Microelectronics
Circuit Analysis and Design

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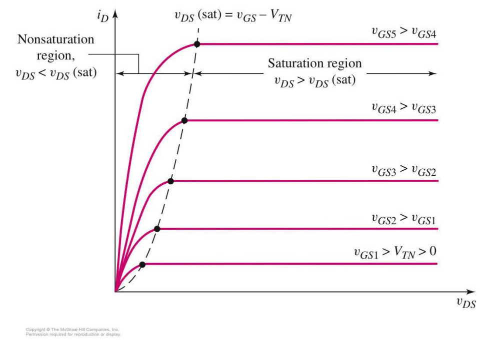
Chapter 3

MOSFET DC ANALYSIS

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



Summary of I-V Relationships

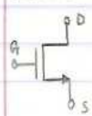
Region	NMOS	PMOS
Nonsaturation	$v_{DS}<v_{DS}(sat)$ $i_D = K_n[2(v_{GS}-V_{TN})v_{DS}-v_{DS}^2]$	$v_{SD}<v_{SD}(sat)$ $i_D = K_p[2(v_{SG}+V_{TP})v_{SD}-v_{SD}^2]$
Saturation	$v_{DS}>v_{DS}(sat)$ $i_D = K_n[v_{GS}-V_{TN}]^2$	$v_{SD}>v_{SD}(sat)$ $i_D = K_p[v_{SG}+V_{TP}]^2$
Transition Pt.	$v_{DS}(sat)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



$V_{TN} = 0.4^V$

$K_n' = 120\ ^{mA}/_{V^2}$, $L = 0.8\mu m$, $W = 10\mu m$

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

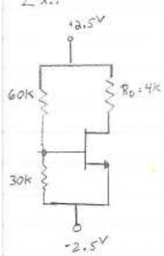
③ $I_D = K_n\left[(V_{GS} - V_{TN})^2\right]$

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	$0.75(2-0.4)^2 = 1.92mA$
(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

$I_D = K_n(V_{GS} - V_{TN})^2$

$= 0.5\ ^{mA}/_{V^2}(1.67 - 0.6)^2$

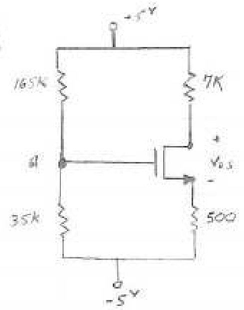
$= \boxed{0.57\ mA}$

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.)

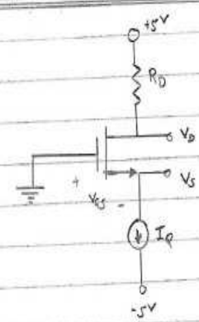
③ $V_{GS} = -3.25 - (-4.75) = 1.5^V > V_{TN}$ ✓

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

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

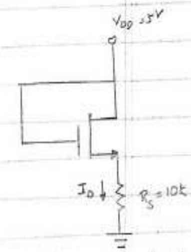
$\therefore \quad V_S = -V_{GS} = \boxed{-2.24^V}$

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

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

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

Example: 5



$K_n = 0.05 \, mA/V$

$V_{TN} = 0.8^V$

$\underline{\text{Assume SAT; then}}$

① $I_D = k_n \left(V_{GS} - V_{TN} \right)^2$

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

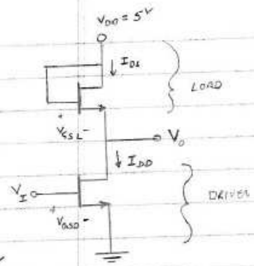
Subst. we get $\quad V_{GS} = 5 - k_n R_S \left(V_{GS} - V_{TN} \right)^2 = 5 - (0.05)(10)(V_{GS} - 0.8)^2$

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

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

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

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

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

$\underline{\text{Find } V_o \text{ for } V_I = 5^V}$

$\underline{\text{Assume } M_D \text{ is in NON-SAT Region; } M_L \text{ is SAT as before}}$

$I_{DD} = I_{DL}$

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

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

then $k_{nD} \left[2 \left(V_I - V_{TND} \right) V_o - V_o^2 \right] = k_{nL} \left[V_{DD} - V_o - V_{TNL} \right]^2$

So $\quad 50 \left[2 (5 - 1) V_o - V_o^2 \right] = 10 \left[5 - V_o - 1 \right]^2$

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

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

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

ALSO $\quad I_D = k_{nL} \left(V_{GSL} - V_{TNL} \right)^2 = k_{nL} \left(V_{DD} - V_o - V_{TNL} \right)^2$

$= 10 \left(5 - 0.349 - 1 \right)^2 = \boxed{133 \mu A}$