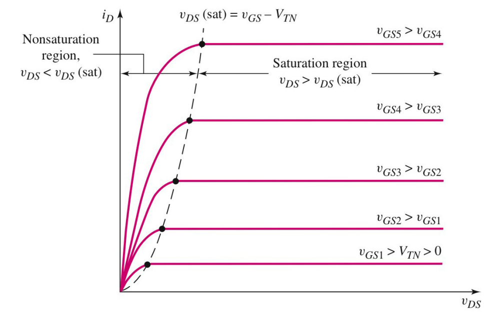
Microelectronics
Circuit Analysis and Design

Donald A. Neamen

Chapter 3

MOSFET DC ANALYSIS

Family of i_D Versus v_{DS} Curves: Enhancement-Mode nMOSFET



Summary of I-V Relationships

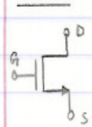
Region	NMOS	PMOS
Nonsaturation	$v_{DS} < v_{DS}(sat)$ $i_D = K_n[2(v_{GS} - V_{TN})v_{DS} - v_{DS}^2]$	$v_{SD} < v_{SD}(sat)$ $i_D = K_p[2(v_{SG} + V_{TP})v_{SD} - v_{SD}^2]$
Saturation	$v_{DS} > v_{DS}(sat)$ $i_D = K_n[v_{GS} - V_{TN}]^2$	$v_{SD} > v_{SD}(sat)$ $i_D = K_p[v_{SG} + V_{TP}]^2$
Transition Pt.	$v_{DS}(sat) = v_{GS} - V_{TN}$	$v_{SD}(sat) = v_{SG} + V_{TP}$
Enhancement Mode	$V_{TN} > 0V$	$V_{TP} < 0V$
Depletion Mode	$V_{TN} < 0V$	$V_{TP} > 0V$

Conduction Parameters

- NMOSFET $$K_n = \frac{W\mu_n C_{ox}}{2L} = k_n' \frac{W}{2L}$$
- PMOSFET $$K_p = \frac{W\mu_p C_{ox}}{2L} = k_p' \frac{W}{2L}$$

where: $$C_{ox} = \varepsilon_o / t_{ox}$$

Ex.. 1 Given: N MOS Enhancement Type MOSFET



$V_{TN} = 0.4^V$

$K_n' = 120\ \mu A/V^2$, $L = 0.8\mu m$, $W = 10\mu m$

FIND: I_D {for table of V_{DS} & V_{GS}}

① $K_n = \frac{K_n'}{2} \cdot \frac{W}{L} = \left(\frac{120}{2}\right)\left(\frac{10}{0.8}\right) = 0.75\ mA/V$

② $I_D = K_n\left[2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2\right]$

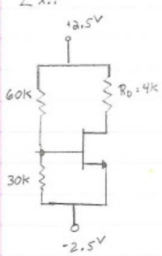
③ $I_D = K_n\left[(V_{GS} - V_{TN})^2\right]$

④ $V_{DS(SAT)} = V_{GS} - V_{TN}$

Ex.. 1 (cont.)

	V_{DS}	V_{GS}	$V_{DS(SAT)}$	I_D
(i)	0.1	0	-0.4	0 $V_{GS} < V_{TN}$ cut-off
(ii)	0.1	1	0.6	$0.75(2[1-0.4]0.1 - (0.1)^2) = 82.5\mu A$
(iii)	0.1	2	1.6	$0.75(2[2-0.4]0.1 - (0.1)^2) = 232\mu A$
(iv)	0.1	3	2.6	$0.75(2[3-0.4]0.1 - (0.1)^2) = 383\mu A$
(v)	4	0	-0.4	0
(vi)	4	1	0.6	$0.75(1-0.4)^2 = 270\mu A$
(vii)	4	2	1.6	$0.75(2-0.4)^2 = 1.92\ mA$
(viii)	4	3	2.6	$0.75(3-0.4)^2 = 5.07\ mA$

Ex.. 2



$V_{TN} = 0.6^V$

$K_n = 0.5\ mA/V^2$

FIND: V_{GS}, I_D, V_{DS}

① $V_G = \left(\frac{30k}{30k+60k}\right)5 - 2.5^V = -0.833^V$

② $V_S = -2.5^V$

③ $V_{GS} = -0.833 - (-2.5) = \boxed{1.67^V}$

EX.. 2

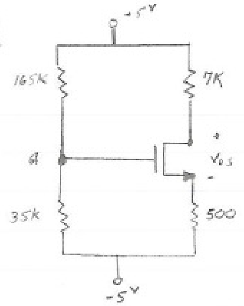
④ Assume SAT. Region.

$$I_D = K_n(V_{GS} - V_{TN})^2$$
$$= 0.5\ mA/V^2\ (1.67 - 0.6)^2$$
$$= \boxed{0.57\ mA}$$

5. $-2.5 + I_D\,4K + V_{DS} - 2.5 = 0$

$$V_{DS} = 5 - (0.57)4$$
$$= \boxed{2.72^V}$$

Ex 3



Given:

$V_{TN} = 0.8^V$

$K_N = 1^{mA}/_{V^2}$

Find: I_D, V_{DS}

① $V_G = \left(\frac{35}{35+165}\right) 10 - 5 = -3.25^V$

② $I_D = K_n (V_{GS} - V_{TN})^2$

Ex.. 3 (Cont.)

② $I_D = K_n (V_{GS} - V_{TN})^2$

$\frac{V_S - (-5)}{R_S} = K_n (V_G - V_S - V_{TN})^2$

$V_S + 5 = (500)(1^{mA}/_{V^2})(-3.25 - V_S - 0.8)^2$

$2V_S + 10 = (-V_S - 4.05)^2$

$V_S^2 + 6.1 V_S + 6.4 = 0$

$V_S = -4.75^V$ or -1.35^V

Ex.. 3 (Cont.)

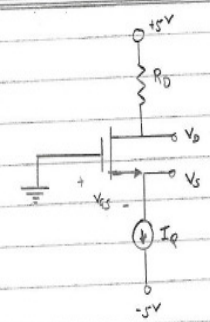
③ $V_{GS} = -3.25 - (-4.75) = 1.5^V > V_{TN}$ ✓

④ $I_D = \frac{V_S + 5}{R_S} = \frac{-4.75 + 5}{500} = \boxed{0.5^{mA}}$

⑤ $-5^V + I_D(7k + 500) + V_{DS} - 5^V = 0$

$V_{DS} = 10 - (0.5)(7.5) = \boxed{6.25^V}$

Ex 4 MOSFET BIASED w/ Constant Current Source



$V_{TN} = 0.8^V$

$k_n' = 80 \mu A/V$

$W/L = 3$

$I_D = 250 \mu A$, $V_D = 2.5^V$

Ex.. 4 cont.

1. $I_D = \frac{k_n'}{2} \cdot \frac{W}{L} (V_{GS} - V_{TN})^2$

$250\,\mu A = \left(\frac{80\,\mu A/V}{2}\right)(3)(V_{GS} - 0.8)^2 \Rightarrow \boxed{V_{GS} = 2.24^V}$

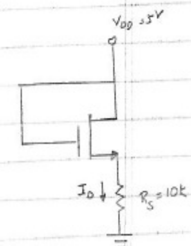
$\therefore \quad V_S = -V_{GS} = \boxed{-2.24^V}$

$I_D = \frac{5 - V_D}{R_D} \Rightarrow$ for $V_O = 2.5 \Rightarrow R_D = \frac{5 - 2.5}{0.25} = \boxed{10 k\Omega}$

$V_{DS} = V_D - V_S = 2.5 - (-2.24) = \underline{4.74^V}$

Since $V_{DS} > V_{DS(SAT)} = 2.24 - 0.8 = \underline{1.44^V}$, $\therefore$ in $\underline{\text{SAT. REGION}}$

Example: 5



$K_n = 0.05\ mA/V$

$V_{TN} = 0.8^V$

Assume SAT; then

① $I_D = k_n (V_{GS} - V_{TN})^2$

$V_{DS} = V_{GS} = 5 - I_D R_S$

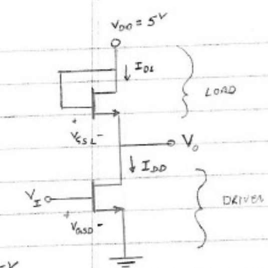
Subst: we get $V_{GS} = 5 - k_n R_S (V_{GS} - V_{TN})^2 = 5 - (0.05)(10)(V_{GS} - 0.8)^2$

$0.5 V_{GS}^2 + 0.2 V_{GS} - 4.68 = 0$

$V_{GS} = -3.27^V$; 2.87^V

V_{GS} must $> V_{TN}$ $\therefore$ $V_{GS} = \boxed{2.87^V}$, $I_D = K_n (2.87 - 0.8)^2 = \boxed{0.213\ mA}$

Ex. 6



Let: $V_{TND} = V_{TNL} = 1^V$

$k_{nD} = 50\,\mu A/V^2$

$k_{nL} = 10\,\mu A/V^2$

Find V_O for $V_I = 5^V$

Assume M_D is in NON-SAT Region ; M_L is SAT as before

$I_{DD} = I_{DL}$

$k_{nD} [2(V_{GSD} - V_{TND}) V_{DSD} - V_{DSD}^2] = k_{nL} [V_{GSL} - V_{TNL}]^2$

Since: $V_{GSD} = V_I$, $V_{DSD} = V_O$, $V_{GSL} = V_{DSL} = V_{DD} - V_O$

then $k_{nD} [2(V_I - V_{TND}) V_O - V_O^2] = K_{nL} [V_{DD} - V_O - V_{TNL}]^2$

So $50 [2(5 - 1) V_O - V_O^2] = 10 [5 - V_O - 1]^2$

$3 V_O^2 - 24 V_O + 8 = 0$

$V_O = \cancel{7.65^V}^{\,> V_{DD}}$ or $\boxed{V_O = 0.349^V}$

Note: $V_{DSD} = V_O < V_{(SAT)} = V_{GSD} - V_{TND} = 5 - 1 = 4^V$ $\{\therefore$ NON SAT DRIVER$\}$

ALSO $I_D = K_{nL} (V_{GSL} - V_{TNL})^2 = K_{nL} (V_{DD} - V_O - V_{TNL})^2$
$= 10 (5 - 0.349 - 1)^2 = \boxed{133\,\mu A}$