b}{R_a+R_b} \cdot V_{DD} = 6 = \frac{1}{\frac{R_a}{R_b}+1} \cdot 9$

$\Rightarrow 6 + 6\frac{R_a}{R_b} = 9 \Rightarrow \frac{R_a}{R_b} = \frac{1}{2}$

$R_b = 2R_a$

choose $R_a = 10$ Meg$\Omega \Rightarrow R_b = 20$ MegΩ

$V_{DS} = V_{DD} - R_D I_D - R_S I_D = 9 - 2 - R_D I_D = 7 - 2\times10^{-3} R_D \doteq 7 - 2\times10^{-3} \cdot \frac{|A_v|}{g_m}$

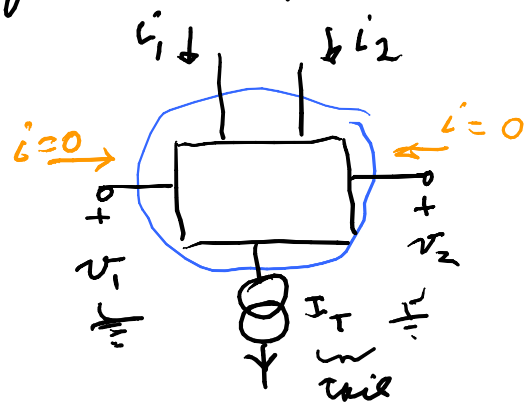
assume that $R_D = 1\,K\Omega \Rightarrow V_{DS} = 9 - 2 = 7$v max $R_D \Rightarrow V_{DS} \geq V_{GS} - V_{TO} \Rightarrow 4-1=3$, $V_{DD}=9$, $V_{DD} - \underset{min}{V_{GS}} = 6$

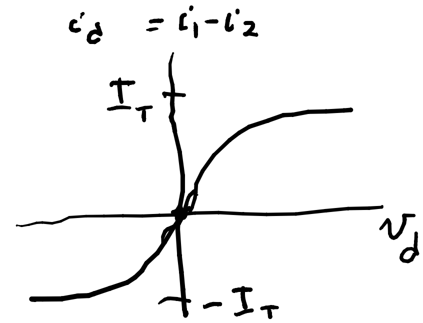
$I_D = 2\,ma \Rightarrow R_D I_D \leq 6$;

$R_D \times 2 \times 10^{-3} = 6 \Rightarrow R_D = \frac{6}{2}\,k\Omega = 3\,k\Omega$

Direct coupled

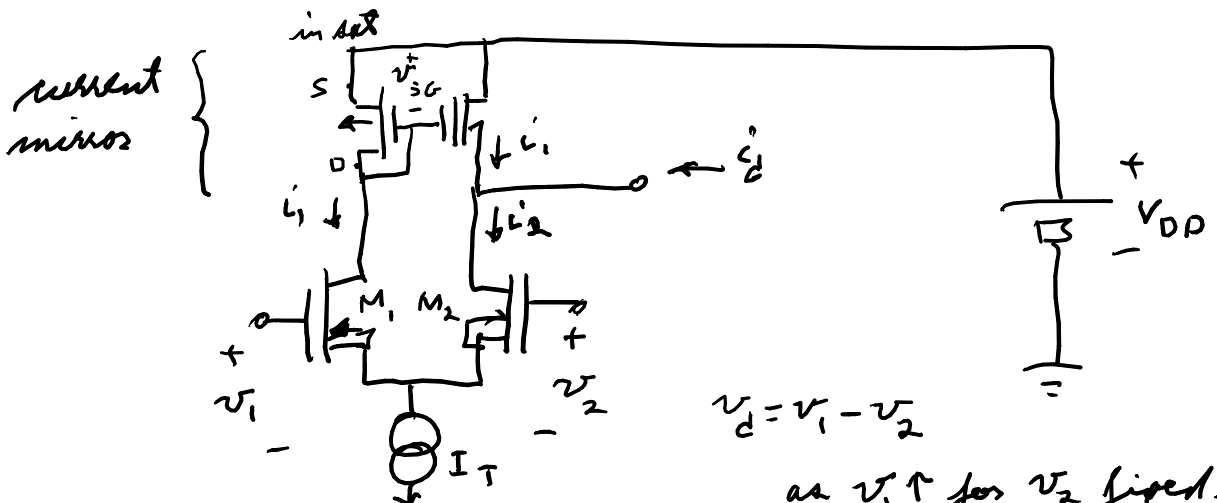
$\Rightarrow$ differential pair, p. 588





$v_d = v_1 - v_2$

KCL: $0 = i_1 + i_2 - I_T \Rightarrow i_1 + i_2 = I_T$



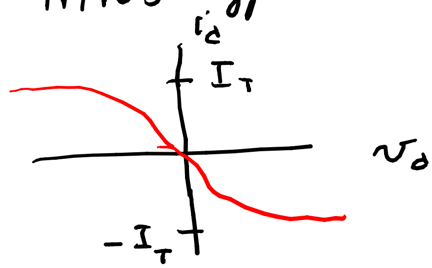
$v_d = v_1 - v_2$

as $v_1 \uparrow$ for v_2 fixed, $v_d \uparrow$ & $i_1 \uparrow$, $i_2 \downarrow$

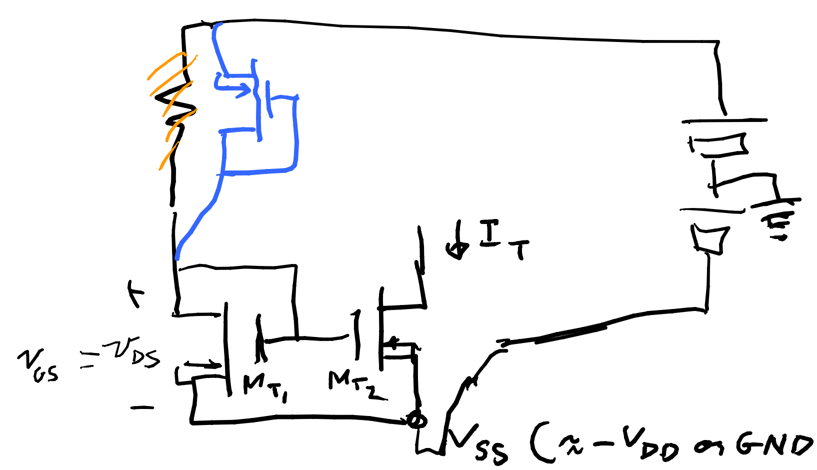
as $i_1 + i_2 =$ constant

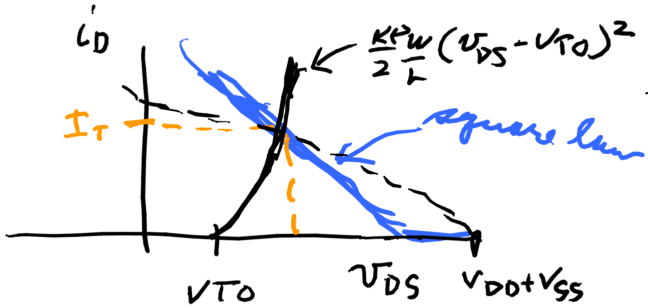
& $i_d \downarrow$

NMOS differential pair



How to make I_T





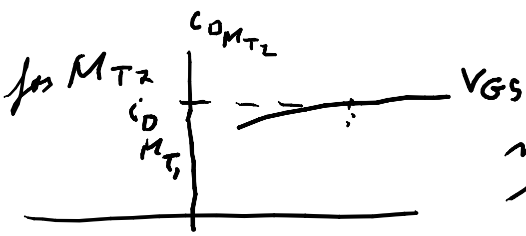
here $v_{DS} = v_{GS}$ for M_{T_1}

$> v_{GS} - VTO$ as $VTO > 0$

means M_{T_1} is in saturation

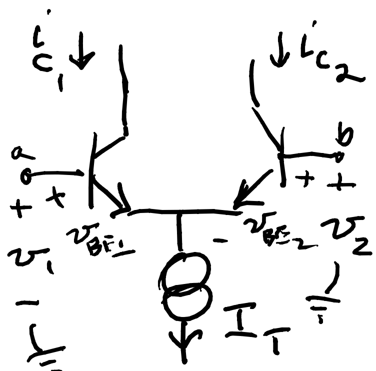
$$i_D = \frac{KP}{2}\frac{W}{L}(v_{GS}-VTO)^2 \text{ if } v_{GS}=v_{DS}>0$$
$$= \frac{KP}{2}\frac{W}{L}(v_{DS}-VTO)^2$$

but if $v_{DS}=v_{GS} \le VTO$ M_{T_1} is off



need to keep in saturation then $i_{D_{M_{T_1}}}$

BJT version



$$v_{ab} = v_d = v_1 - v_2 = v_{BE_1} - v_{BE_2}$$

$$i_d = i_2 - i_1$$

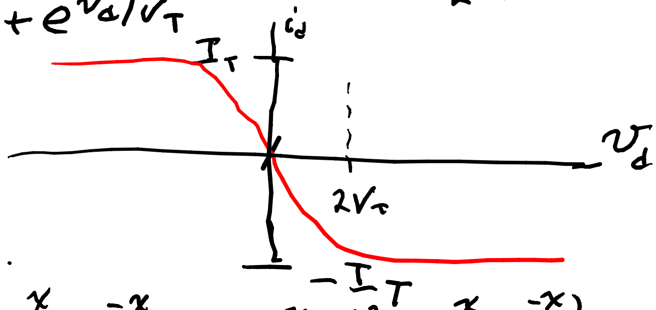
$$i_{C_1} = I_S e^{v_{BE_1}/V_T}, \quad i_{C_2} = I_S e^{v_{BE_2}/V_T}$$

$$i_d = i_{C_2} - i_{C_1} = I_S\left(e^{v_{BE_2}/V_T} - e^{v_{BE_1}/V_T}\right) = I_S e^{v_{BE_2}/V_T}\left(1 - e^{(v_{BE}-v_{BE_2})/V_T}\right)$$
$$= I_S e^{v_{BE_2}/V_T}\left(1 - e^{v_d/V_T}\right)$$

$$I_T = i_{C_2} + i_{C_1} = I_S e^{v_{BE_2}/V_T}\left(1 + e^{v_d/V_T}\right)$$

$$\frac{i_d}{I_T} = \frac{1-e^{v_d/V_T}}{1+e^{v_d/V_T}} = \tanh\left(-\frac{v_d}{2V_T}\right) \Rightarrow i_d = I_T \tanh\left(-\frac{v_d}{2V_T}\right)$$

as $\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$



$$\frac{d \tanh x}{dx} = \frac{e^x+e^{-x}}{e^x+e^{-x}} - \frac{(e^x-e^{-x})(e^x-e^{-x})}{(e^x+e^{-x})^2} = 1 - \tanh^2 x$$