Lecture 23
EE 2303/001-Electronics I
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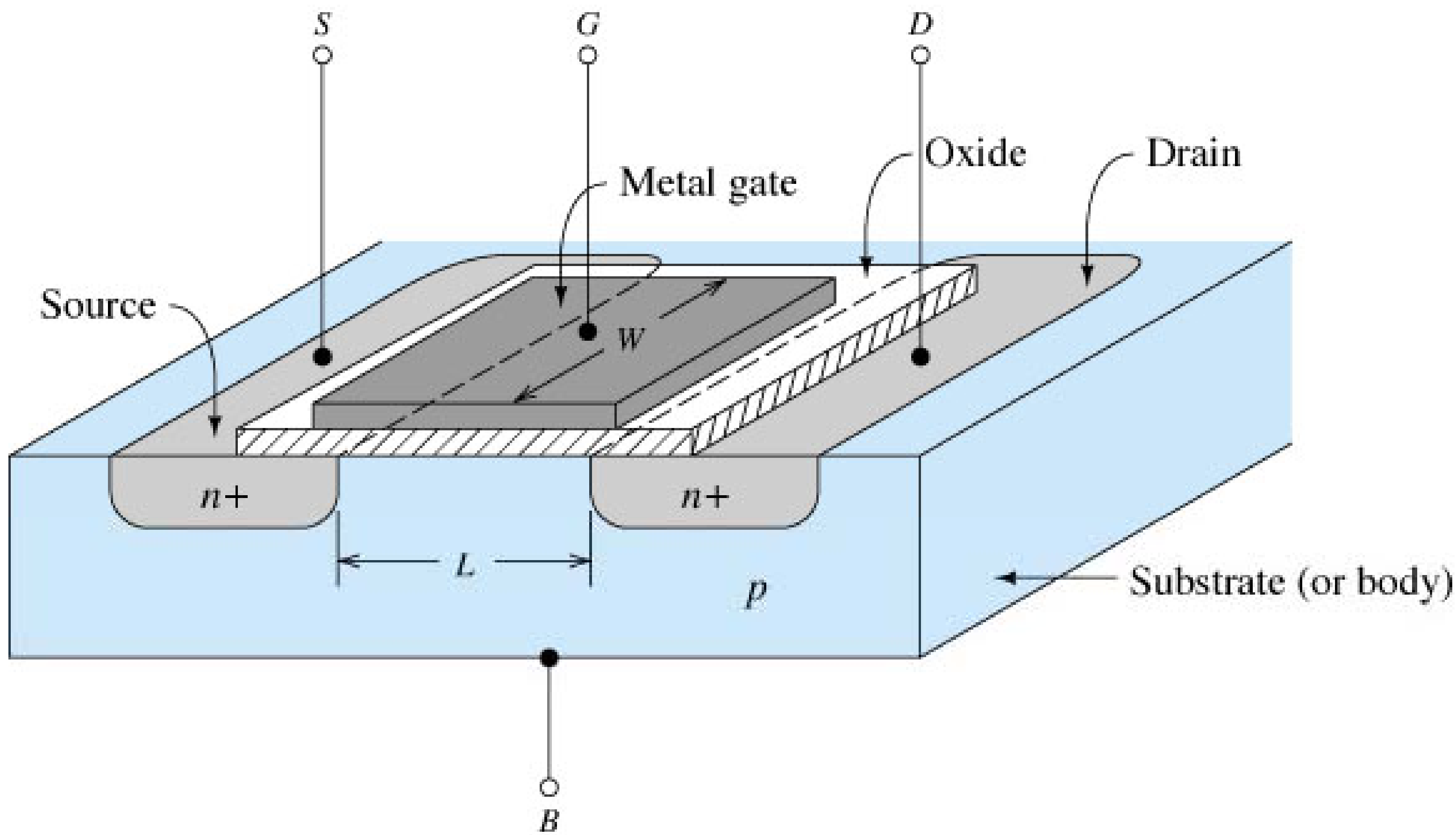
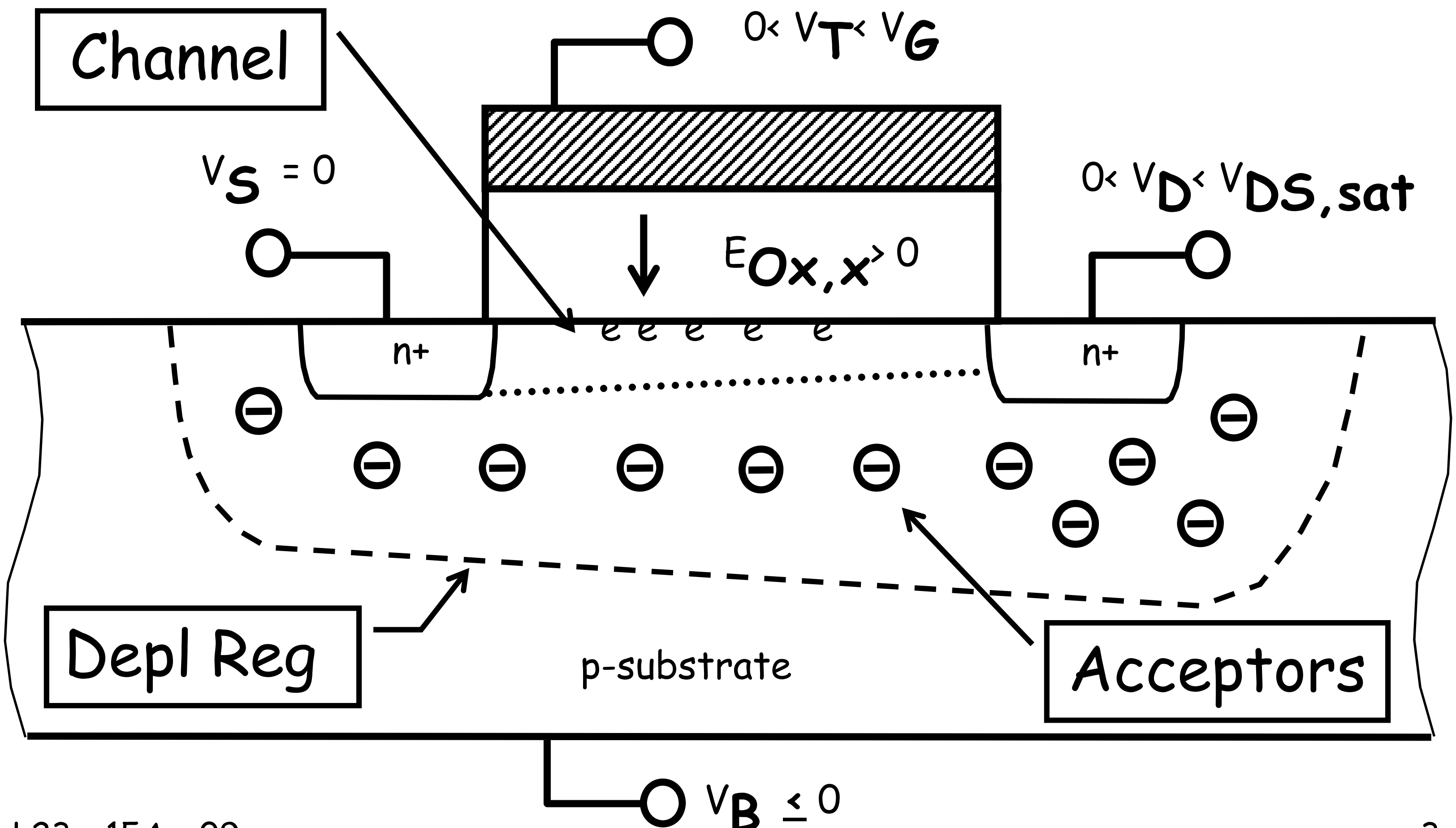


Figure 5.1 *n*-Channel enhancement MOSFET showing channel length *L* and channel width *W*.

n-channel enhancement MOSFET in ohmic region



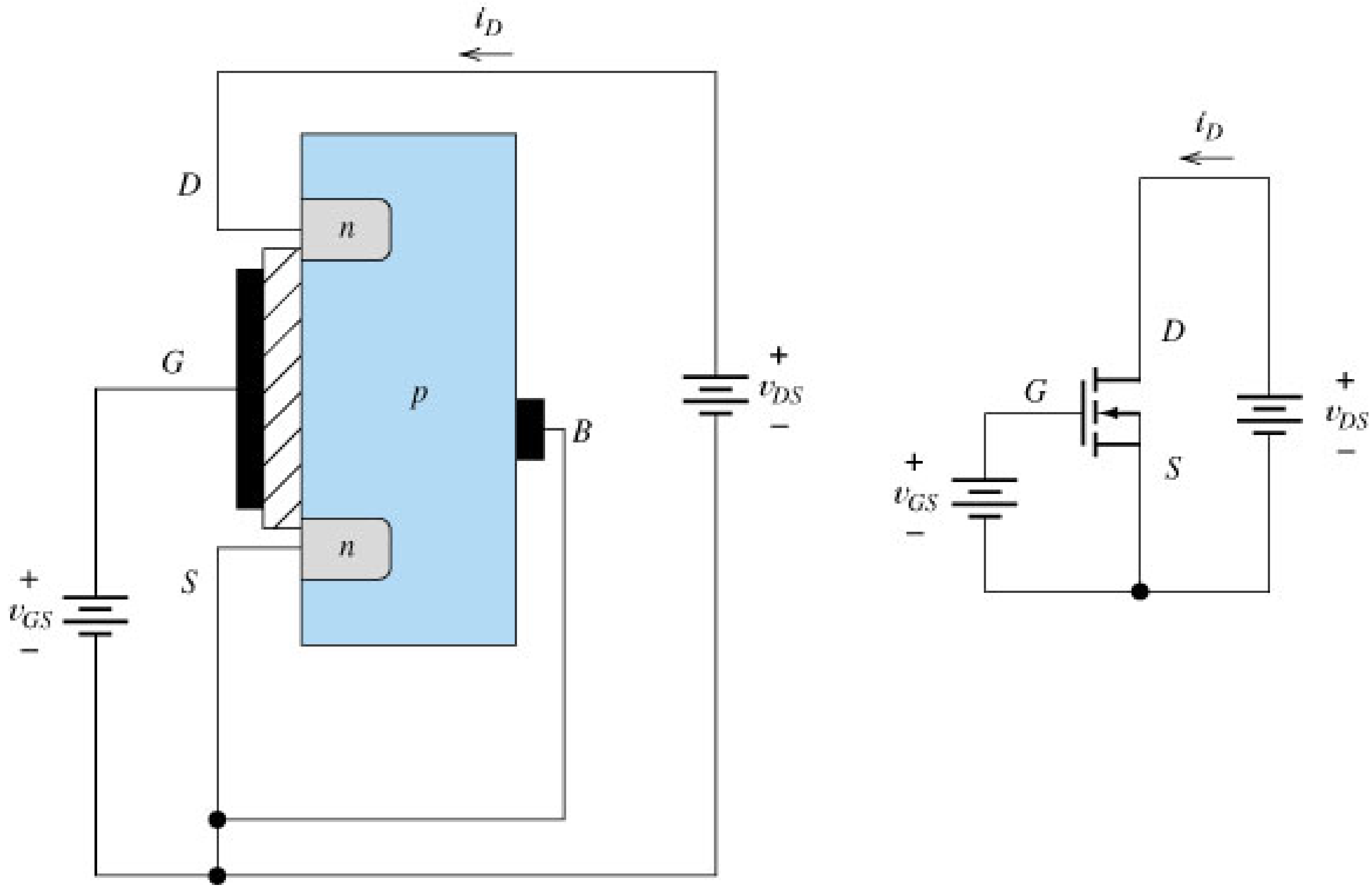


Figure 5.3 For $v_{GS} < V_{to}$ the *pn* junction between drain and body is reverse biased and i_D=0.

Conductance of inverted channel

- $Q'_n = - C'_{Ox}(V_{GC}-V_T)$
- $n'_s = C'_{Ox}(V_{GC}-V_T)/q$, (# inv elect/cm^2)
- The conductivity $\sigma_n = (n'_s/t)\, q\, \mu_n$
- $G = \sigma_n(Wt/L) = n'_s\, q\, \mu_n\, (W/L) = 1/R$, so
- $I = V/R = dV/dR$, $dR = dL/(n'_s q \mu_n W)$

$$I\int_0^L dL = \int_{V_S}^{V_D} C'_{Ox}\left(\left(V_G - V_C\right) - V_T\right)\mu_n W dV$$

Basic I-V relation for MOS channel

$$I_D = \frac{W\mu_n C_{Ox}}{2L}\left(2(V_G - V_T)V_{DS} - V_{DS}^2\right),\; V_{DS} < V_G - V_T$$

At $V_{DS} = V_{DS,sat} = V_G - V_T,\; Q'_n(y = L) = 0 \Rightarrow$ Sat.

so let I_D be given by $I_D(V_{DS,sat})$,

for $V_{DS} > V_{DS,sat} = V_G - V_T$ so

$$I_D = I_{D,sat} = \frac{W\mu_n C_{Ox}}{2L}(V_G - V_T)^2$$

$$KP = \mu_n C'_{Ox}$$

$$K = \mu_n C'_{Ox}\frac{W}{L} = KP\frac{W}{L}$$

I-V relation for n-MOS (ohmic reg)

$I_D = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\left(2(V_G - V_T)V_{DS} - V_{DS}^2\right)$. Note for

$V_{DS} \geq V_G - V_T = V_{DS,sat}$,

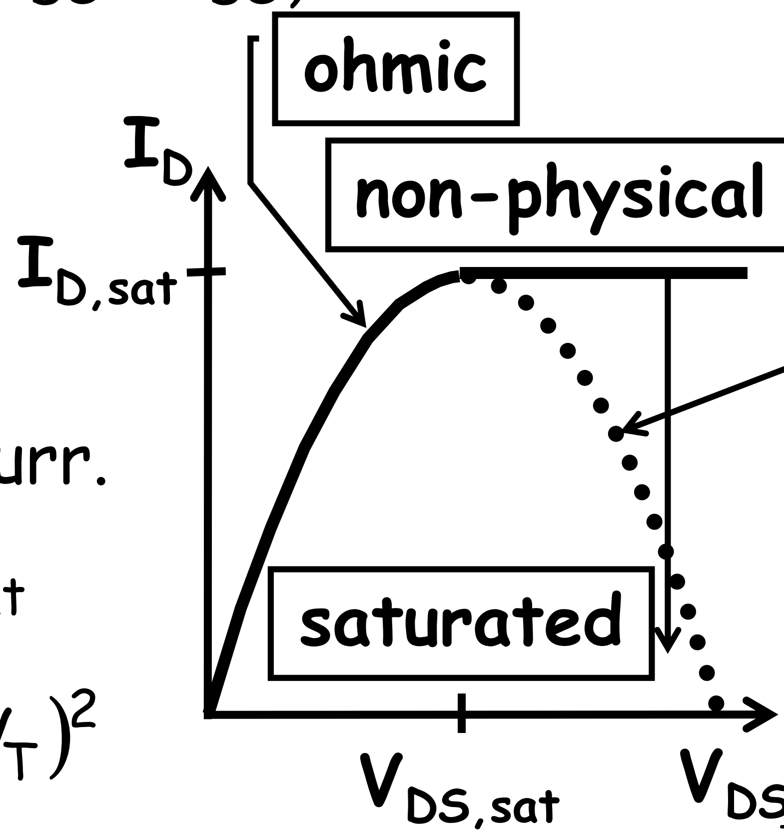
result is non-physical.

At $V_{DS,sat}$, $n'_{s,y=L} = 0$

assume that channel curr.

is const for $V_{DS} \geq V_{DS,sat}$

$I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2$



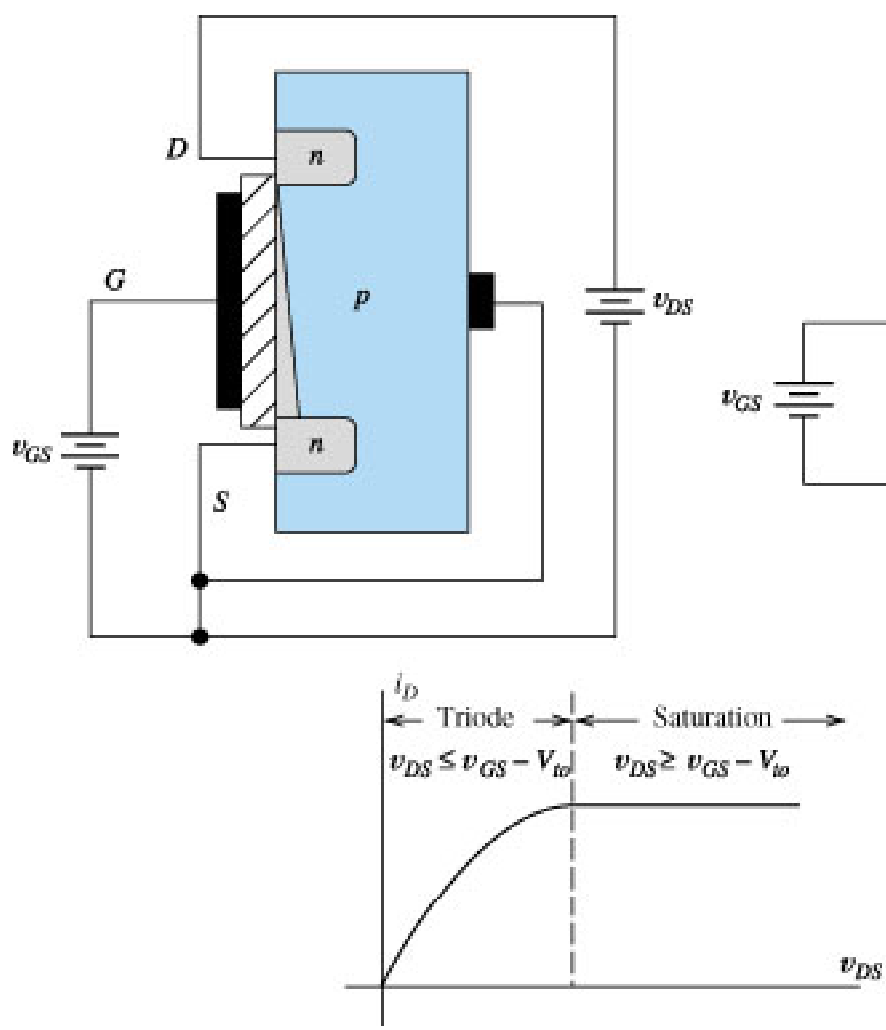


Figure 5.5 As v_{DS} increases, the channel pinches down at the drain end and i_D increases more slowly. Finally for $v_{DS} > v_{GS} - V_{to}$, i_D becomes constant.

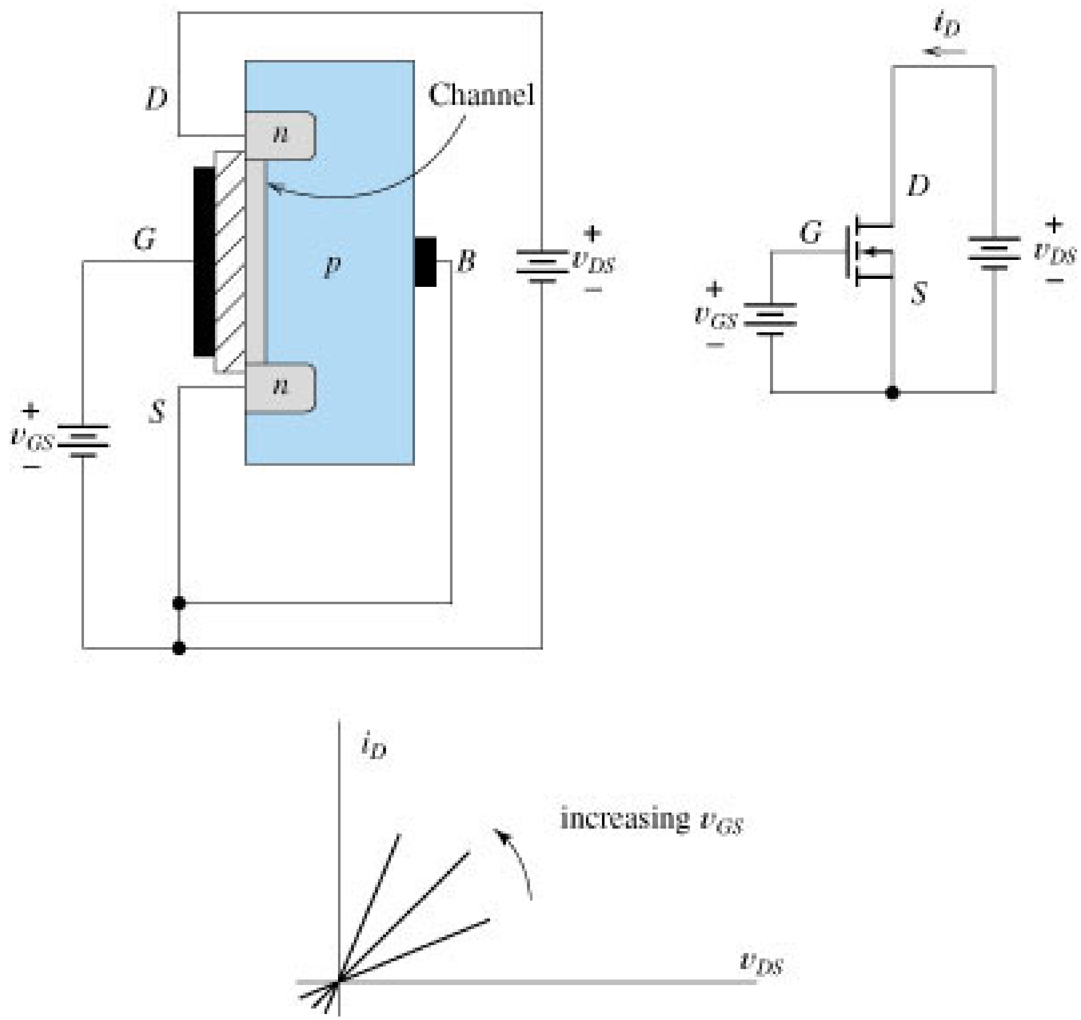
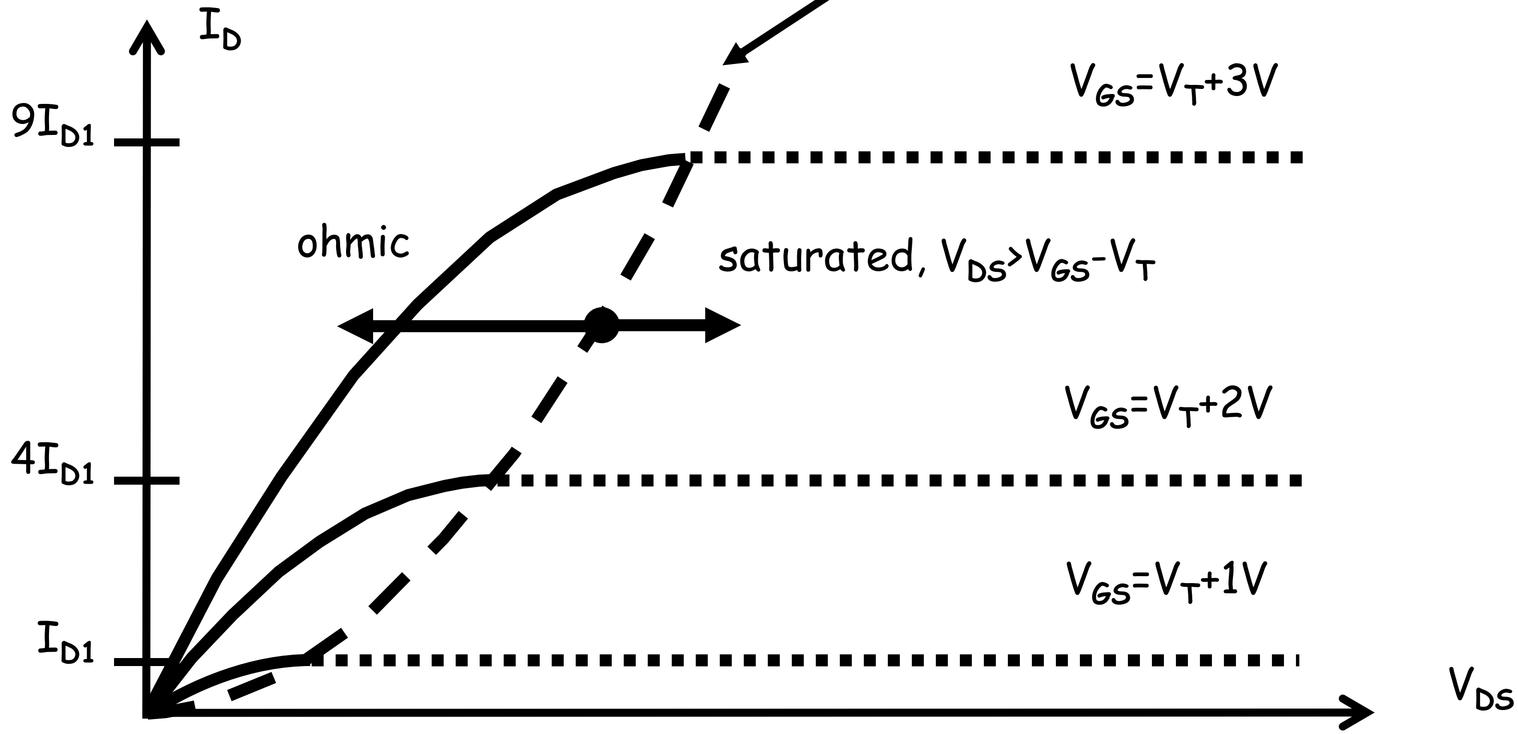


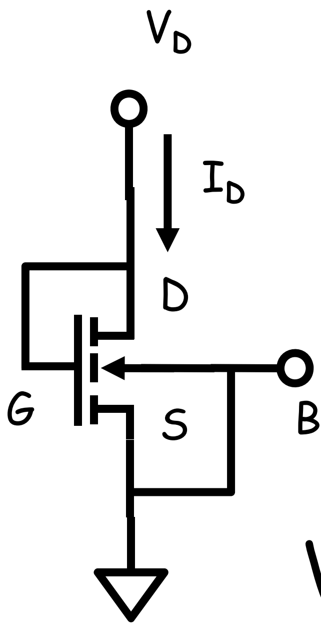
Figure 5.4 For $v_{GS} > V_{to}$ a channel of *n*-type material is induced in the region under the gate. As v_{GS} increases, the channel becomes thicker. For small values of v_{DS}, i_D is proportional to v_{DS}. The device behaves as a resistor whose value depends on v_{GS}.

Universal drain characteristic

$$I_{D1} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\times(1V)^2 \qquad I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}V_{DS}^2$$



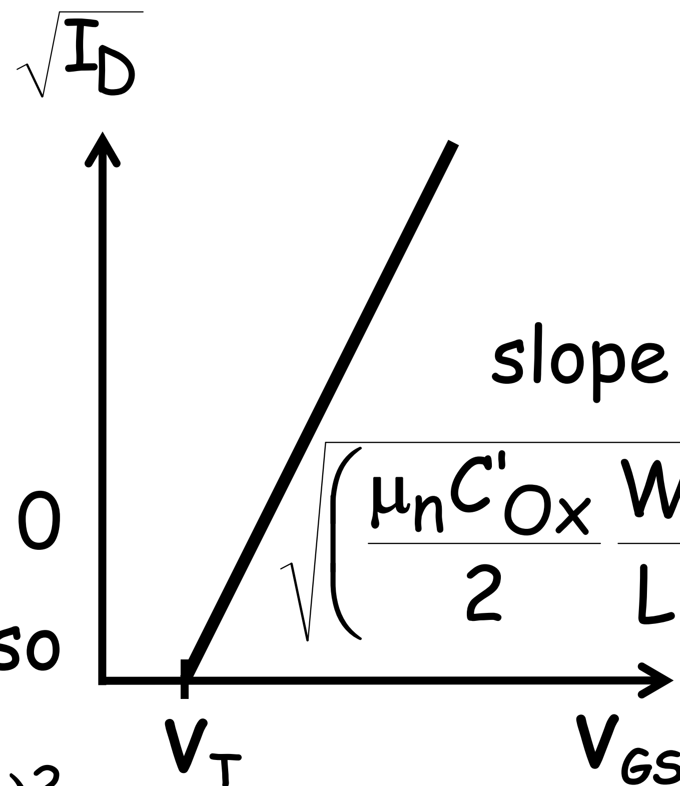
Characterizing the n-ch MOSFET



$$V_{DS} = V_{GS}\ ,\ V_T \geq 0$$

$$V_{DS} \geq V_{GS} - V_T\ ,\ \text{so}$$

$$I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2$$



slope = $\sqrt{\left(\frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\right)}$

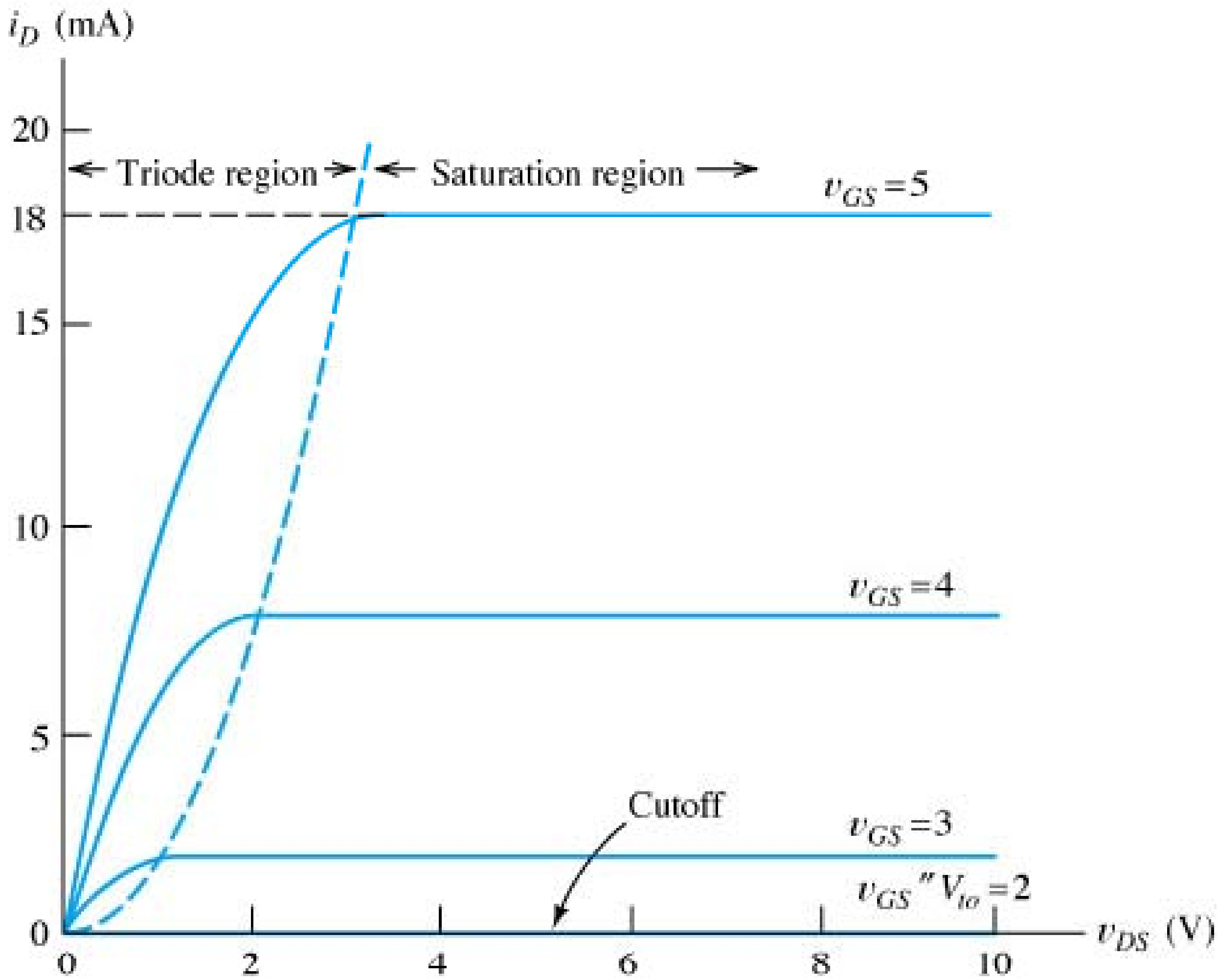


 Figure 5.6 Characteristic curves for an NMOS transistor.

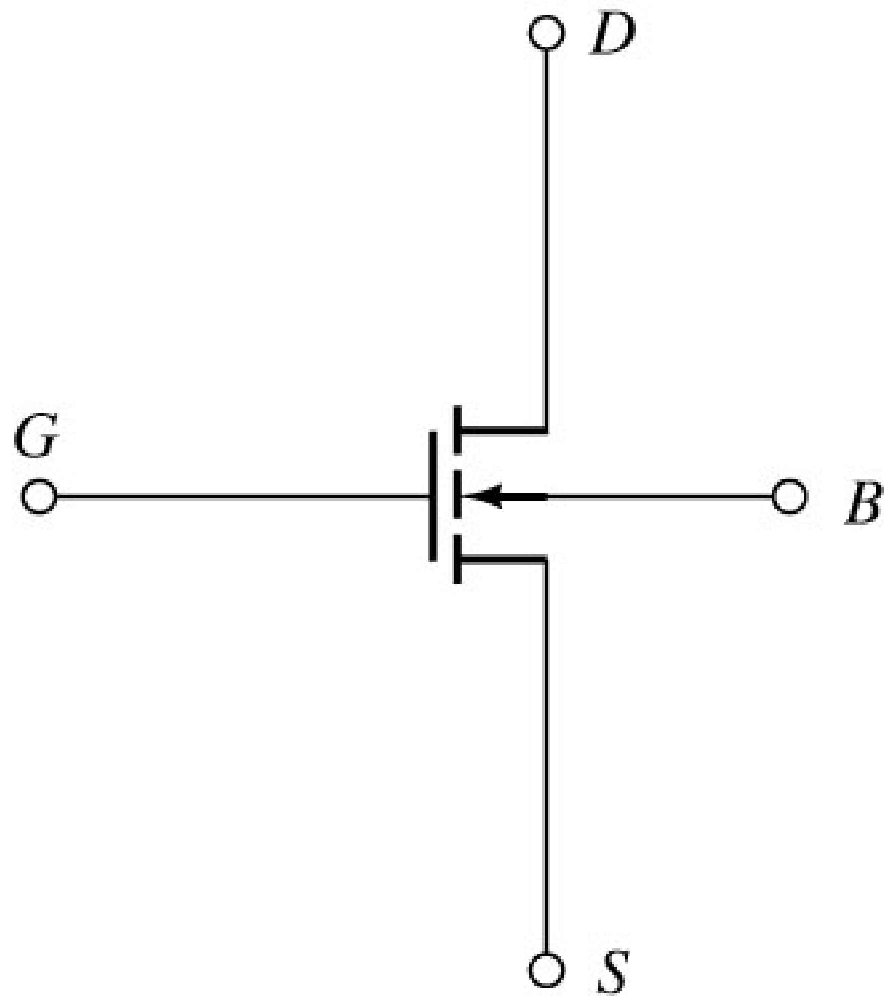


Figure 5.2 Circuit symbol for an enhancement-mode *n*-channel MOSFET.

Low field ohmic characteristics

$$I_D = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\left(2\left(V_{GS} - V_T\right)V_{DS} - V_{DS}^2\right),$$

for ohmic region. Furthermore, let

$V_{DS} << V_G - V_T$, so that

$$I_D \approx \mu_n C'_{Ox}\frac{W}{L}\left(V_{GS} - V_T\right)V_{DS}$$

$$= KP\frac{W}{L}\left(V_{GS} - V_T\right)V_{DS},\ KP = \mu_n C'_{Ox},\ KP\frac{W}{L} = K$$

$$\left[\frac{dI_D}{dV_{GS}}\right]_{V_{DS} << V_G - V_T} \approx KP\frac{W}{L}V_{DS}$$

MOSFET circuit parameters

Transconductance

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

$$g_{ms} = \frac{W\mu_n C'_{Ox}}{L} V_{DS} = KV_{DS}, \text{ saturation}$$

$$g_{mL} = \frac{W\mu_n C'_{Ox}}{L} \left(V_{GS} - V_T\right) = K\left(V_{GS} - V_T\right), \text{ ohmic region}$$

MOSFET circuit parameters (cont)

Output or drain conductance

$$g_d \equiv \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}}$$

$$g_{ds} = 0, \text{ saturation}$$

$$g_{dL} = \frac{W\mu_n C'_{Ox}}{L}\left(V_{GS} - V_T - V_{DS}\right), \text{ ohmic}$$

Substrate bias effect on V_T (body-effect)

Letting V_T calculation be relative to Source

$$V_T - V_S = V_{FB} - 2\left|\phi_p\right| - \frac{-qN_a x_{d,max}}{C'_{Ox}}, \text{ where}$$

$$x_{d,max} = \sqrt{\frac{2\varepsilon\left(2\left|\phi_p\right| + V_{SB}\right)}{qN_a}}, \text{ so } \Delta V_T = V_T\left(V_{SB}\right) -$$

$$V_T\left(V_{SB} = 0\right) = \frac{\sqrt{2\varepsilon_{Si} qN_a}}{C'_{Ox}}\left(\sqrt{2\left|\phi_p\right| + V_{SB}} - \sqrt{2\left|\phi_p\right|}\right)$$

Body effect data

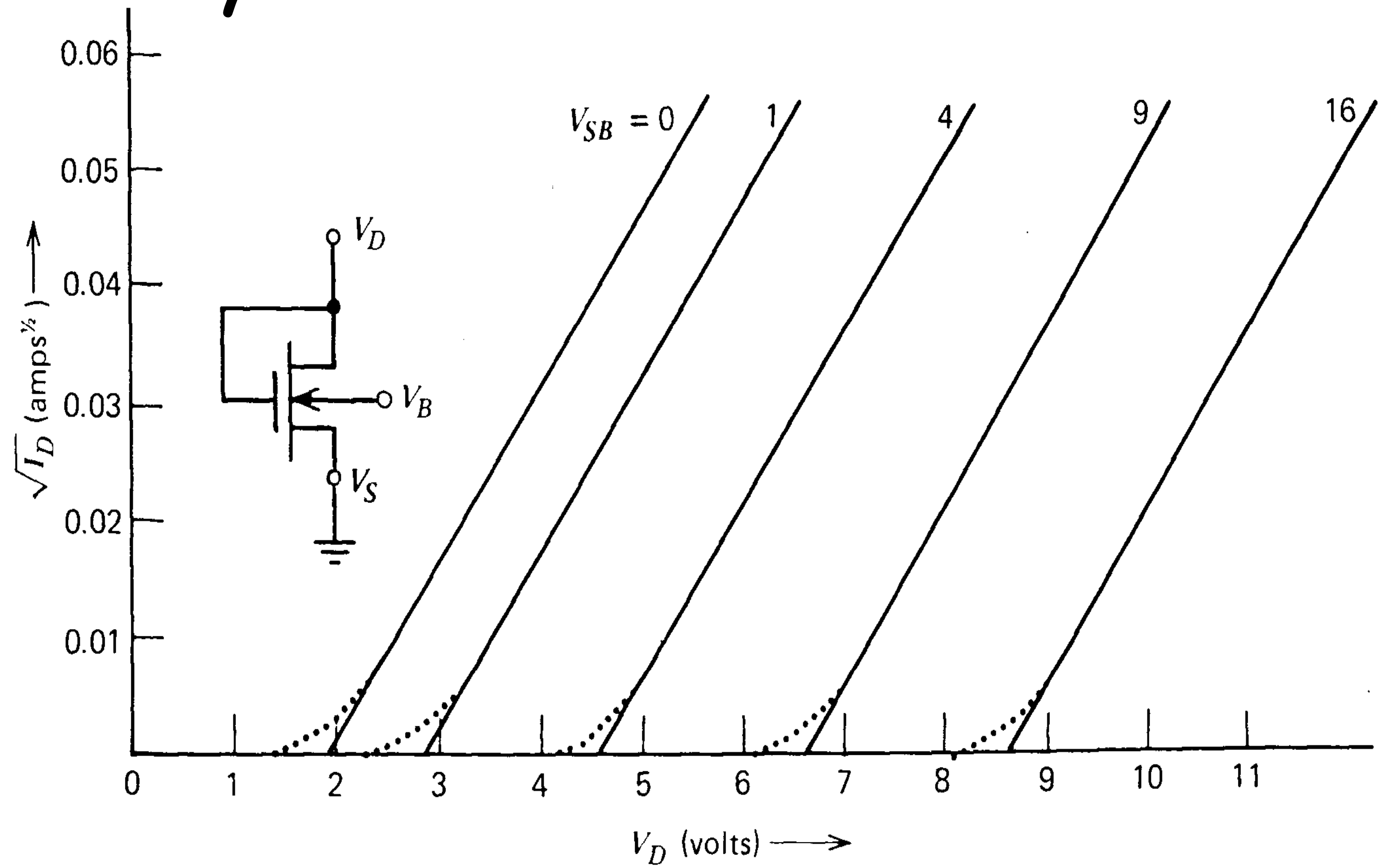


Fig 9.9, *Device Electronics for Integrated Circuits*, 2nd ed., by Richard S. Muller and Theodore I. Kamins, Wiley, NY, 1986

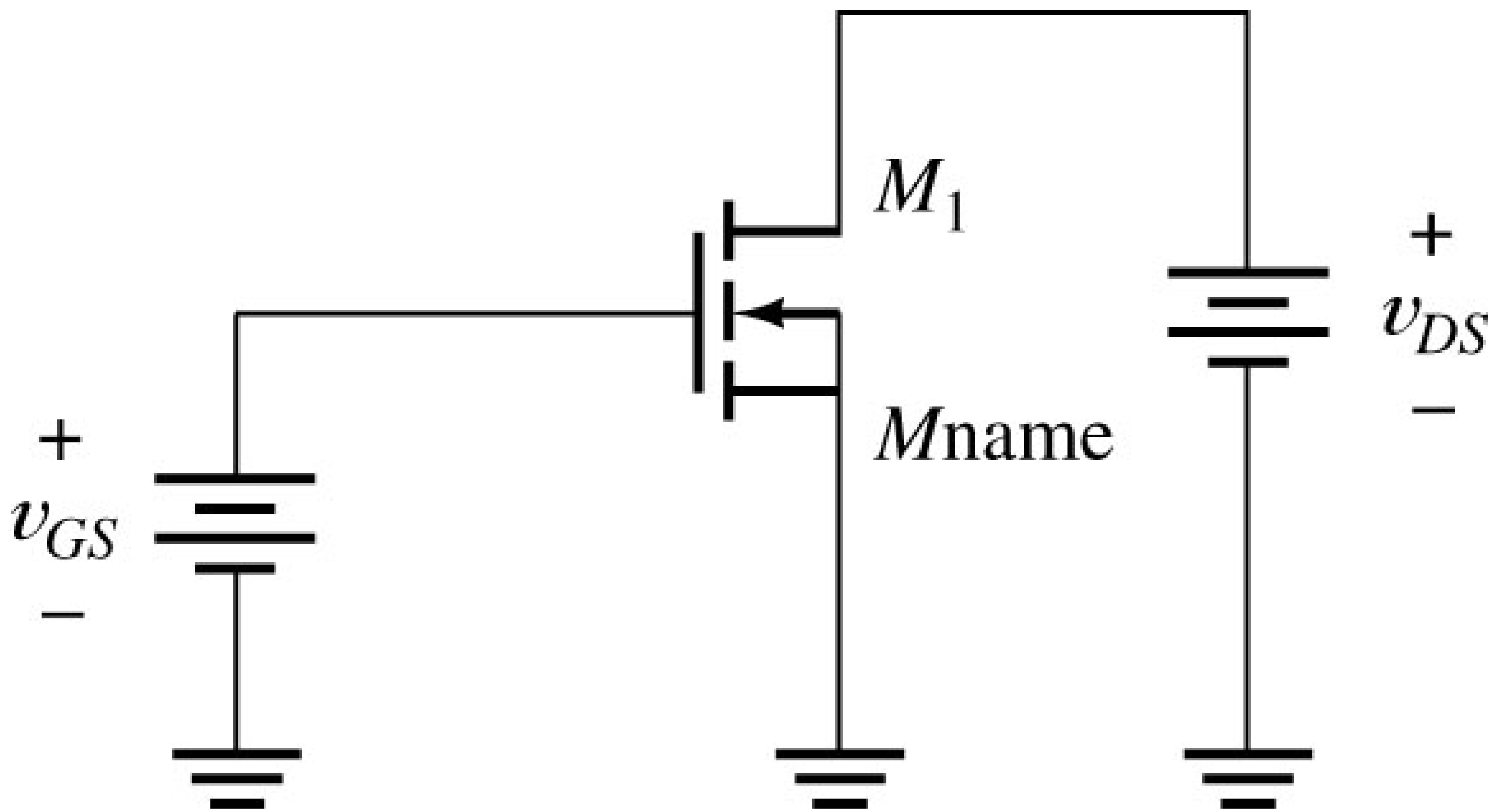


Figure 5.7 This circuit can be used to plot drain characteristics.

$$I_D = I_{D,Ohmic} = \frac{K}{2}\left(2\left(V_G - V_T\right)V_{DS} - V_{DS}^2\right),\ V_{DS} < V_G - V_T$$

$$I_{D,sat} = \frac{K}{2}V_{DS,sat}^2$$

$$I_D = I_{D,sat} = \frac{K}{2}\left(V_G - V_T\right)^2,\ V_{DS} > V_{DS,sat}$$

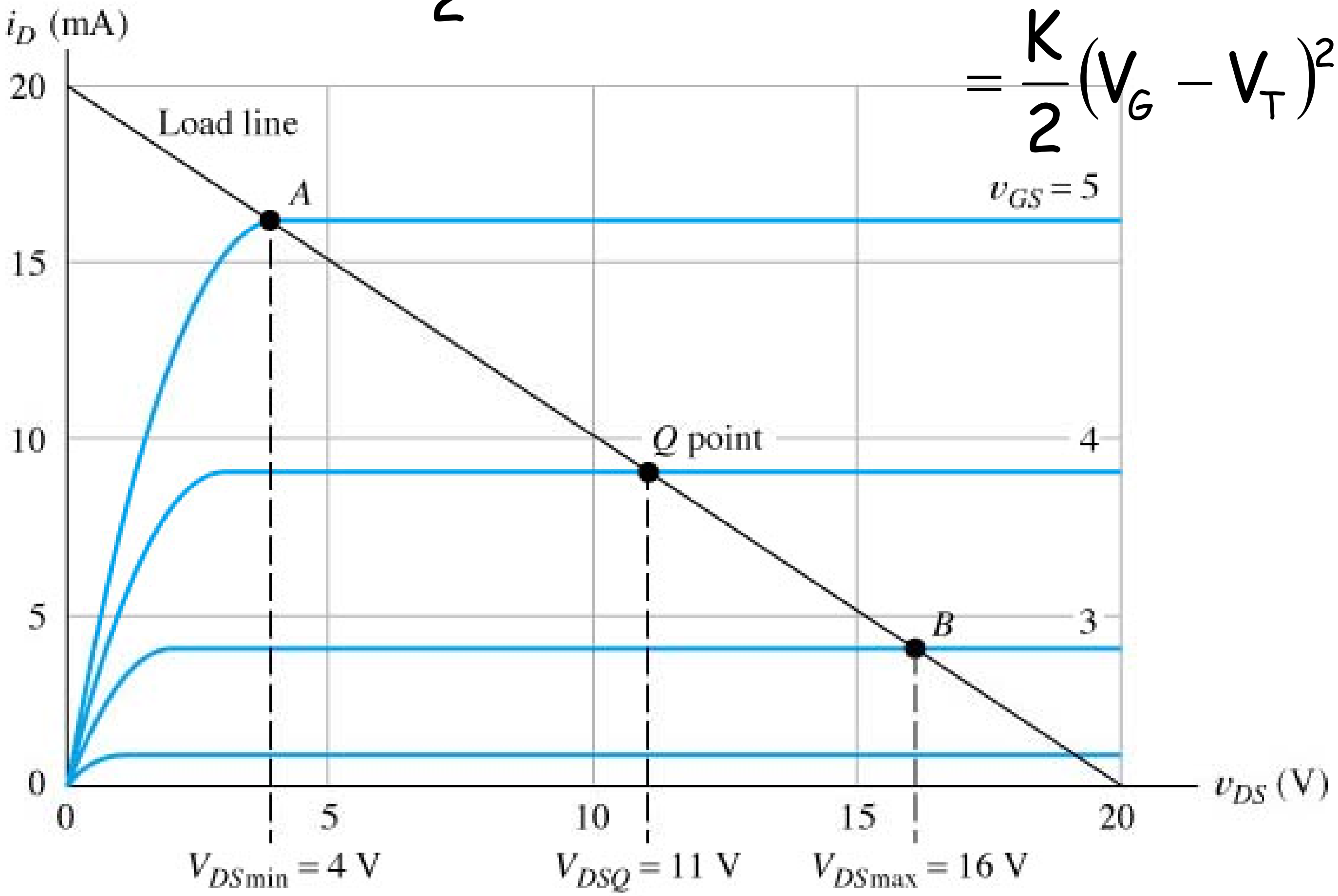


Figure 5.14 Drain characteristics and load line for the circuit of Figure 5.13.

References and Endnotes

- Where not otherwise noted, figures with a figure number (e.g., Fig 3.2) are taken from:
  - Electronics, 2nd edition, by Allan R. Hambley, Prentice Hall, Upper Saddle River, NJ, © 2000.