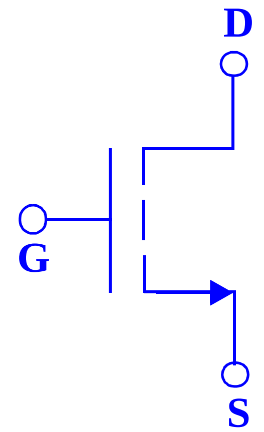
Summary of NMOS FET Mathematical Model Expressions

$K_n = \mu_n C_{ox} \frac{W}{L}$, $i_G = 0$, $i_B = 0$



Cut-off Region - $i_{DS} = 0$ for $v_{GS} \leq V_{TN}$

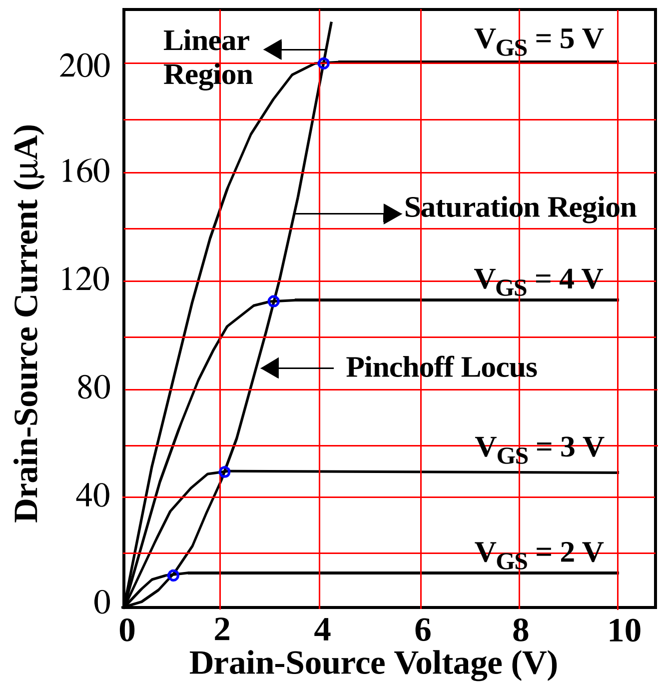
Linear region - $v_{GS} - V_{TN} \geq v_{DS} \geq 0$

$$i_{DS} = K_n \left(v_{GS} - V_{TN} - \frac{v_{DS}}{2} \right) v_{DS}$$

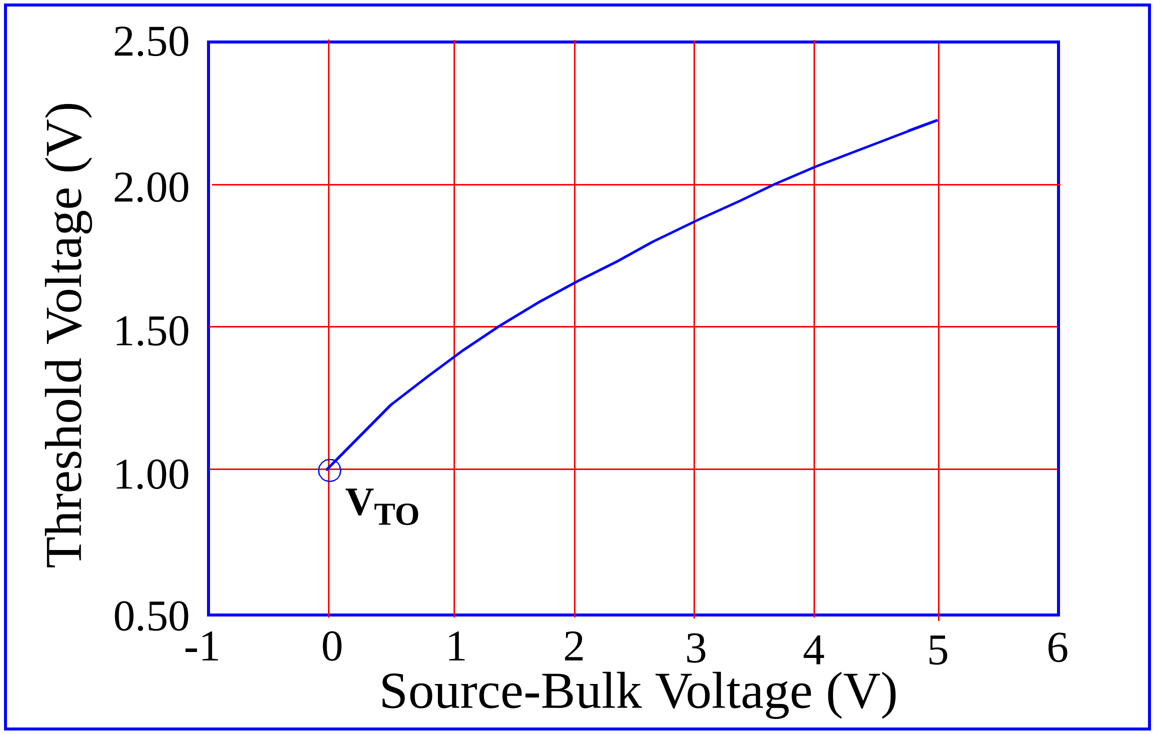
Saturation region

$v_{DS} \geq v_{GS} - V_{TN} \geq 0$

$$i_{DS} = \frac{K_n'}{2} \frac{W}{L} (v_{GS} - V_{TN})^2 (1 + \lambda v_{DS})$$



Body-Effect or Substrate Sensitivity



Threshold Voltage is $V_{TN} = V_{T0} + \gamma\left(\sqrt{v_{SB} + 2\phi_F} - \sqrt{2\phi_F}\right)$

V_{T0} = zero substrate bias value of V_{TN}

γ = body effect parameter $(V^{0.5})$

$2\phi_F$ = surface potential parameter

Enhancement mode NMOSFETs $V_{TN} > 0$

Depletion mode NMOSFETs $V_{TN} \leq 0$

Example: Given an NMOS transistor with $V_{T0} = 1V$, $\phi_F = 0.3V$, $\gamma = 0.7\sqrt{V}$, find V_{TN} for v_{SB} = 0, 1, 2, 3, 4 and 5 V respectively. (Ans. = 1, 1.34, 1.59, 1.79, 1.96 and 2.11 V respectively.)

Use $V_{TN} = V_{T0} + \gamma(\sqrt{v_{SB} + 2\phi_F} - \sqrt{2\phi_F})$:

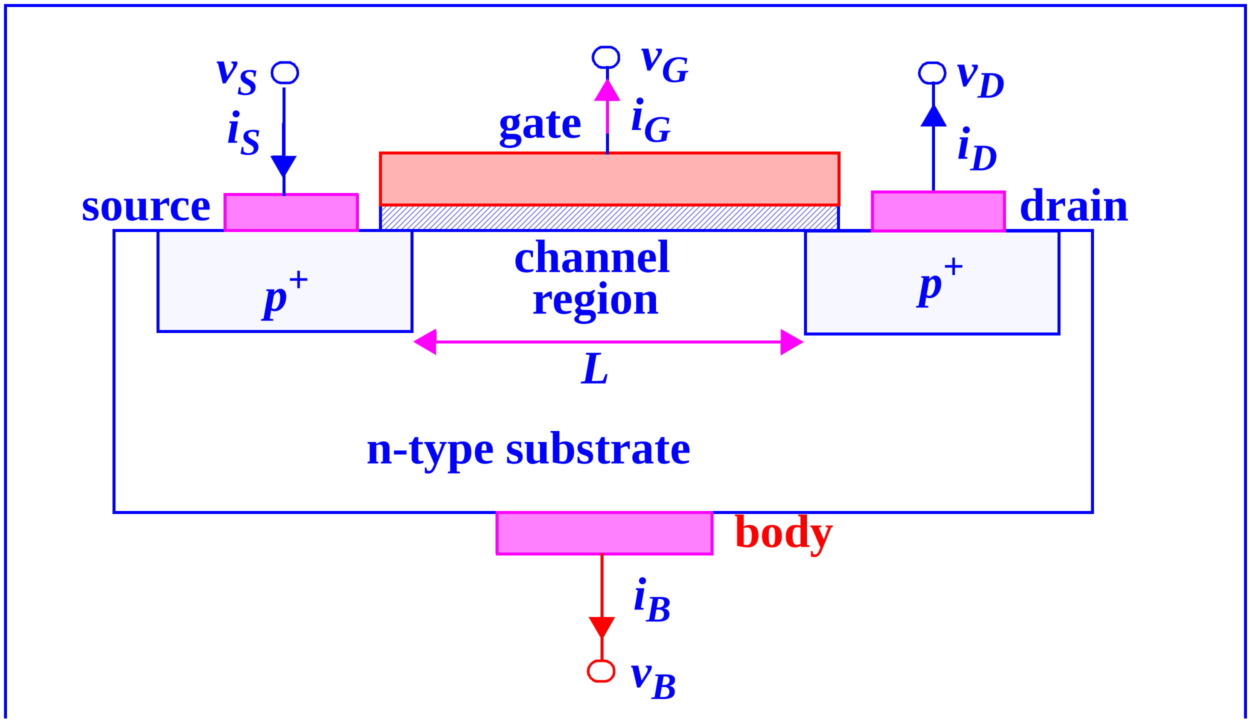
for v_{SB} = 1 V,

$$V_{TN} = V_{T0} + \gamma(\sqrt{v_{SB} + 2\phi_F} - \sqrt{2\phi_F}) = 1 + 0.7(\sqrt{1 + 2 \times 0.3} - \sqrt{2 \times 0.3}) = 1.34V$$

for v_{SB} = 4 V,

$$V_{TN} = V_{T0} + \gamma(\sqrt{v_{SB} + 2\phi_F} - \sqrt{2\phi_F}) = 1 + 0.7(\sqrt{4 + 2 \times 0.3} - \sqrt{2 \times 0.3}) = 1.96V$$

PMOS FET



To Obtain an inversion layer throughout the channel we must have

$${}_G - v_c \le V_{Tp} \Rightarrow -v_G \ge -v_c - V_{Tp} \Rightarrow v_S - v_G \ge v_S - v_c - V_{Tp}$$

$$v_{SG} + V_{TP} \ge v_{SD}$$

Summary of PMOS FET Mathematical Model Expressions

$K_p = \mu_p C_{ox} \frac{W}{L}$, $i_G = 0$, $i_B = 0$

Cut-off Region - $i_{SD} = 0$ **for** $v_{SG} \leq -V_{TP}$ **or** $v_{GS} \geq V_{TP}$

Linear region - $v_{SG} + V_{TP} \geq v_{SD} \geq 0$

$$i_{SD} = K_p\left(v_{SG} + V_{TP} - \frac{v_{SD}}{2}\right)v_{SD}$$

Saturation region - $v_{SD} \geq v_{SG} + V_{TP} \geq 0$

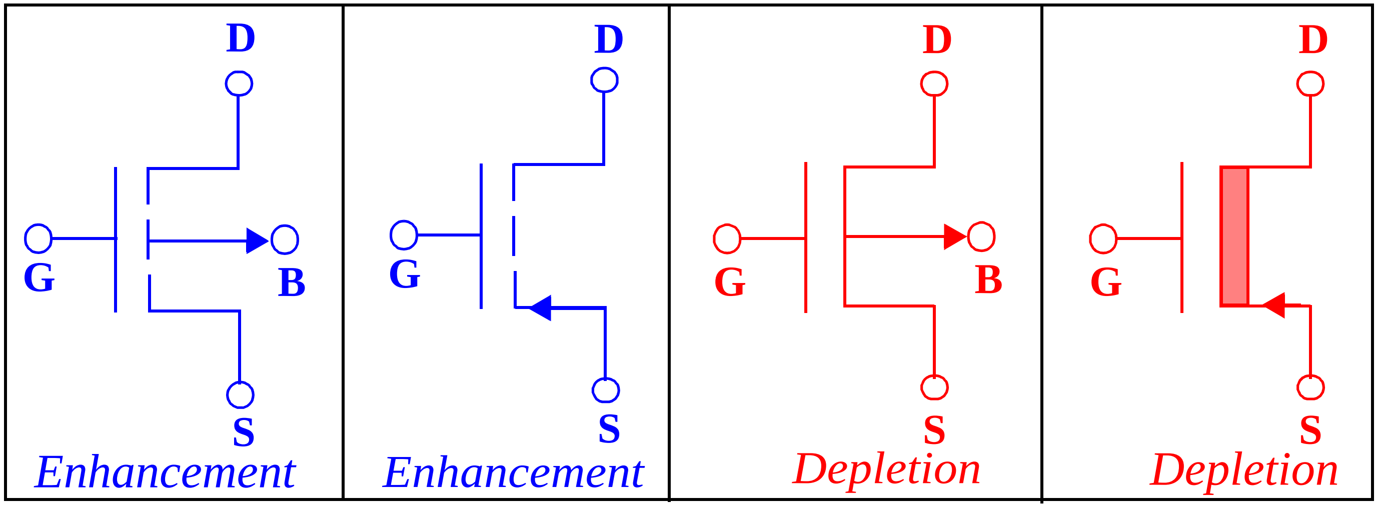
$$i_{SD} = \frac{K_p}{2}(v_{SG} + V_{TP})^2(1 + \lambda v_{SD})$$

Threshold Voltage is $V_{TP} = V_{T0} - \gamma(\sqrt{v_{BS} + 2\phi_F} - \sqrt{2\phi_F})$

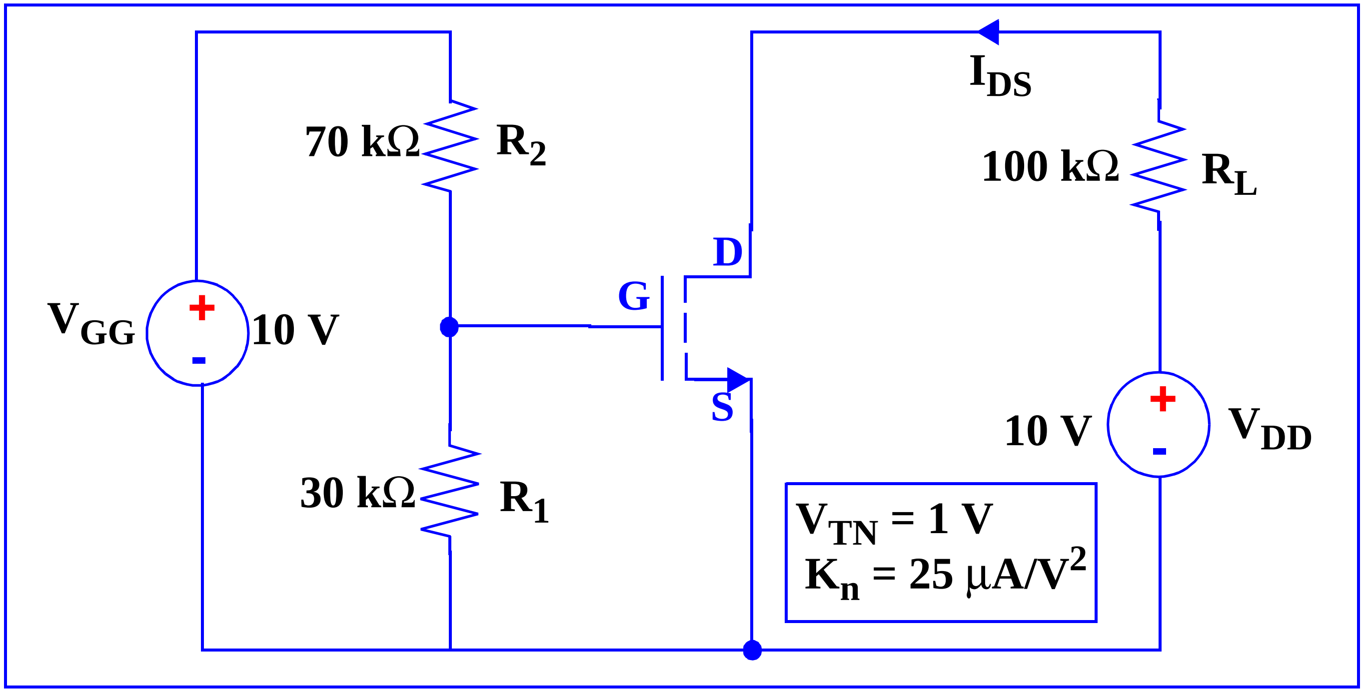
Enhancement mode PMOSFETs $V_{TP} < 0$

Depletion mode PMOSFETs $V_{TP} \geq 0$

Symbols of the p-channel MOS Transistor or PMOSFET



Biasing the MOSFET



$$V_G = \frac{30k\Omega}{30k\Omega + 70k\Omega}10V = 3V \text{ and } V_S = 0V. \therefore V_{GS} = 3V$$

Assume MOSFET is in saturation mode, so the drain current is

$$I_{DS} = \frac{K_n}{2}(V_{GS} - V_{TN})^2 = \frac{25}{2}(3-1)^2 = 50\mu A.$$

$$V_{DS} = V_{DD} - I_{DS}R_L = 10V - 50\mu A \cdot 100k\Omega = 5V.$$

But $V_{GS} - V_{TN} = 3V - 1V = 2V \Rightarrow V_{DS} > V_{GS} - V_{TN}$.

Therefore, our assumption of the operating mode of the MOS transistor is correct.

The Q-Point of the MOSFET is $I_{DS}, V_{DS}, V_{GS} = 50\mu A, 5V, 3V$.

For load-line - $V_{DD} = I_{DS}R_L + V_{DS}$ or $10 = 10^5 I_{DS} + V_{DS}$