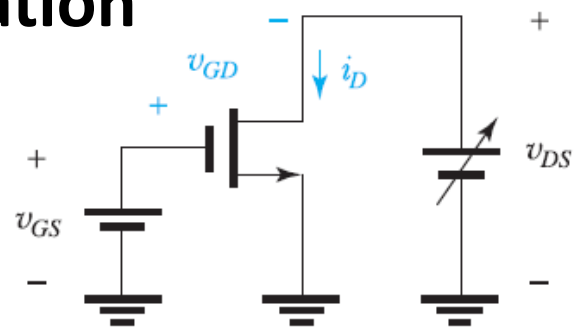
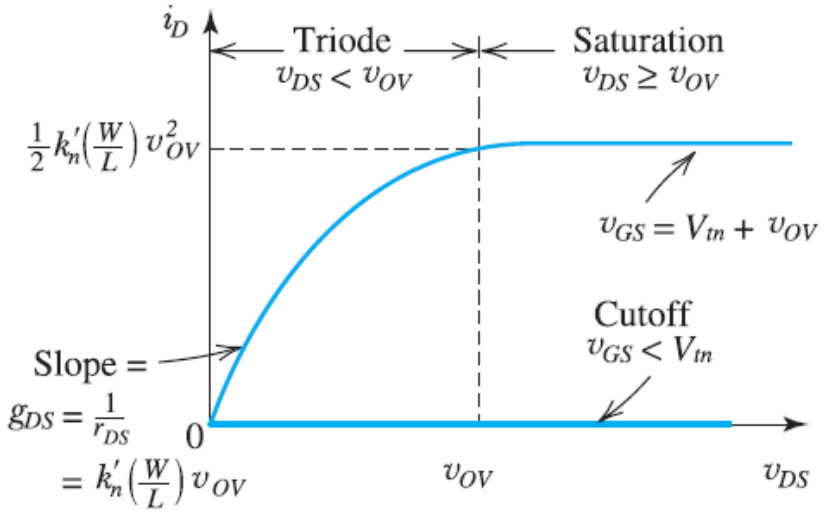
Modes of Operation





- $v_{GS} < V_{tn}$: no channel; transistor in cutoff; $i_D = 0$
- $v_{GS} = V_{tn} + v_{OV}$: a channel is induced; transistor operates in the triode region or the saturation region depending on whether the channel is continuous or pinched off at the drain end;

Triode Region

Continuous channel, obtained by:

$$v_{GD} > V_{tn}$$

or equivalently:

$$v_{DS} < v_{OV}$$

Then,

$$i_D = k_n'\left(\frac{W}{L}\right)\left[(v_{GS} - V_{tn})v_{DS} - \frac{1}{2}v_{DS}^2\right]$$

or equivalently,

$$i_D = k_n'\left(\frac{W}{L}\right)\left(v_{OV} - \frac{1}{2}v_{DS}\right)v_{DS}$$

Saturation Region

Pinched-off channel, obtained by:

$$v_{GD} \leq V_{tn}$$

or equivalently:

$$v_{DS} \geq v_{OV}$$

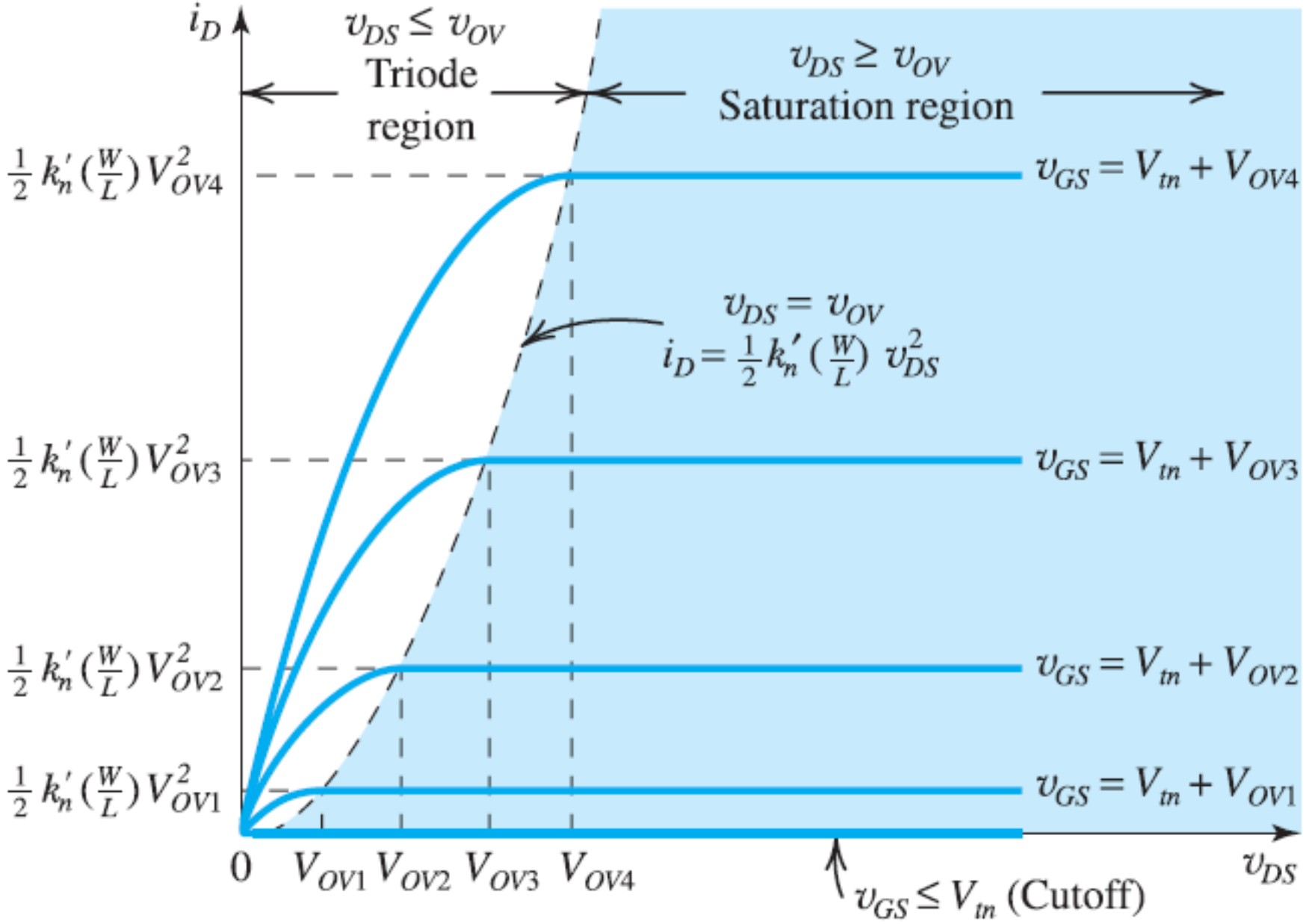
Then

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)(v_{GS} - V_{tn})^2$$

or equivalently,

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)v_{OV}^2$$

i_D vs v_{DS} curves



The $i_D - v_{GS}$ Characteristic

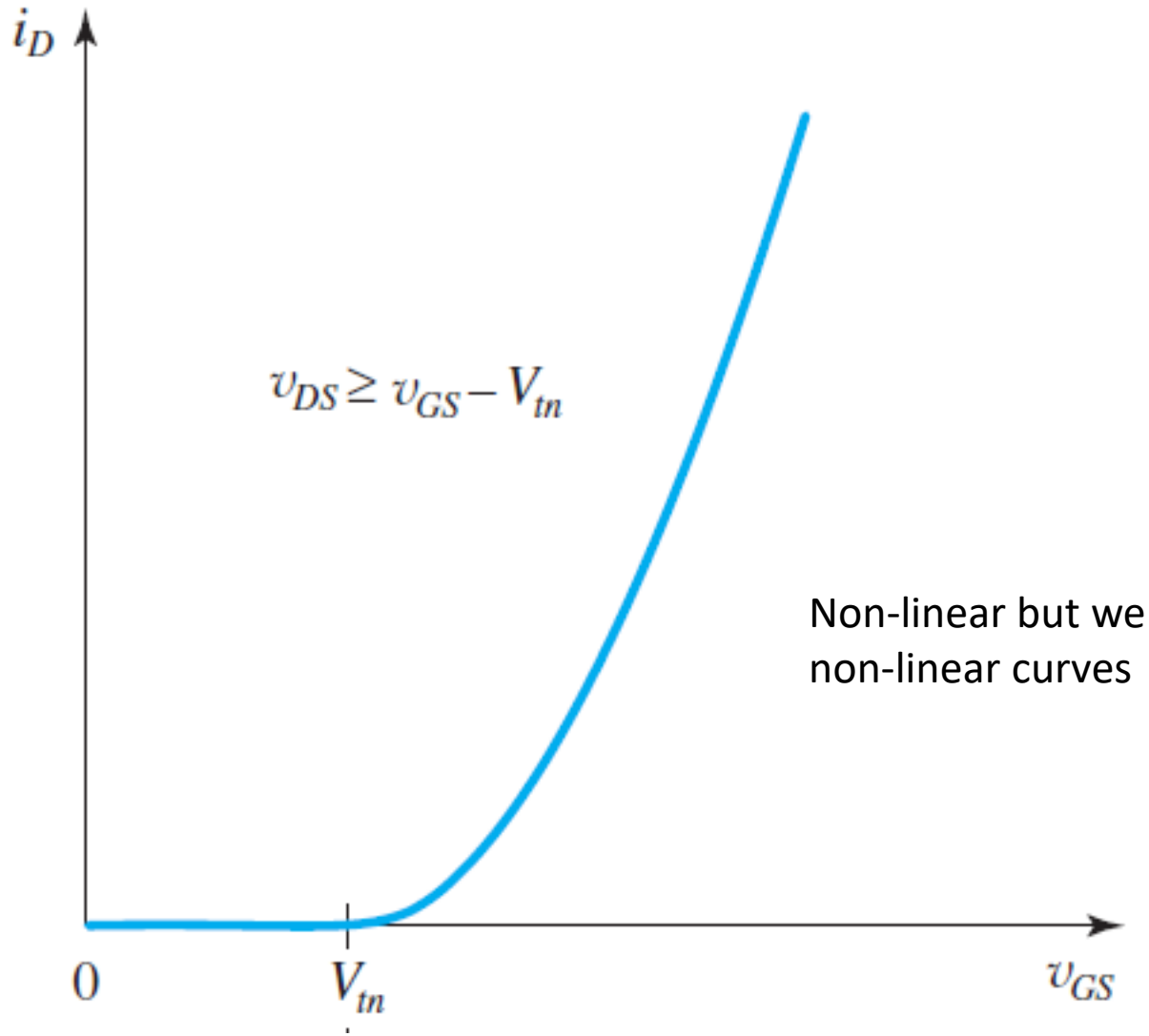
Voltage-controlled current source

Saturation current

$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L} \right) (v_{GS} - V_{tn})^2$$

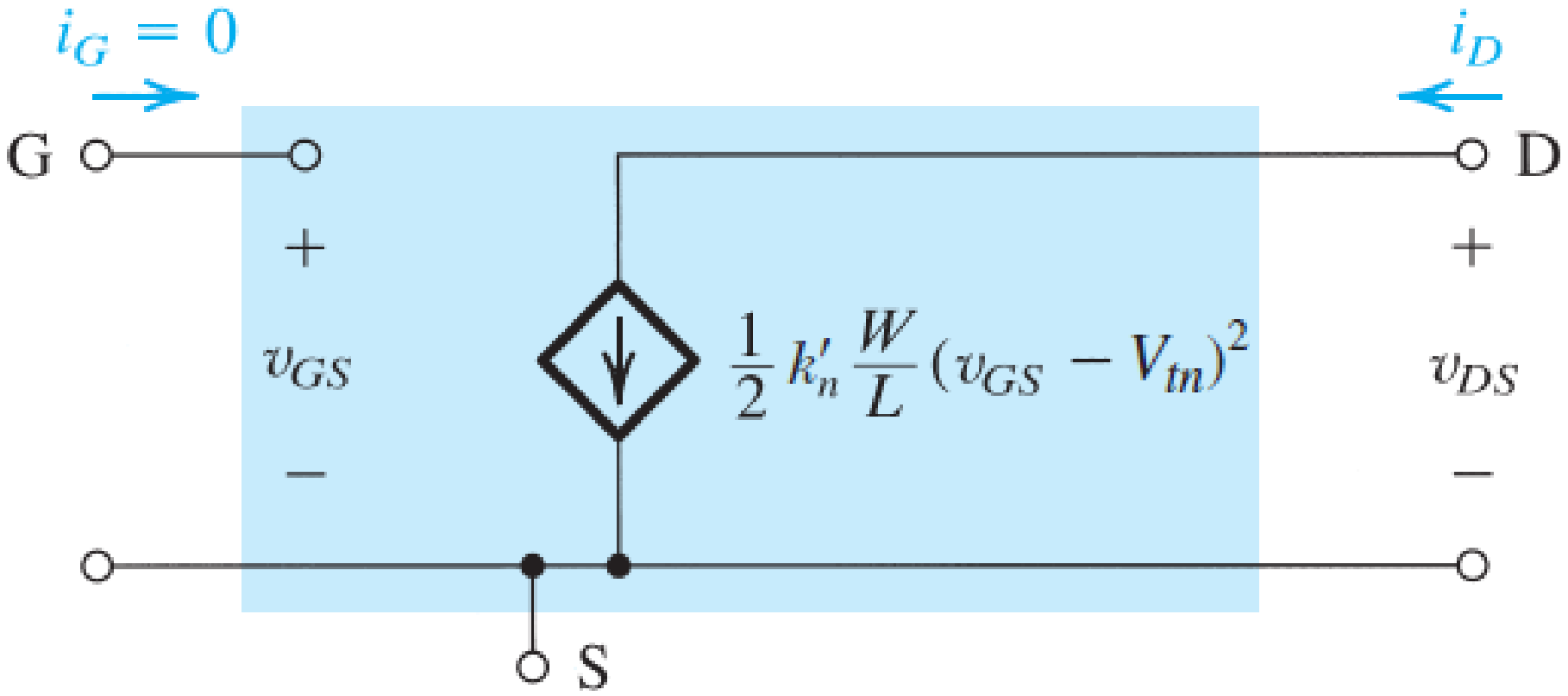
$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L} \right) v_{OV}^2$$

i_D vs v_{GS} curve



Non-linear but we know what to do with non-linear curves

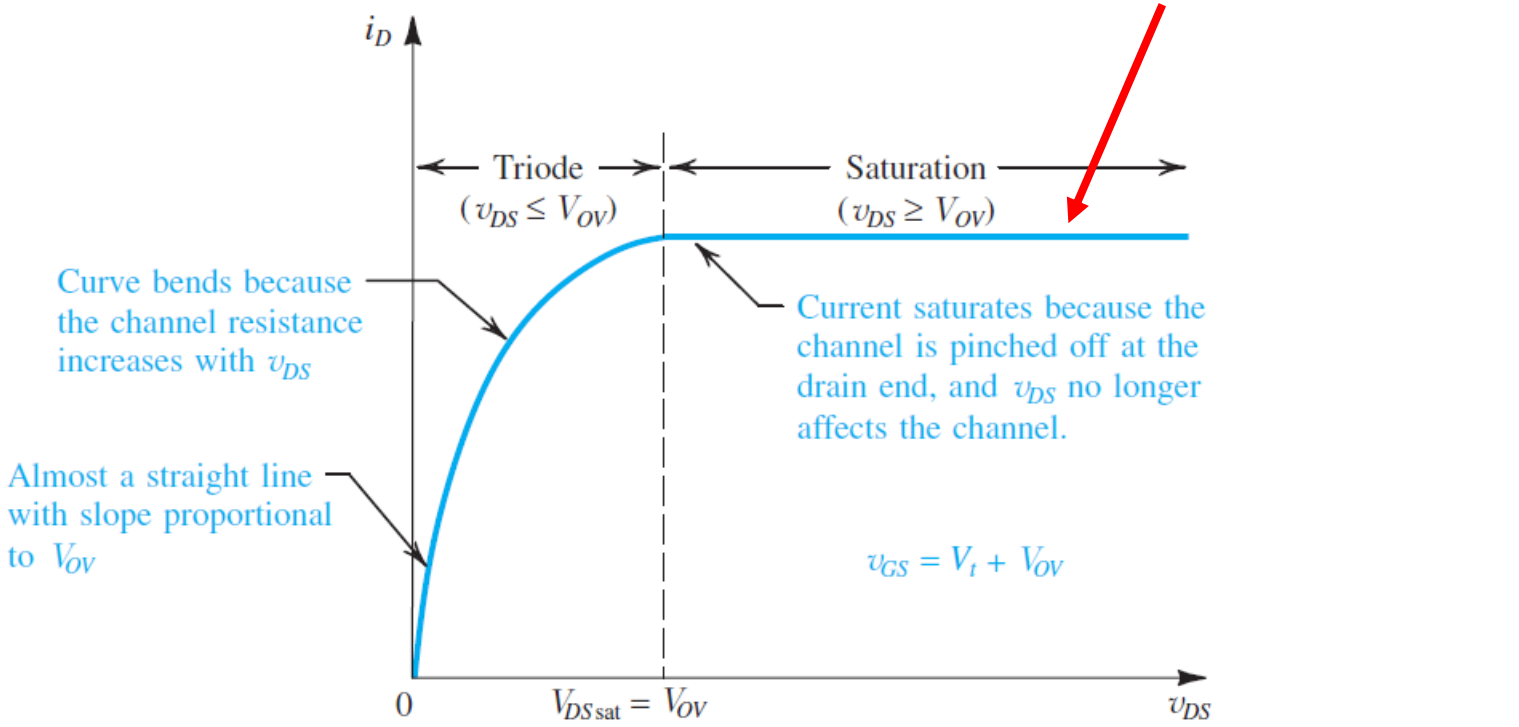
Large-Signal Model



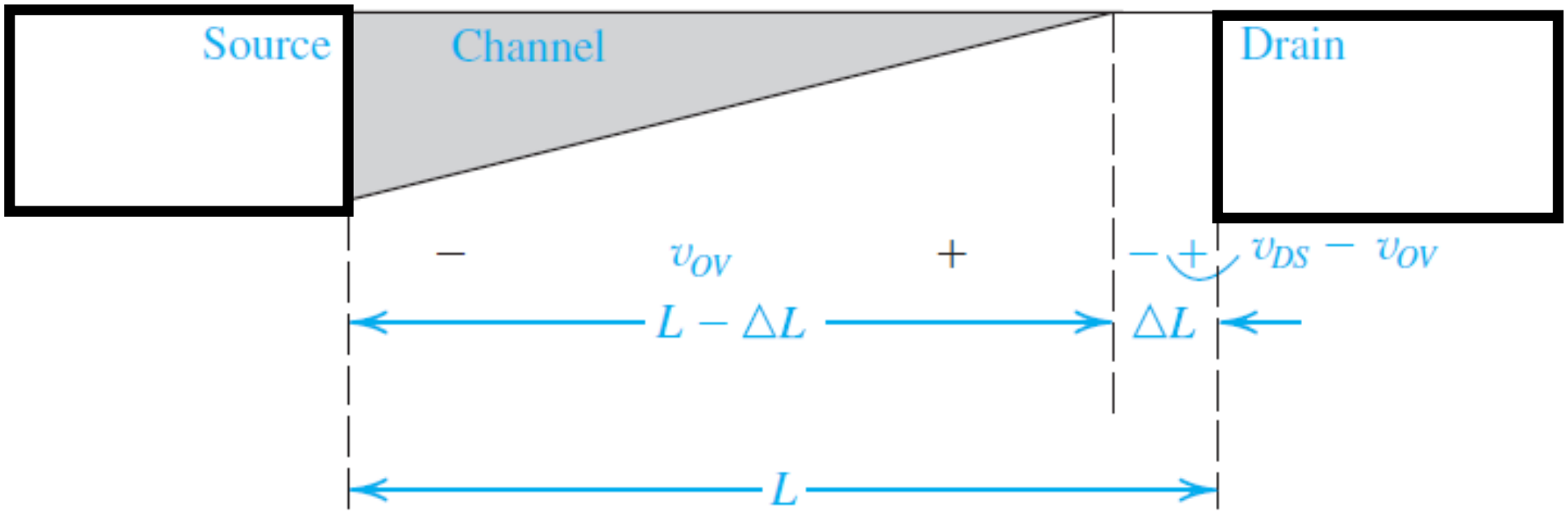
However

Finite Output Resistance in Saturation

ideal infinite output resistance



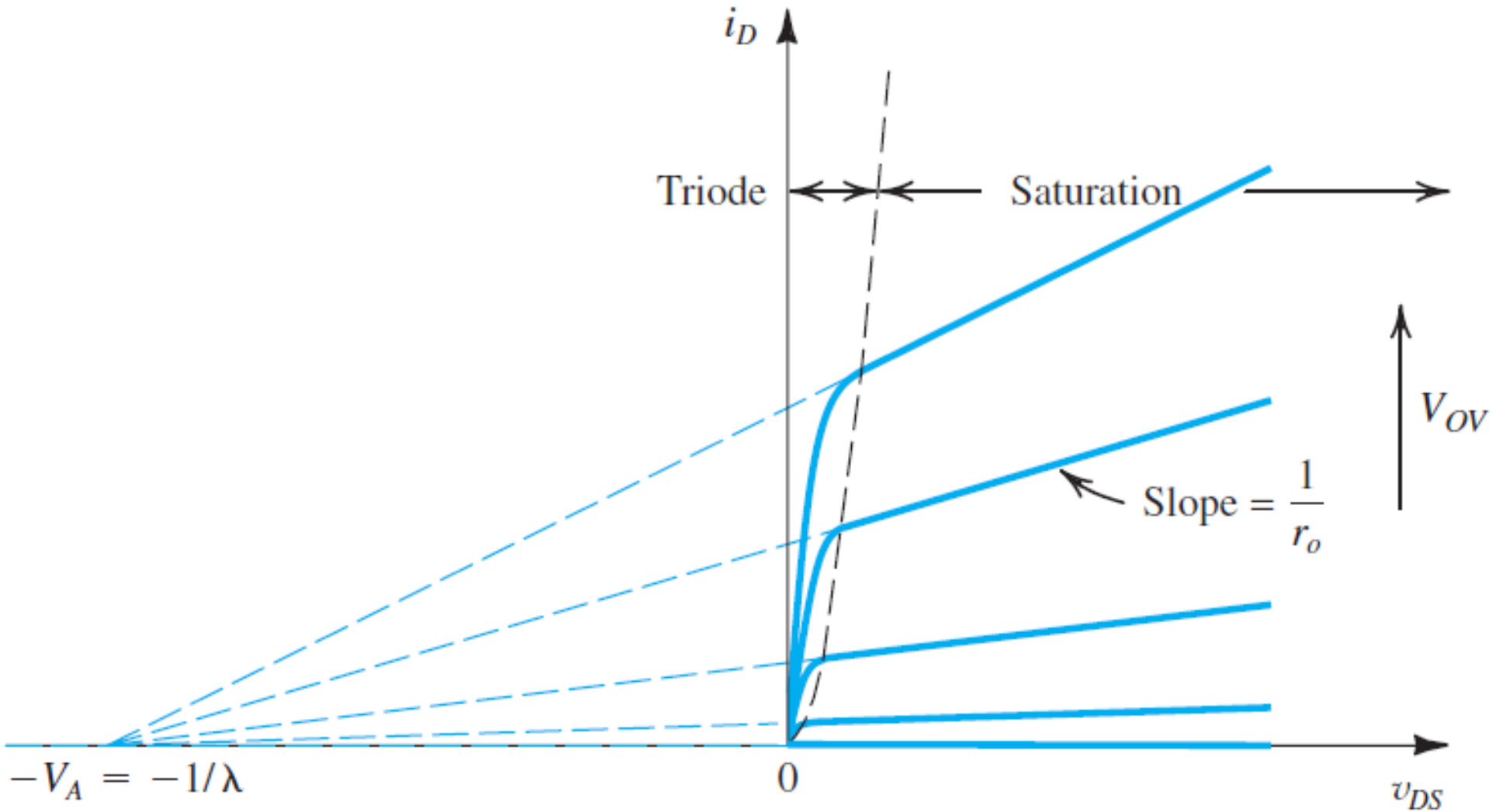
Channel-length modulation



$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L} \right) (v_{GS} - V_{tn})^2 (1 + \lambda v_{DS})$$

(V^{-1})

“lamda” parameter
channel-length modulation parameter
ideal λ = 0


i_D
Triode
Saturation
V_{OV}
Slope = $\frac{1}{r_o}$
$-V_A = -1/\lambda$
0
v_{DS}