ELEC 401 Formula Sheet

MOS Transistors

Regions of Operation:

NMOS:

$$\begin{cases} V_{GS} < V_{TH} & \text{Cut-off} \\ V_{GS} > V_{TH}, V_{DS} \ll 2(V_{GS} - V_{TH}) & \text{Deep Triode} \\ V_{GS} > V_{TH}, V_{DS} < V_{GS} - V_{TH} & \text{Triode} \\ V_{GS} > V_{TH}, V_{DS} > V_{GS} - V_{TH} & \text{Saturation} \end{cases}$$

PMOS:

$$\begin{cases} V_{SG} < |V_{TH}| & \text{Cut-off} \\ V_{SG} > |V_{TH}|, V_{SD} \ll 2(V_{SG} - |V_{TH}|) & \text{Deep Triode} \\ V_{SG} > |V_{TH}|, V_{SD} < V_{SG} - |V_{TH}| & \text{Triode} \\ V_{SG} > |V_{TH}|, V_{SD} > V_{SG} - |V_{TH}| & \text{Saturation} \end{cases}$$

Long Channel Current Equations:

NMOS (I_{DS}):

$$\begin{cases} 0 & \text{Cut-off} \\ \mu_n C_{\text{ox}} \dfrac{W}{L}(V_{GS} - V_{TH})V_{DS} & \text{Deep Triode} \\ \mu_n C_{\text{ox}} \dfrac{W}{L}\left[(V_{GS} - V_{TH})V_{DS} - \dfrac{V_{DS}^2}{2}\right] & \text{Triode} \\ \dfrac{1}{2}\mu_n C_{\text{ox}} \dfrac{W}{L}(V_{GS} - V_{TH})^2 & \text{Saturation} \end{cases}$$

PMOS (I_{SD}):

$$\begin{cases} 0 & \text{Cut-off} \\ \mu_p C_{\text{ox}} \dfrac{W}{L}(V_{SG} - |V_{TH}|)V_{SD} & \text{Deep Triode} \\ \mu_p C_{\text{ox}} \dfrac{W}{L}\left[(V_{SG} - |V_{TH}|)V_{SD} - \dfrac{V_{SD}^2}{2}\right] & \text{Triode} \\ \dfrac{1}{2}\mu_p C_{\text{ox}} \dfrac{W}{L}(V_{SG} - |V_{TH}|)^2 & \text{Saturation} \end{cases}$$

Transconductance (NMOS):

$$g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}}$$

$$g_m = \mu_n C_{\text{ox}} \frac{W}{L}(V_{GS} - V_{TH})$$

$$g_m = \sqrt{2\mu_n C_{\text{ox}} \frac{W}{L} I_D} = \frac{2I_D}{V_{GS} - V_{TH}}$$

Body Effect:

$$V_{\text{TH}} = V_{\text{TH0}} + \gamma\left(\sqrt{|2\Phi_F + V_{SB}|} - \sqrt{|2\Phi_F|}\right)$$

$$\gamma = \frac{\sqrt{2q\varepsilon_{\text{si}} N_{\text{sub}}}}{C_{\text{ox}}}$$

Channel Length Modulation:

$$I_D = \frac{1}{2}\mu_n C_{\text{ox}} \frac{W}{L}(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

Sub-threshold Conduction:

$$I_D = I_0 e^{\frac{V_{GS}}{\zeta V_T}}$$

Device Capacitances:

	Cut-off	Triode	Saturation
C_{GS}	C_{ov}	$C_{\text{ov}} + \frac{C_1}{2}$	$C_{\text{ov}} + \frac{2}{3}C_1$
C_{GD}	C_{ov}	$C_{\text{ov}} + \frac{C_1}{2}$	C_{ov}
C_{GB}	$\frac{C_1 C_2}{C_1 + C_2} \le C_{GB} \le C_1$	0	0
C_{SB}	C_5	$C_5 + \frac{C_2}{2}$	$C_5 + \frac{2}{3}C_2$
C_{DB}	C_6	$C_6 + \frac{C_2}{2}$	C_6

Small-Signal Model:

$$i_D = g_m v_{GS} + \frac{v_{DS}}{r_o} + g_{mb} v_{BS}$$

$$g_{mb} = \eta g_m = \frac{\gamma}{2\sqrt{|2\Phi_F + V_{SB}|}} g_m$$

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https://github.com/DonneyF/formula-sheets