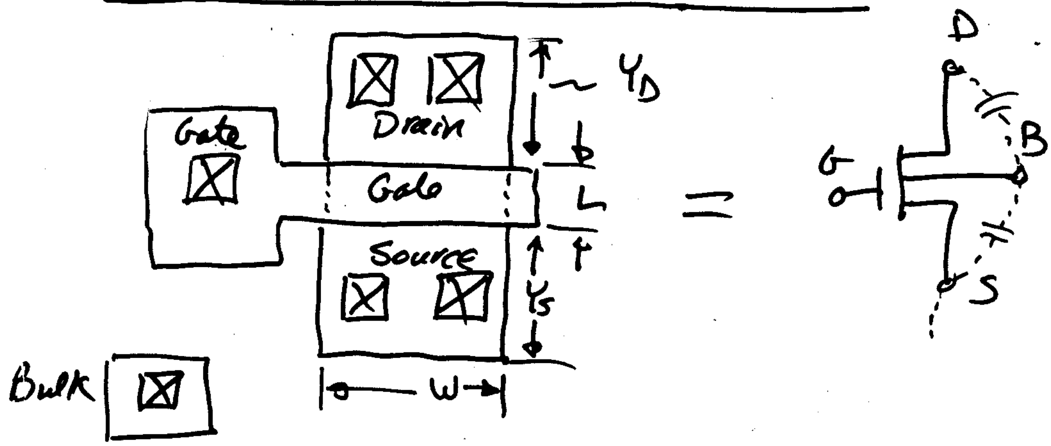
MODELS FOR CIRCUIT SIMULATION

(See handout on Model Generations)

Specify MOS Transistor for SPICE



MOSFET:

MXXX D G S B Modelname L W AD AS PD PS

where

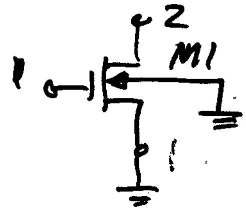
MXXX = the instance name of the MOSFET
D = drain node
G = Gate "
S = Source "
B = Bulk "

Modelname – The name of the model NXXX or PXXX
L = the length of channel
W = the width of the channel

AS(AD) = area of source (drain)
PS(PD) = perimeter of the source (drain)

Example

NMOS with $w = 0.4\mu m$, $L = 0.2\mu m$, $Y_D = Y_S = 0.5\mu m$



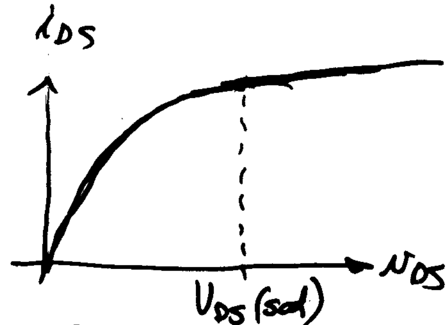
M1 2 1 0 0 NMOS1 L=0.2U W=0.4U
+ AD=0.2P PD=1.8U AS=0.2P PS=1.8U

Scale factor option:

.OPT SCALE=0.1U

M1 2 1 0 0 NMOS1 L=2 W=4 AD=20 PD=18
+ AS=20 PS=18

SPICE MODELS



Thinking model — SPICE 1

Computer model — BSIM

Thinking model:

$$i_{DS} = \frac{W_{eff}}{L_{eff}} \frac{KP}{2}\left[2(v_{GS}-V_T)v_{DS} - v_{DS}^2\right](1 + LAMBDA \cdot v_{DS})$$

for $v_{GS} \geq V_T$ and $v_{DS} \leq V_{GS} - V_T = V_{DS}(sat)$

$W_{eff} = W - LD$ and $L_{eff} = L - LD$

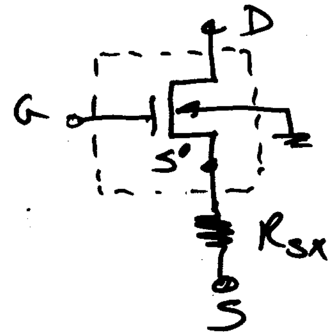
$$i_{DS} = \frac{W_{eff}}{L_{eff}} \frac{KP}{2}(v_{GS}-V_T)^2(1 + LAMBDA \cdot v_{DS})$$

for $v_{GS} \geq V_T$ and $v_{DS} \geq V_{GS} - V_T = V_{DS}(sat)$

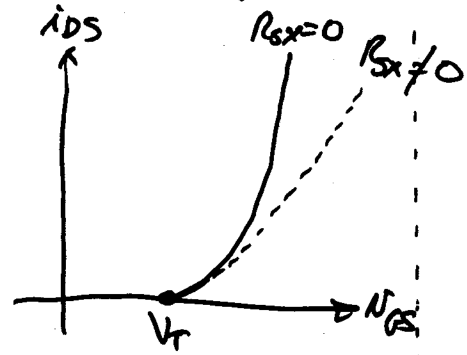
where

$$V_T = VTO + GAMMA\left(\sqrt{PHI - v_{BS}} - \sqrt{PHI}\right)$$

Improving the Level I model for DSM technology -

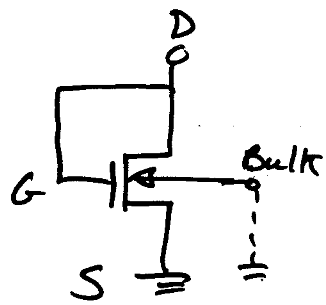


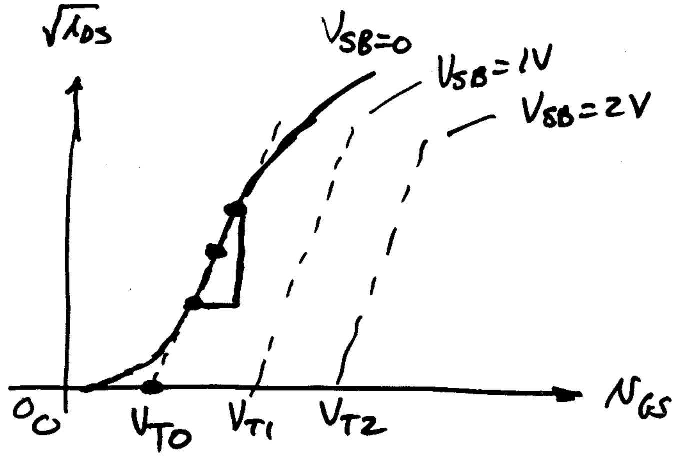
→ Velocity saturation of DSM technology



If we want a good "thinking" model, how do we get it?
Extract the simple model from the more sophisticated computer model (BSIM3).

Extraction:



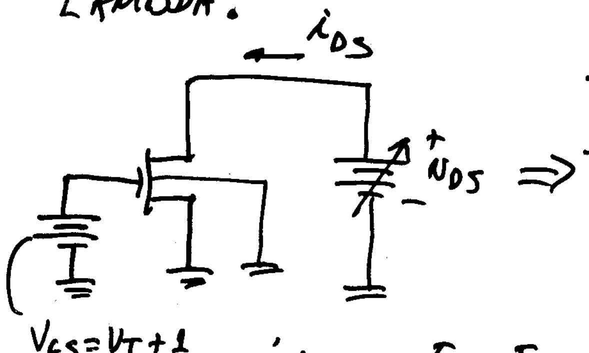


Slope → KP
Intercept → V_T

Plot V_T as a function V_{SB}

$$GAMMA = \frac{V_T(V_{SB}) - V_{T0}}{\sqrt{V_{SB} - 2\phi_F} - \sqrt{2\phi_F}}$$

LAMBDA:



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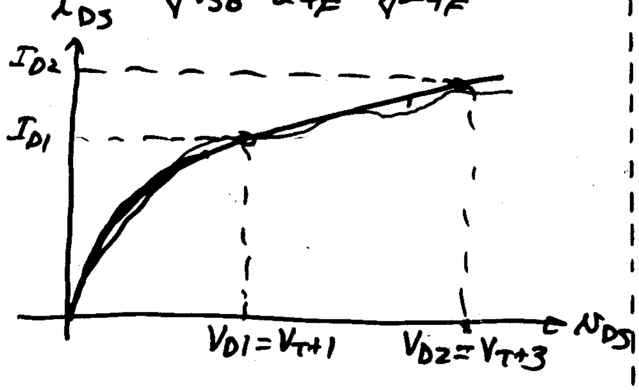


$$\text{Slope} = \frac{I_{D2} - I_{D1}}{V_{D2} - V_{D1}}$$

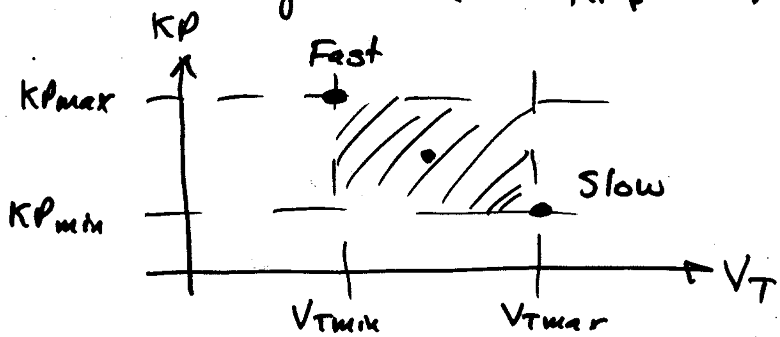
More Resources:

Appendix B of Allen & Holberg, CMOS Analog Ckt. Design
www.aicdesign.org
Chapter 3 of CMOS 2003
Section 10 – Extraction

Additional Effects in MOSFETS

Parameter Variations

"Fast" – gm large KP ↑ VT ↓
"Slow" – gm small KP ↓ VT ↑



Monte Carlo –
Know the statistics of KP, VT, etc.

1.) Simulate with arbitrary values for each transistor model.
2.) Repeat with other choices
⋮
3.) Learn what the statistical aspects of the circuit performance.

Temperature Next –

FET Computer Simulation Model Generations

- First Generation – Physically based analytical model including all geometry dependence.
- Second Generation – Model equations became subject to mathematical conditioning for circuit simulation. Use of empirical relationships and parameter extraction.
- Third Generation – A return to simpler model structure with reduced number of parameters which are physically based rather than empirical. Uses better methods of mathematical conditioning for simulation including more specialized smoothing functions.

Performance Comparison of Models (from Cheng and Hu, *MOSFET Modeling & BSIM3 Users Guide*)

Model	Minimum L (µm)	Minimum Tox (nm)	Model Continuity	i_D Accuracy in Strong Inversion	i_D Accuracy in Subthreshold	Small signal parameter	Scalability
MOS1	5	50	Poor	Poor	Not Modeled	Poor	Poor
MOS2	2	25	Poor	Poor	Poor	Poor	Fair
MOS3	1	20	Poor	Fair	Poor	Poor	Poor
BSIM1	0.8	15	Fair	Good	Fair	Poor	Fair
BSIM2	0.35	7.5	Fair	Good	Good	Fair	Fair
BSIM3v2	0.25	5	Fair	Good	Good	Good	Good
BSIM3v3	0.15	4	Good	Good	Good	Good	Good