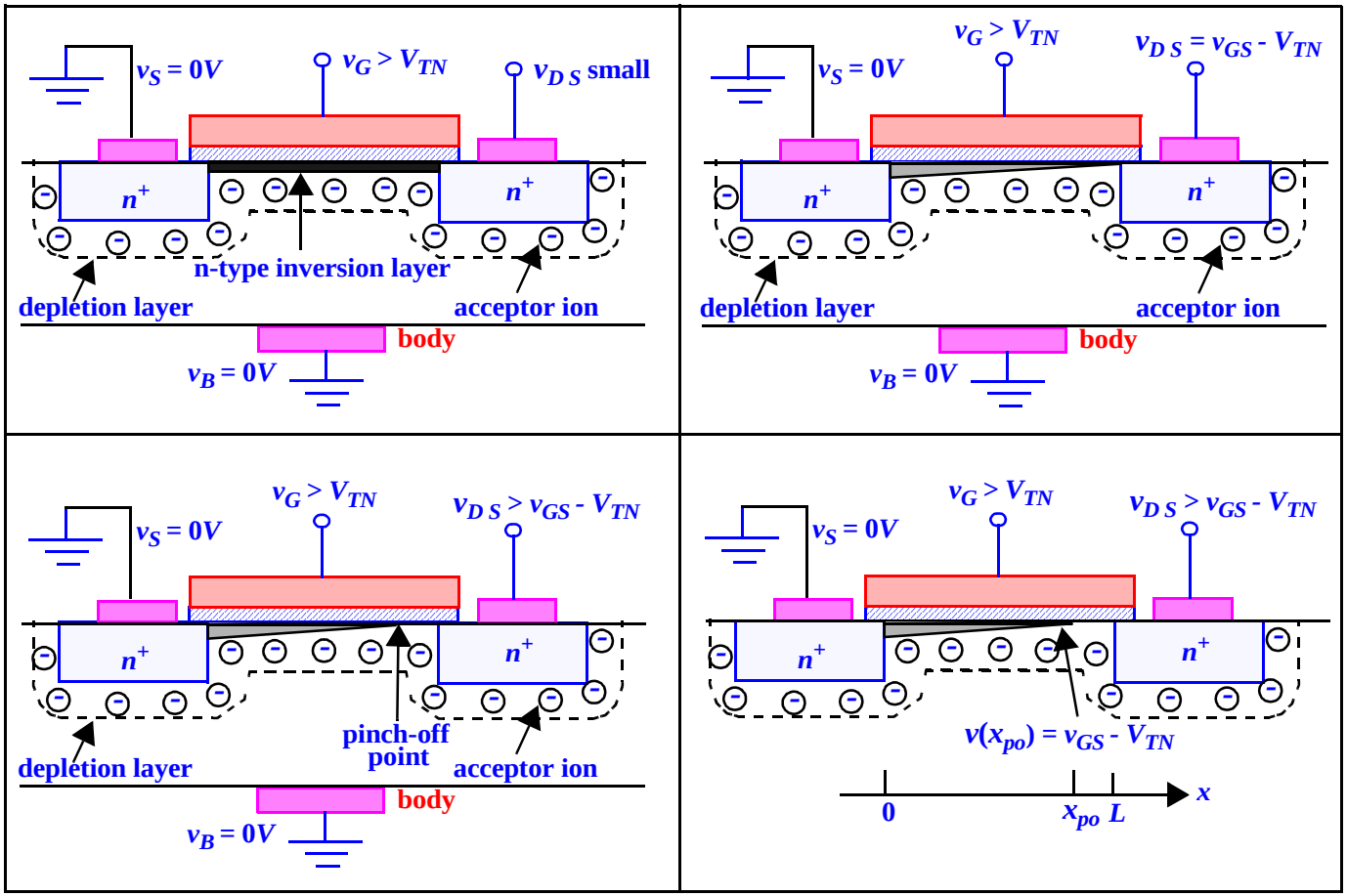
Saturation of the I-V Characteristics

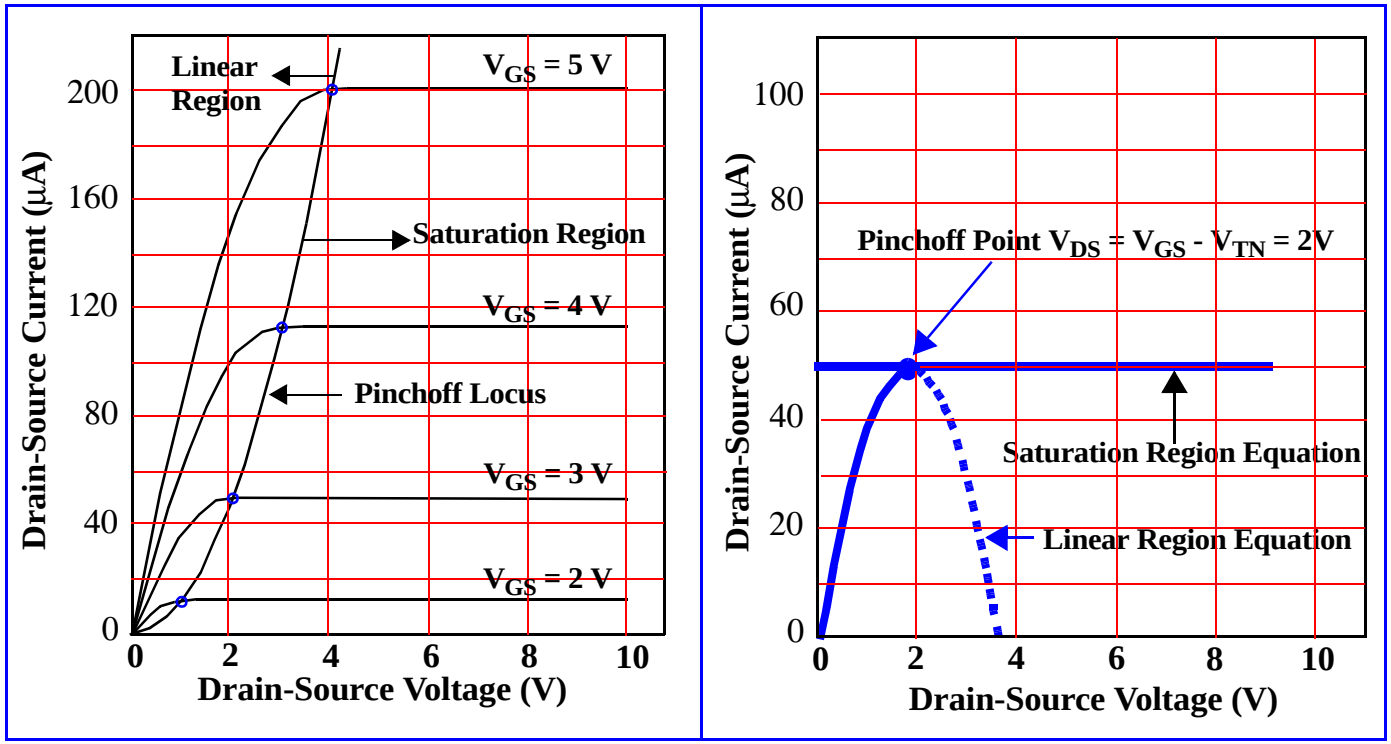


At pinch-off, the voltage is $v_{GS} - v(x_{po}) = V_{TN}$

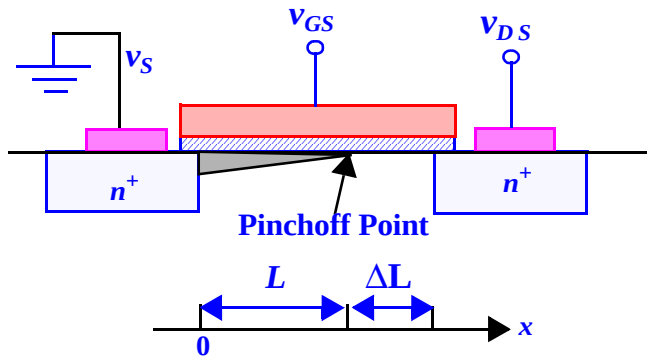
Current is $i_{DS} = \frac{K_n' W}{2 L}(v_{GS} - V_{TN})^2$ for $v_{DS} \geq v_{GS} - V_{TN} \geq 0$

The saturation drain voltage is $v_{DSAT} = v_{GS} - V_{TN}$

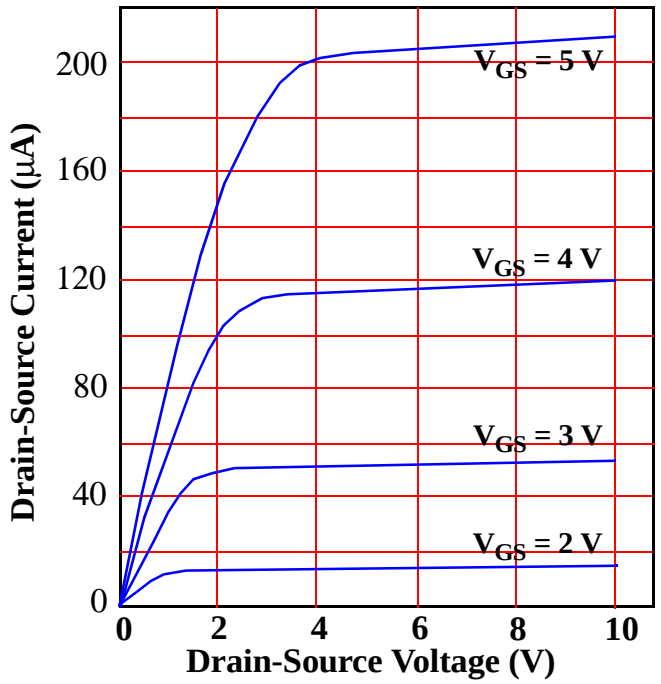
Current is $i_{DS} = \left[WC_{ox}\left(\frac{v_{GS} - V_{TN}}{2}\right)\right] \bullet \left[\mu_n\left(\frac{v_{GS} - V_{TN}}{L}\right)\right]$



Channel Length Modulation



Channel Length Modulation



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

and $$0.001\,\mathrm{V}^{-1} \le \lambda \le 0.1\,\mathrm{V}^{-1}$$

In saturation, the on-resistance R_{on} and transconductance g_m

$$R_{on} = \left[\frac{\partial i_{DS}}{\partial v_{DS}}\right]^{-1} = \frac{1}{\frac{K_n'}{2}\frac{W}{L}(v_{GS} - V_{TN})^2\lambda} \cong \frac{1}{\lambda i_{DS}} \text{ in } \Omega.$$

$$g_m = \left[\frac{\partial i_{DS}}{\partial v_{GS}}\right] = K_n'\frac{W}{L}(v_{GS} - V_{TN})(1 + \lambda v_{DS}) \text{ in S or A/V.}$$

Example: An enhancement NMOSFET has V_{TN} = 1.5V, $K_n'\frac{W}{L} = 0.2\frac{mA}{V^2}$ and $\lambda = 0.02V^{-1}$. It is operated at V_{GS} = 3.5V. If V_{DS} = 2 V, find I_{DS}, R_{on} and g_m.

Since $2 = 3.5 - 1.5 \Rightarrow v_{DS} \geq v_{GS} - V_{TN} \geq 0$, operates in saturation region.

$$\therefore I_{DS} = \frac{K_n'}{2}\frac{W}{L}(v_{GS} - V_{TN})^2(1 + \lambda v_{DS}) = \frac{0.2m}{2}(3.5 - 1.5)^2(1 + 0.02 \times 2) = 0.416mA$$

$$R_{on} = \frac{1}{\frac{K_n'}{2}\frac{W}{L}(v_{GS} - V_{TN})^2\lambda} = \frac{1}{\frac{0.2m}{2}(3.5 - 1.5)^2(0.02)} = 125k\Omega$$

$$g_m = K_n'\frac{W}{L}(v_{GS} - V_{TN})(1 + \lambda v_{DS}) = 0.2m(3.5 - 1.5)(1 + 0.02 \times 2) = 0.416mS$$

Summary of NMOS FET Mathematical Model Expressions

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

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

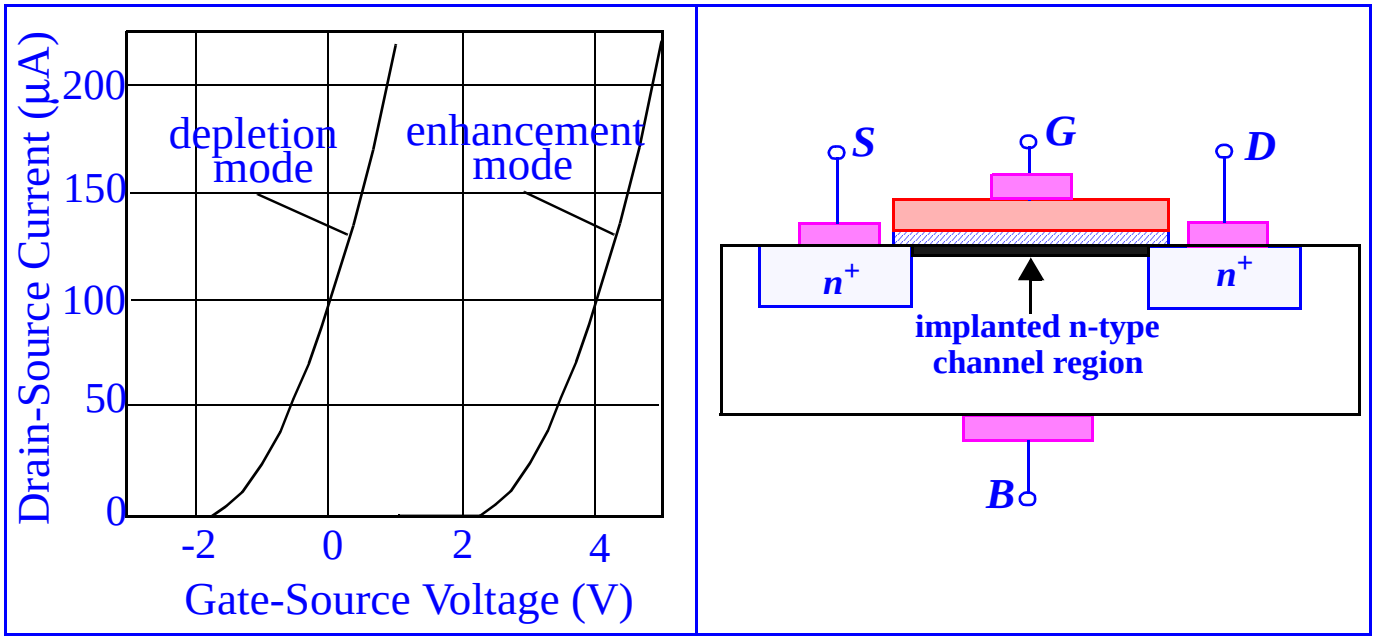
Linear region - $v_{GS} - V_{TN} \geq v_{DS} \geq 0$

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

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

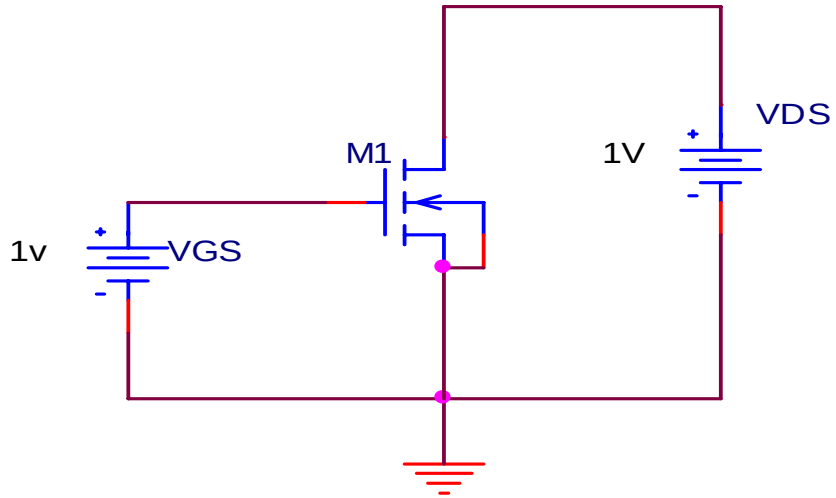
$$i_{DS} = \frac{K_n'}{2}\frac{W}{L}(v_{GS} - V_{TN})^2(1 + \lambda v_{DS})$$

Depletion Mode MOSFET



In depletion mode MOSFETs, a channel is present for $V_{GS} = 0$ V. In n-channel depletion mode devices, V_{TN} is negative.

PSPICE EXAMPLE




```
*Libraries:
* Local Libraries :
.LIB ".\example6.lib"
* From [PSPICE NETLIST] section of C:\Program Files\OrcadLite\PSpice\PSpice.ini file:
.lib "nom.lib"
*Analysis directives:
.DC LIN V_VDS 0 5 0.1
+ LIN V_VGS 0 5 1
.PROBE V(*) I(*) W(*) D(*) NOISE(*)
.INC ".\example6-SCHEMATIC1.net"
**** INCLUDING example6-SCHEMATIC1.net ****
* source EXAMPLE6
```

PSPICE EXAMPLE (Cont'd)

```
M_M1         N00072 N00091 0 0 Mbreakn
V_VGS         N00091 0 1v
V_VDS         N00072 0 1V

**** RESUMING example6-SCHEMATIC1-Example6Profile.sim.cir ****
.END
****     MOSFET MODEL PARAMETERS
**********************************************************************************
 Mbreakn
 NMOS
 LEVEL    1
 L  100.000000E-06
 W  100.000000E-06
 VTO    1
 KP   50.000000E-06
 GAMMA    0
 PHI     .6
 LAMBDA    0
 IS   10.000000E-15
 JS    0
 PB     .8
```

PSPICE EXAMPLE (Cont'd)

```
PBSW    .8
CJ   0
CJSW   0
CGSO   0
CGDO   0
CGBO   0
TOX   0
XJ   0
UCRIT   10.000000E+03
DIOMOD   1
VFB   0
LETA   0
WETA   0
U0   0
TEMP   0
VDD   0
XPART   0
```