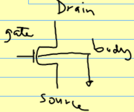
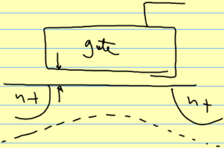
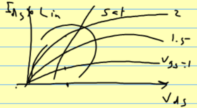
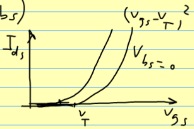
MOS Tr



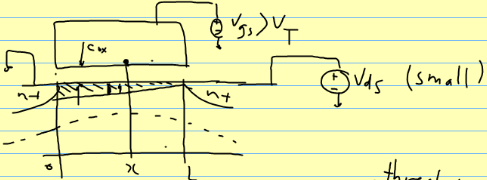


$$I_{ds} = f(v_{gs}, v_{ds}, v_{bs})$$





Triode (Linear) region



threshold volts

$$Q(x) = -C_{ox}\left(V_{gs} - V(x) - V_t\right)$$

$$C_{ox} \rightarrow \frac{\varepsilon_{ox}}{t_{ox}}$$

$$I_{ds} = -C_{ox}\left(v_{gs} - V(x) - V_t\right) \cdot v_n(x) \cdot W$$

$$v_n(x) = -\mu_e E(x) = -\mu \frac{dV(x)}{dx}$$

Simple Model Linear Region

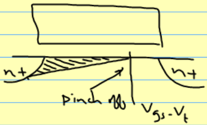
$$\int_0^L I_{ds} \cdot dx = \int_0^{V_{ds}} \mu_e C_{ox} \left(V_{gs} - V_t - V(x) \right) \cdot W \cdot dV(x)$$

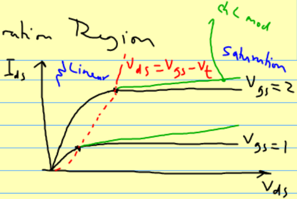
$$I_{ds} = \mu C_{ox} \frac{W}{L} \left((V_{gs} - V_t) \cdot V_{ds} - \frac{1}{2} V_{ds}^2 \right)$$

$$\underbrace{(V_{gs} - V_t) \cdot V_{ds}}_{\approx \frac{1}{R_{ch}}}$$

what if $V_{ds} > V_{gs} - V_t$

Saturation Region





$$I_{ds}\Big|_{V_{ds}=V_{gs}-V_t} = \mu C_{ox} \frac{W}{L}\left((V_{gs}-V_t)\cdot(V_{gs}-V_t) - \frac{1}{2}(V_{gs}-V_t)^2\right)$$

$$I_{ds}\Big|_{V_{ds}=V_{gs}-V_t} = \mu C_{ox} \frac{W}{2L}(V_{gs}-V_t)^2$$

Channel Modulation

$$L_{real} = L - \varsigma \cdot V_{ds}$$

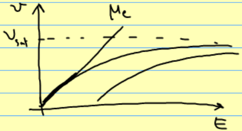
$$I_{ds} = \mu C_{ox} \frac{W}{2(L - \varsigma V_{ds})} \cdot (V_{gs} - V_t)^2$$

$$= \mu C_{ox} \frac{W}{2L} (V_{gs} - V_t)^2 \cdot \frac{1}{1 - \varsigma \frac{V_{ds}}{L}}$$

$$\left(1 + \frac{\varsigma}{L} V_{ds}\right)$$

λ — ch Length modulation param

Velocity Sat



$$v = \begin{cases} v_{sat} & E > E_c \\ \dfrac{\mu_e E}{\left(1+\left(\frac{E}{E_c}\right)^n\right)^{1/n}} & E < E_c \end{cases}$$

$n=1$ for PMOS

$n=2$ for NMOS

$$I_{ds} = C_{ox}\left(V_{gs} - V_t - V(x)\right) \cdot \frac{\mu_e \frac{dV(x)}{dx}}{1 + \frac{dV_x}{dx} \cdot \frac{1}{E_c}} \cdot W$$

$$\int_0^L (\quad) dx = \int_0^{V_{ds}} (\qquad\qquad) dV(x)$$

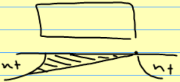
Velocity Sat Eq

$$I_{ds} = \mu_e C_{ox} \frac{W}{L}\left((V_{gs}-V_t)\cdot V_{ds} - \frac{1}{2}V_{ds}^2\right)\frac{1}{1+\frac{V_{ds}}{E_c \cdot L}}$$

extreme cases $L \longrightarrow \infty$ $K(V_{ds}) \Longrightarrow 1$ Long ch $K(V_{ds})$

$K(V_{ds}) < 1$ Short ch

Long ch



$V_{ds} = V_{dsat}$

$v = v_{sat}$

$E = E_c$

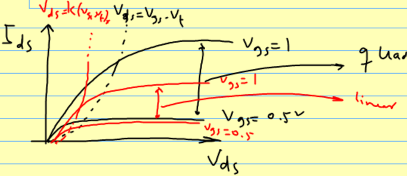
$$I_{ds} = C_{ox} (V_{gs} - V_t - V_{dsat}) \cdot v_{sat} \cdot W \quad \circledast$$

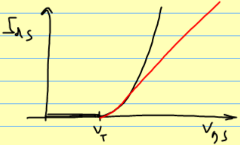
$I_{ds} \circledast = I_{ds} \circledast\circledast$ Solve for V_{dsat}

$$V_{dsat} = \frac{1}{1 + \frac{V_{gs} - V_t}{E_c L}} \cdot (V_{gs} - V_t)$$

$$= K(V_{gs} - V_t) \cdot (V_{gs} - V_t)$$

Long ch vs Short ch



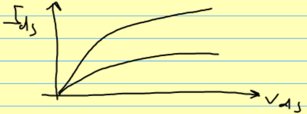


Velocity Saturation

1- The current prematurely saturates in short ch device. (extended sat region)

2. I_{dsat} linear relationship V_{gs}

3. I_{dsat} has a weaker L dependence

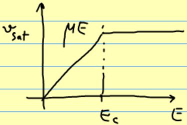


Simplified Velocity Sat Model

(i) assumption I

$$v = \begin{cases} v_{sat} & E > E_c \\ \mu E & E < E_c \end{cases}$$

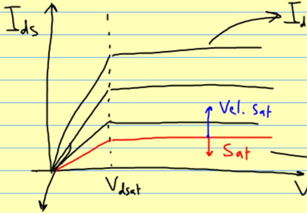
$$v_{sat} = \mu E_c$$



(ii) Assumption II for large $(V_{gs} - V_t)$

$$V_{dsat} = \text{Const} \approx E_c . L = L \frac{v_{sat}}{\mu}$$

Unified MOS Model



$$I_{ds} = \mu C_{ox} \frac{W}{L} \left((V_{gs} - V_t) \cdot V_{dsat} - \frac{1}{2} V_{dsat}^2 \right)$$

$$I_{ds} = \mu C_{ox} \frac{W}{L} \left((V_{gs} - V_t) \cdot (V_{g} - V_t) - \frac{1}{2} (V_{gs} - V_t)^2 \right)$$

$$I_{ds} = \mu C_{ox} \frac{W}{L} \left((V_{gs} - V_t) V_{ds} - \frac{1}{2} V_{ds}^2 \right)$$

Unified Model

$$I_{ds} \begin{cases} 0 & V_{gs} < V_t \\ \mu C_{ox} \frac{W}{L} \left((V_{gs} - V_t) V_{min} - \frac{1}{2} V_{min}^2 \right) \times (1 + \lambda V_{ds}) \end{cases}$$

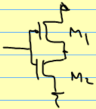
$$V_{min} = \min \left(V_{gs} - V_t , V_{ds} , V_{dsat} \right)$$

$V_{gs} - V_t$ → Sat

V_{ds} → linear

V_{dsat} → Vel. Sat.

CAD Tools



↓ extract netlist

M1 W= L=

M2 W= L=

wire — - -

↓

Run HSpice