ECE 318 - Lecture 18

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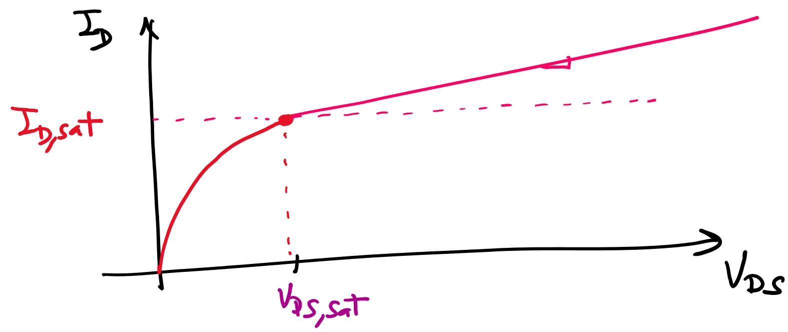
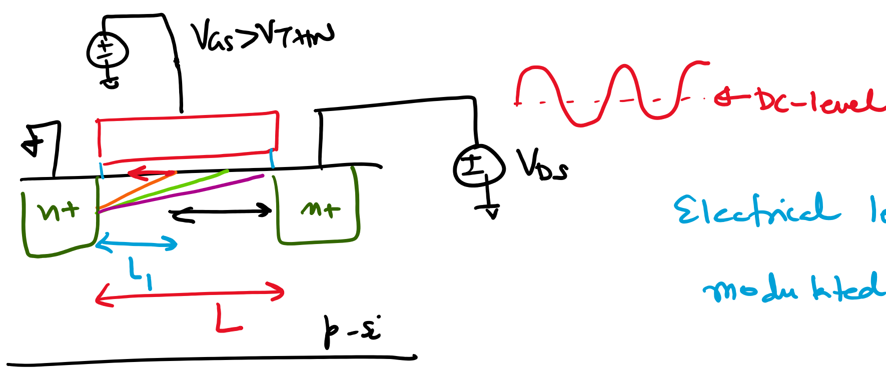


$V_{GS} > V_{THN}$

$V_{DS,sat} = V_{GS} - V_{THN}$

Channel Length Modulation (CLM)



physical length

Electrical length ($L_1 < L$) is modulated by V_{DS}

$V_{DS} \uparrow \Rightarrow L_1 \downarrow \Rightarrow I_D \uparrow$ ⇐ Short-channel MOSFETs $L < 1\mu m$

Sat: $I_D = \frac{1}{2}\mu_n C_{ox}' \frac{W}{L_1}\left[V_{GS} - V_{THN}\right]^2$

I_{Dsat}

If we want to include "CLM" into saturation I_D equation

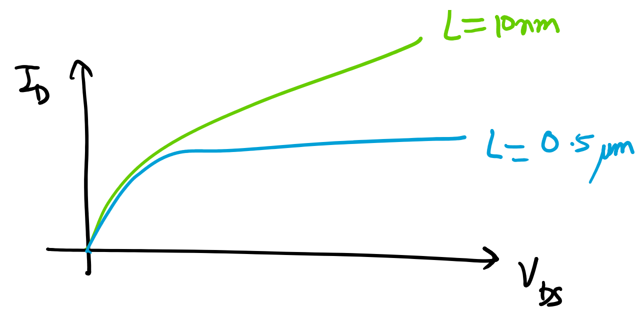
$$I_D = \frac{1}{2}\mu_n C_{ox}' \frac{W}{L}(V_{GS} - V_{THN})^2 \times (1 + \lambda V_{DS})$$

λ ← curve fitting parameter

$\frac{1}{2}\mu_n C_{ox}' \frac{W}{L}(V_{GS} - V_{THN})^2 \cdot \lambda V_{DS}$ ← some textbooks use this

$\lambda \propto \frac{1}{L}$

ΔL is now comparable to L



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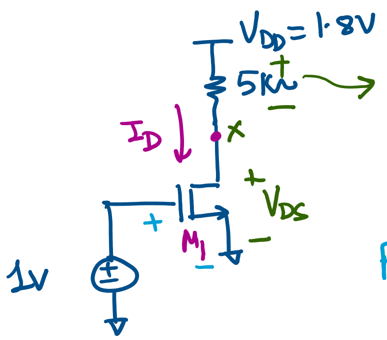
180nm CMOS
($L_{min} = 180nm$)
$V_{DD} = 1.8V$

Ex 6.6 Calculate bias current of M_1

$KP_n = \mu_n C_{ox}' = 100 \frac{\mu A}{V^2}$

$V_{THN} = 0.4V$

$\frac{W}{L} = \frac{2\mu m}{0.18\mu m}$



$V_{GS} = 1V > 0.4V$
$\Rightarrow$ ON

Is M_1 SAT or TRIODE Region?

For SAT: $V_{DS} \geq \underbrace{V_{GS} - V_{THN}}_{V_{DS,sat}}$

* Assume M_1 is in SAT

$KP_n = \mu_n C_{ox}'$
↑ Transconductance parameter of the NMOS.

$$I_D = \frac{1}{2} KP_n \frac{W}{L} (V_{GS} - V_{THN})^2$$

$$= 200\mu A$$

for hand calculations $\lambda = 0$

Go back and verify the assumption of SAT.

$$V_{DS} = V_{DD} - I_D \cdot R_D$$
$$= 1.8 - 200\mu A \times 5k\Omega$$
$$= 0.8V$$

$$V_{DS,sat} = 1 - 0.4 = 0.6V$$

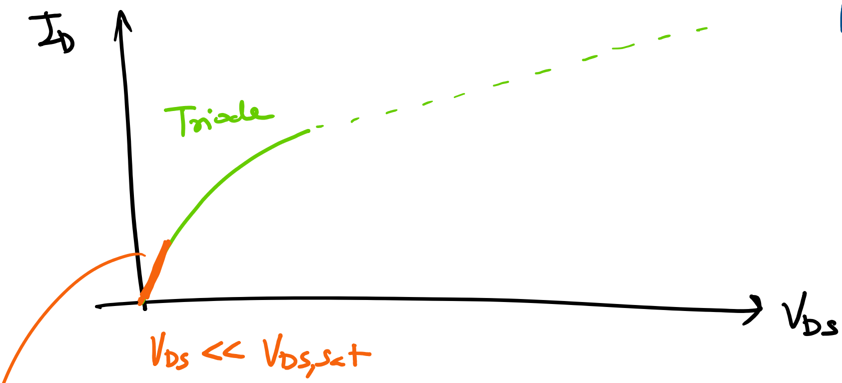
$\because V_{DS} > V_{DS,sat}$ M_1 is really in SAT.

$I_D = 200\mu A$
$V_{DS} = 0.8V$

Ans.

$ax^2 + bx + c = 0$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$



NMOS is a non linear resistor in Triode

"deep Triode" → can be approximated as a linear resistor.
$V_{DS} << V_{DS,sat} = V_{GS} - V_{THN}$

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right] \longrightarrow (1)$$

ON resistance

$$R_{on} = \frac{\partial V_{DS}}{\partial I_D} = \left[\frac{\partial I_D}{\partial V_{DS}}\right]^{-1} = \boxed{\frac{1}{\mu_n C_{ox} \frac{W}{L}\left[V_{GS} - V_{THN} - V_{DS}\right]}}$$

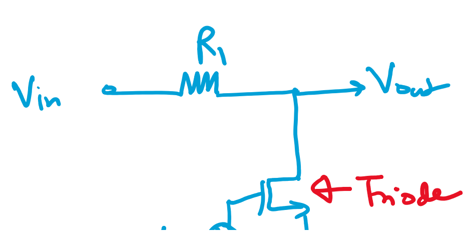
R_{on} depends upon V_{DS} → non linear resistance

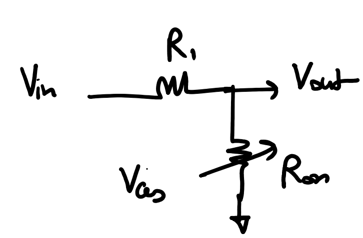
But for $V_{DS} << (V_{GS} - V_{THN})$ In Deep Triode

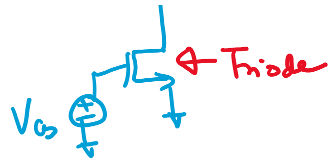
$$\longrightarrow R_{on} \simeq \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{THN})} = \boxed{\frac{1}{K P_n \frac{W}{L}(V_{GS} - V_{THN})}}$$

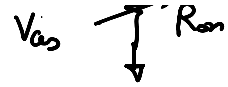
Resitance that depends upon V_{GS}

⇒ voltage controlled Resistor









$$\frac{V_{out}}{V_{in}} = \frac{R_{on}}{R_{on} + R_1}$$

programmable voltage divider

$R_{on} = R_{on}(V_{GS})$

Small Signal Model

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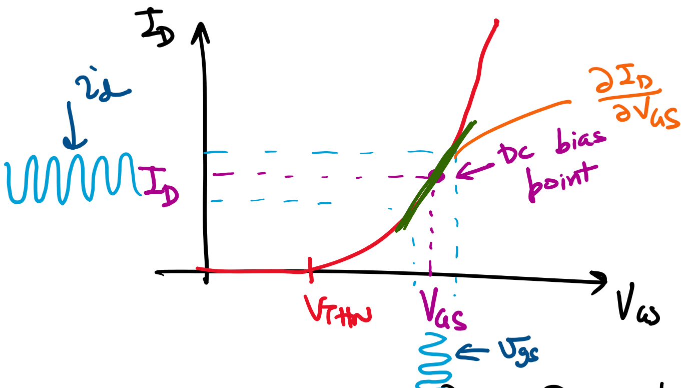
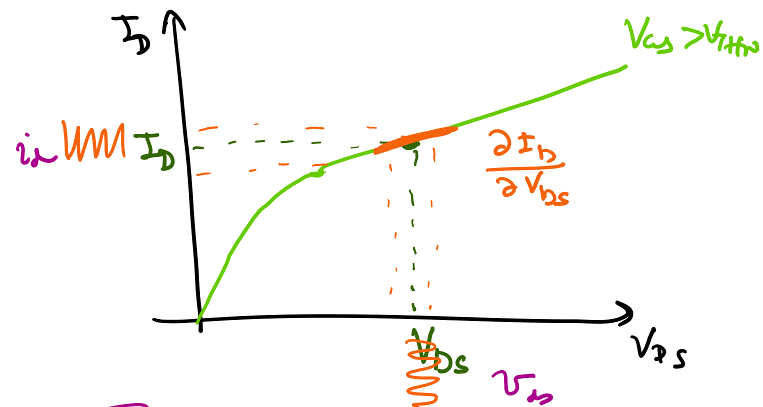
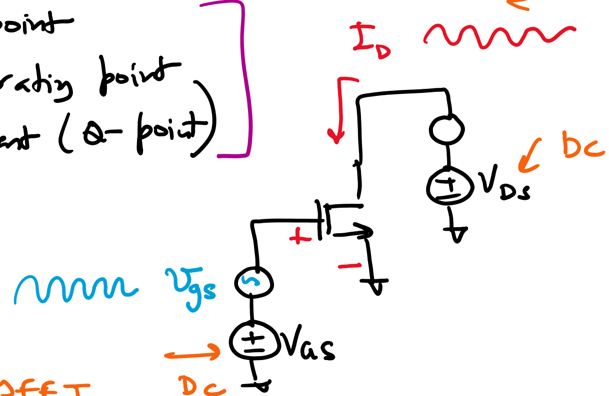




$(V_{GS}, V_{DS}, I_D) \in$ Bias point
DC operating point
Quescient (Q-point)



Transconductance of the MOSFET

$$g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{v_{GS} = V_{GS}} \leftarrow \text{DC bias point}$$

$$i_d = g_m v_{gs} \rightarrow (1)$$

g_m depends upon the bias point

Output resistance

$$r_o = \left[\frac{\partial I_D}{\partial V_{DS}}\right]^{-1}$$

$$I_D = \underbrace{\frac{1}{2} KP_n \frac{W}{L} (V_{GS} - V_{THN})^2}_{I_{D,sat}} (1 + \lambda V_{DS})$$

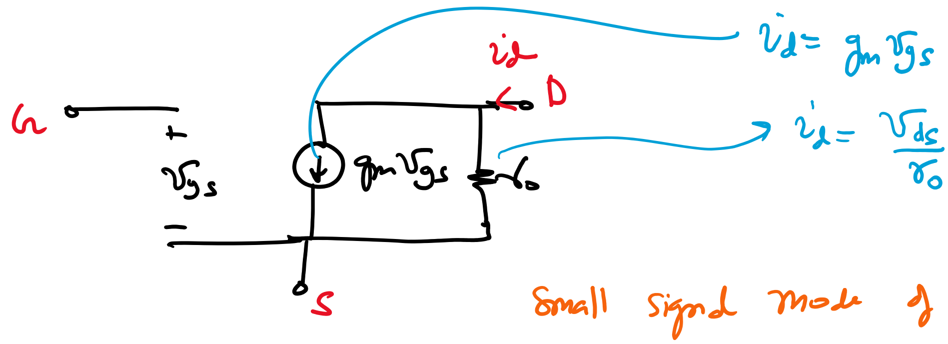
$$= I_{Dsat} (1 + \lambda V_{DS})$$

$$\boxed{r_o = \frac{1}{\lambda I_{D,sat}}}$$

$$i_d = \frac{v_{ds}}{r_o} \rightarrow (2)$$

Small signal parameters ⇒ g_m, r_o

↳ can relate small change in input to other currents & voltages in the MOSFET circuit.



Small signal model of NMOS in Saturation.