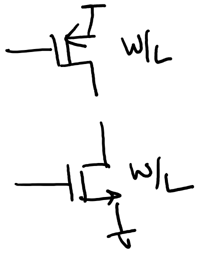
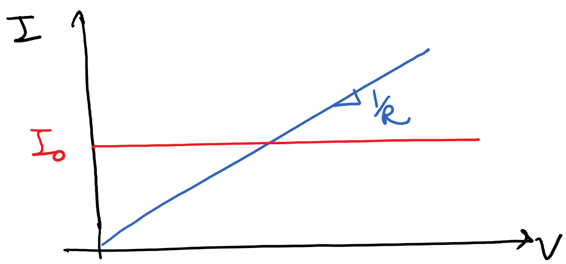
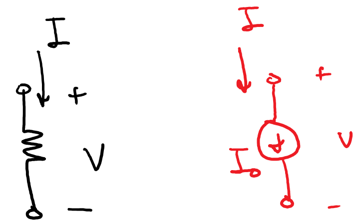
ECE 515 - Lecture 1

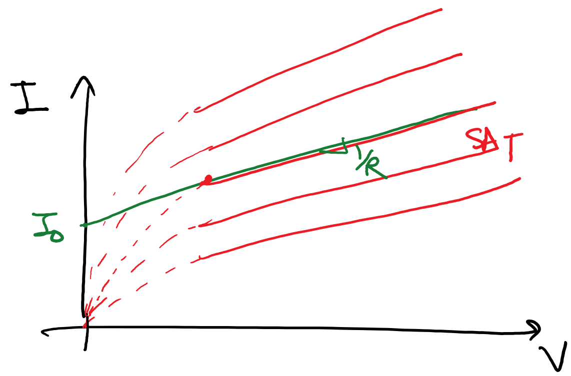
Thursday, August 23, 2018 11:01 AM

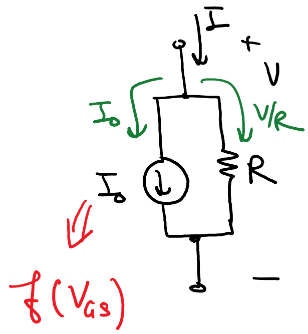


LVT, HVT,









MOSFET in SATURATION

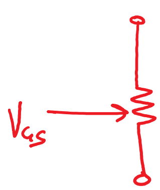
MOSFET

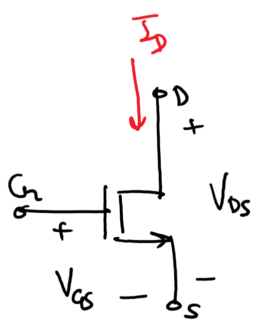
↳ VCCS with output resistance

⇓

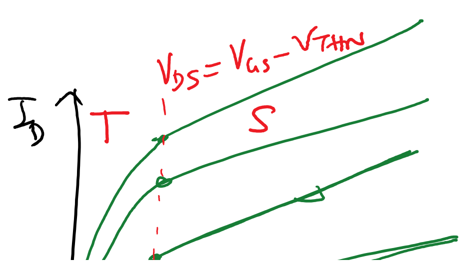
Voltage Controlled Current Source

Triode

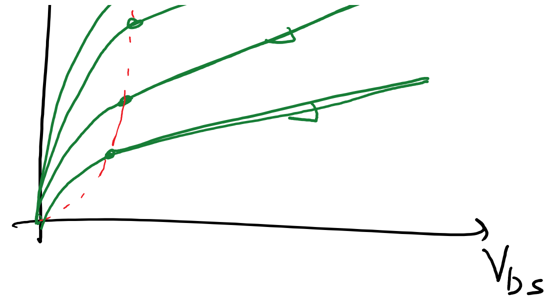




$$I_D = f(V_{GS}, V_{DS})$$



$V_{DS} > V_{DS,sat}$



Saturation: Ideally $V_{DS} > V_{DS,sat} = V_{GS} - V_{THN}$

Channel length modulation $L \leq 5\mu m$

Thursday, August 23, 2018 11:35 AM

Long channel Equations

Short-channel effects
BSIM models

$$I_D = \begin{cases} 0 & V_{GS} < V_{THN} \\ Kp_n \frac{W}{L}\left[(V_{GS}-V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right] & V_{GS} > V_{THN},\ 0 < V_{DS} < V_{DS,sat} \\ \frac{1}{2} Kp_n \frac{W}{L}(V_{GS}-V_{THN})^2 \underbrace{\left[1+\lambda(V_{DS}-V_{DS,sat})\right]}_{\text{Channel length modulation}} & V_{GS} > V_{THN},\ V_{DS} > V_{DS,sat} \end{cases}$$

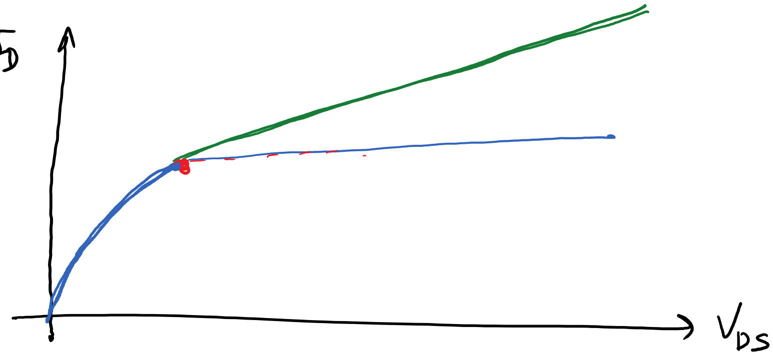
Square-Law

λ: CLM parameter

$Kp_n = \mu_n C'_{ox}$

μ_n: mobility

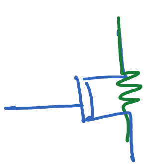
C'_{ox}: oxide cap p.u. area



$V_{DS,sat} = V_{GS} - V_{THN} = V_{OV}$ ← overdrive voltage

In triode:

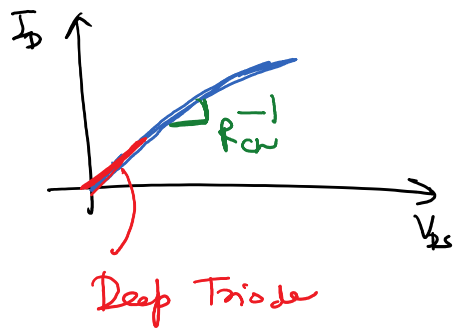
$\beta = Kp_n \frac{W}{L}$ → $\mu_n C_{ox}$



$$I_D = \boxed{Kp_n \frac{W}{L}}\left((V_{GS}-V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right)$$

$$\partial I_D = Kp_n \frac{W}{L}\left[V_{GS} - V_{THN} - V_{DS}\right]$$

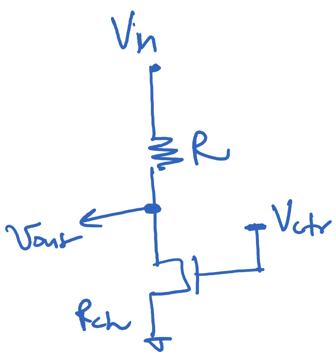
$$R_{ch}^{-1} = \frac{\partial I_D}{\partial V_{DS}} = K'_n \frac{W}{L}\left[V_{GS} - V_{THN} - V_{DS}\right]$$



$$R_{ch} = \frac{1}{K'_n \frac{W}{L}\left[\underbrace{V_{GS} - V_{THN}} - V_{DS}\right]}$$

$V_{DS} << (V_{GS} - V_{THN})$

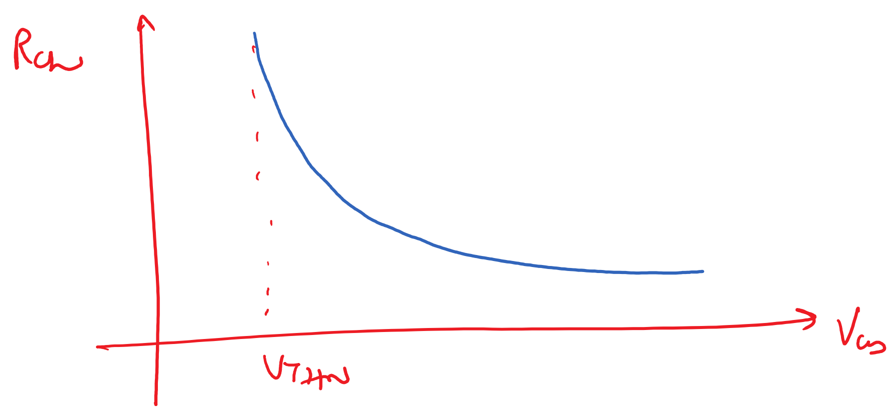
$$\simeq \frac{1}{K'_n \frac{W}{L}\left(V_{GS} - V_{THN}\right)}$$ in Deep Triode



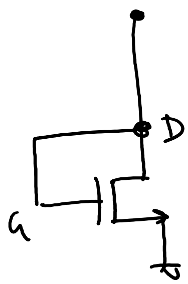
Voltage controlled resistance

$$R_{ch} = R_{DS} = f(V_{GS} - V_{THN})$$

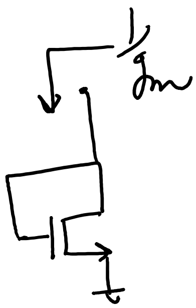
$$R_{ch} \propto \frac{1}{\underbrace{V_{GS} - V_{THN}}}$$



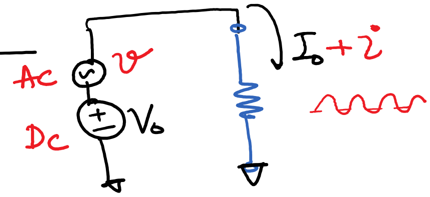
Diode - connected

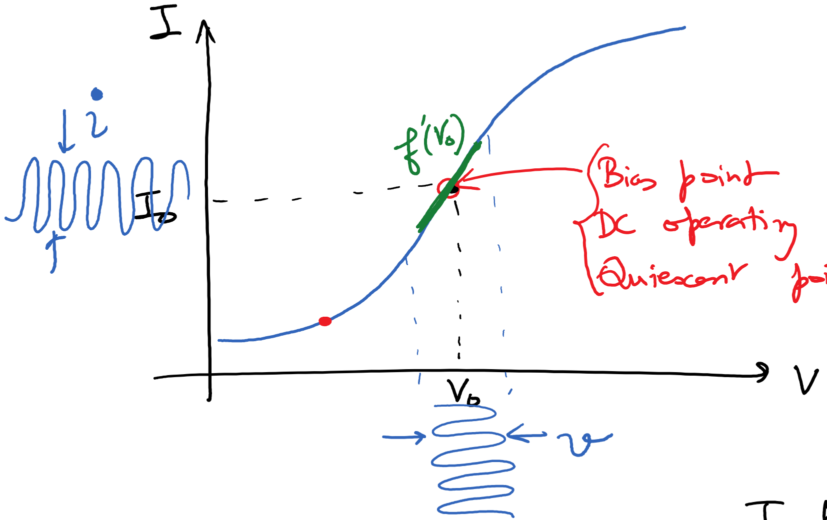


$V_{GS} = V_{DS} > V_{THN}$ always in SAT



Non linear Resistor





Bias point
DC operating point
Quiescent point

$I = f(V)$ non-linear

Taylor's Series Expansion

$$I = f(V)$$

$$\Rightarrow \quad I = \underbrace{f(V_0)}_{I_0} + \frac{f'(V_0)}{\lfloor 1}\underbrace{(V-V_0)}_{v} + \frac{f''(V_0)}{\lfloor 2}\underbrace{(V-V_0)^2}_{v^2} + \frac{f'''(V_0)}{\lfloor 3}\underbrace{(V-V_0)^3}_{v^3} + \cdots$$

$$V = V_0 + v$$

$$\Rightarrow v = V - V_0$$

$$\underbrace{I - I_0}_{i} = f'(V_0).v + \frac{f''(V_0)}{\lfloor 2} v^2 + \frac{f'''(V_0)}{\lfloor 3} v^3 + \cdots$$

$I_0 = f(V_0)$

$$\Rightarrow \boxed{i = f'(V_0).v + \frac{f''(V_0)}{\lfloor 2} v^2 + \frac{f'''(V_0)}{\lfloor 3} v^3 + \cdots} \rightarrow (1)$$

$$f'(V_0) = \left.\frac{\partial I}{\partial V}\right|_{V=V_0}$$

Slope at the Bias point depends upon the Bias point

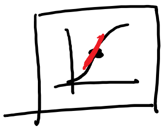
v, i are small-signals, incremental signals, AC signals perturbation if v is very small

$$i \simeq \underbrace{f'(V_0)}_{g}\, v$$

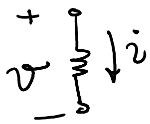
$$i = g v$$

$$g = \left.\frac{\partial I}{\partial V}\right|_{V=V_0}$$

Small-signal parameter that depends upon the Bias point



$\Rightarrow$ Small-signal Equivalent circuit



(Ac picture)

$$i = g v$$

$\longrightarrow$ slope at the bias point

from Eqn (1)

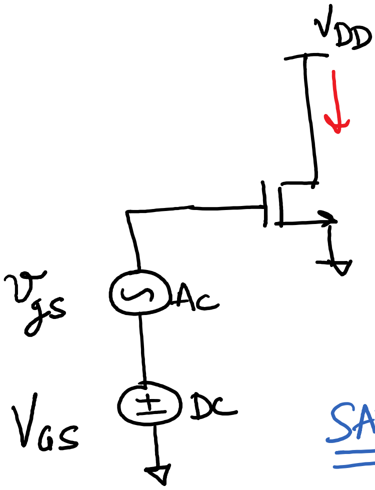
$$\boxed{i = \overset{f'(V_0)}{g_1}\, v} + \underbrace{g_2 v^2 + g_3 v^3 + \cdots}_{\text{Distortion terms}}$$

Linearized Equation

Can ignore distortion terms if $g_2 v^2 < \frac{1}{10} g_1 v$

$$\underline{v} < \frac{g_1}{10\, g_2}$$

MOSFET small-signal parameters



$i_D = I_D + i_d$

$$\underbrace{v_{GS}}_{\text{total voltage}} = \underbrace{V_{GS}}_{DC} + \underbrace{v_{gs}}_{AC}$$

$$\underbrace{i_D}_{\text{total current}} = \underbrace{I_D}_{DC} + \underbrace{i_d}_{AC}$$

$\underline{\underline{SAT}}$ & $\lambda = 0$

$$i_D = \frac{K'_n}{2} \frac{W}{L} (v_{GS} - V_{THN})^2$$

$$I_D + i_d = \frac{K'_n}{2} \frac{W}{L} \left(V_{GS} + v_{gs} - V_{THN} \right)^2$$

$$i_d = g_m \cdot v_{gs}$$

$$g_m = \left. \frac{\partial i_D}{\partial v_{GS}} \right|_{v_{GS} = V_{GS}}$$