INTERRELATIONS BETWEEN THRESHOLD VOLTAGE DEFINITIONS AND EXTRACTION METHODS

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Advanced Compact MOSFET model:

to be used in the analysis

Variable	Expression
I_D	$I_S(q'_{IS} - q'_{ID})(q'_{IS} + q'_{ID} + 2)$
g_m	$\frac{2I_S}{n\phi_t}(q'_{IS} - q'_{ID})$
V_P - $V_{S(D)}$	$\phi_t\left[q'_{IS(D)} - 1 + \ln\left(q'_{IS(D)}\right)\right]$
ϕ_S	$2\phi_F + V_C + \phi_t \ln\left(\frac{n}{n-1} q'_I\right)$

$$q'_I = -\frac{Q'_I}{nC'_{ox}\phi_t}$$

$$I_S = \mu C'_{ox} \frac{W}{L} \frac{n}{2} \phi_t^2$$

Classical definition of threshold voltage

surface concentration of electrons = bulk concentration of holes → $\phi_S = 2\phi_F$

$$\phi_S = 2\phi_F$$

$$V_G = V_{T0} \rightarrow V_C = 0$$

model →

$$q'_{IT0} = \frac{(n-1)}{n}$$

model ↓

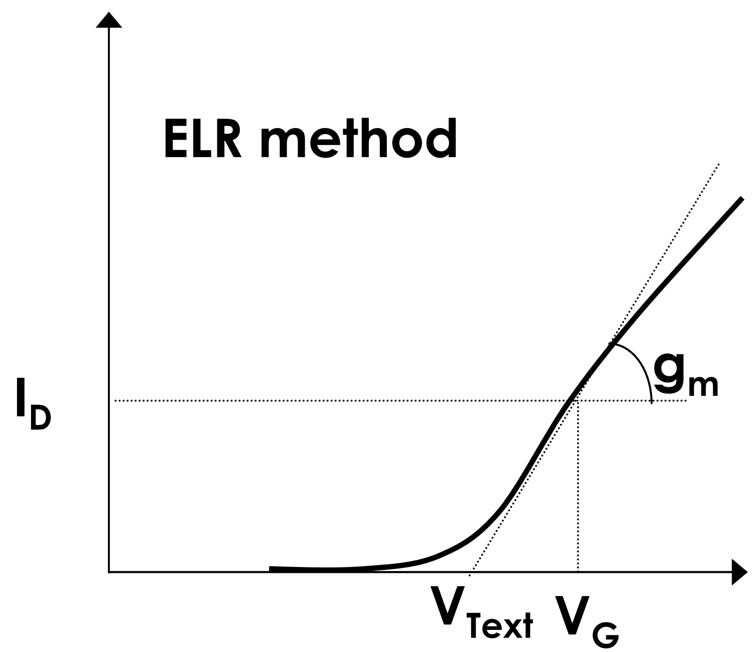
$$\frac{g_m}{I_D} \Big/ \left(\frac{g_m}{I_D}\right)_{max} = \frac{n}{2n-1}$$

Threshold definition by extrapolation of strong inversion characteristic

$q'_{IS} \cong q'_{ID}$ (for $V_{DS} << \phi_t$)

model

$$V_G - V_{Text} = \frac{I_D}{g_m} = n\phi_t(q'_{IS} + 1)$$

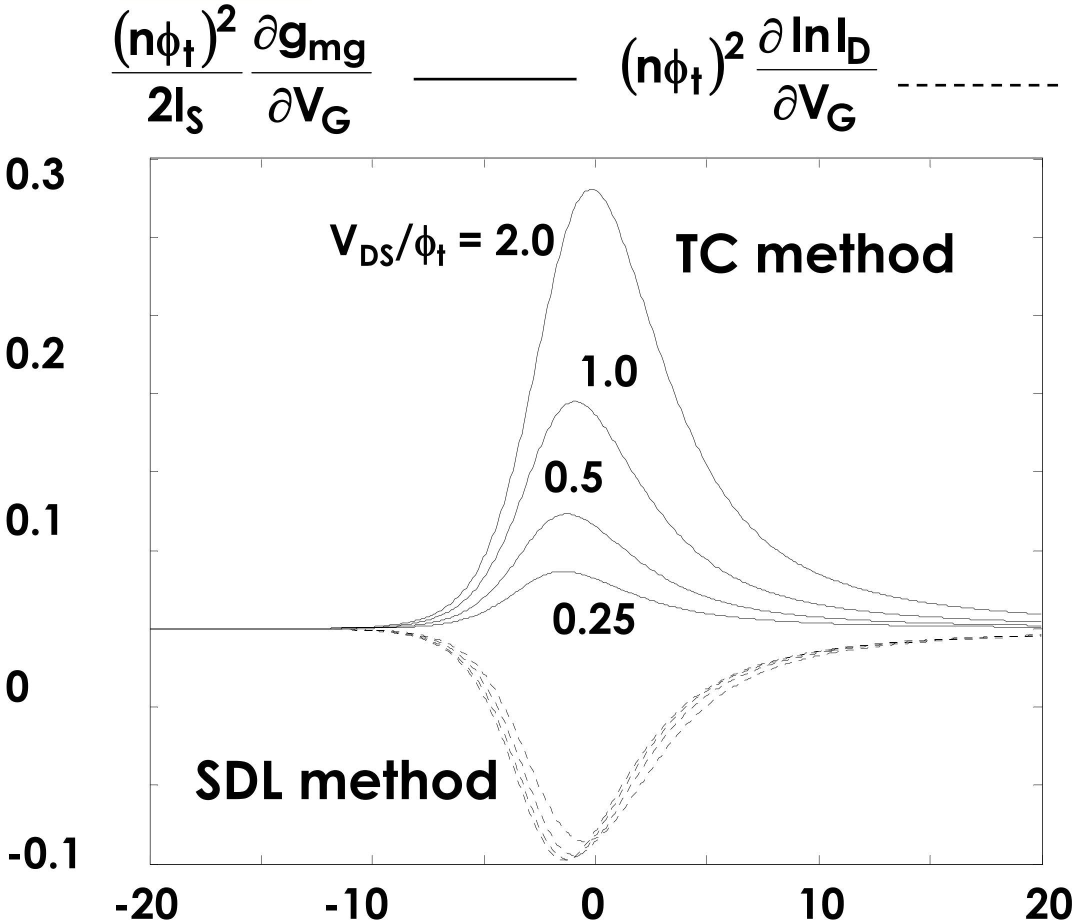


$$V_P = \phi_{Sa} - \phi_0$$

model

$$V_{Text} = V_{FB} + (n-1)\phi_{Sa} + n[\phi_0 + \phi_t(\ln q'_{IS} - 2)]$$

Threshold definition by maximum of $\partial g_m / \partial V_G$ or minimum of $\partial^2 \ln I_D / \partial V_G^2$



$V_{DS} \ll \phi_t$

model

$$\frac{dg_m}{dV_G} = \mu C'_{ox}\frac{W}{L}\frac{V_{DS}}{n\phi_t}\frac{q'_{IS}}{(q'_{IS}+1)^3}$$

min

$q'_{IS} = 0.5$

$$\frac{dg_m}{dV_G} = -2I_S\frac{V_{DS}}{\phi_t}\frac{d^2 \ln I_D}{dV_G^2}$$

Threshold definition by the constant current method

drift component of I_D = diffusion component of I_D

$V_{DS} << \phi_t$ **model**

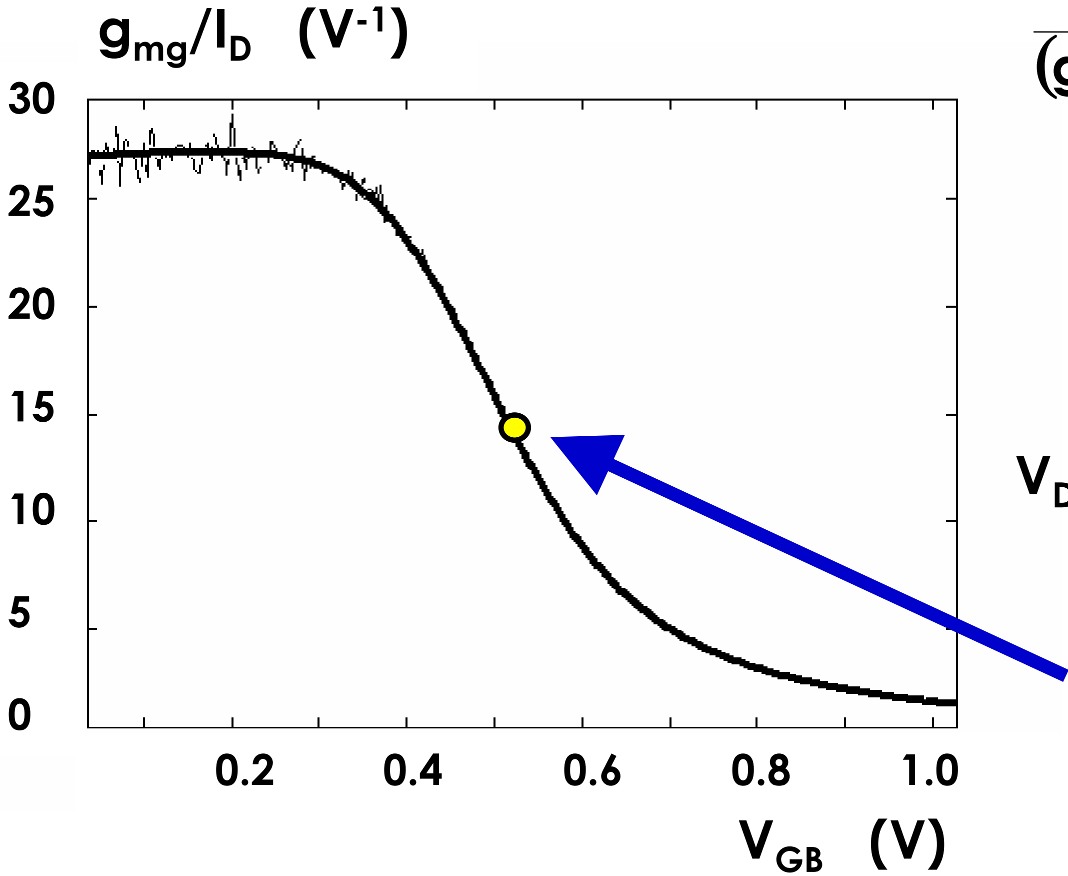
$$I_D = 2I_S \frac{V_{DS}}{\phi_t} q'_{IS} = 2I_{SQ} \frac{W}{L} \frac{V_{DS}}{\phi_t} q'_{IS}$$

I_{SQ} = sheet specific current

$q'_{IS} = 1$

$$\frac{I_D}{(W/L)} = I_{SQ} \frac{V_{DS}}{\phi_t}$$

Threshold definition by g_m/I_D method



$$\frac{g_m/I_D}{(g_m/I_D)_{max}} = \frac{2}{q'_{IS} + q'_{ID} + 2}$$

$q'_{IS} = 1 \Rightarrow V_G = V_{T0}$

$V_{DS} = \phi_t/2 \Rightarrow q'_{ID} = 0.766$

$$\frac{g_m/I_D}{(g_m/I_D)_{max}} = 0.5310$$

Experimental results

0.18 μm CMOS technology (TSMC)

L_m (μm)	V_{T0} (mV) - NMOSFET			
	ELR	SDL	g_m/I_D	CC
0.2	481	490	520	501
0.3	483	478	510	508
0.4	482	468	503	509
0.5	476	463	495	504
0.6	473	455	493	501
0.8	462	448	483	491
2.0	435	423	458	466

Threshold Definition	Physical Meaning	ϕ_S at threshold	Q'_I at threshold
$\phi_S = 2\phi_F + V_C$	Surface concentration of electrons = bulk concentration of holes	$2\phi_F + V_C$	$-(n-1)C'_{ox}\phi_t$
$Q'_I = -nC'_{ox}\phi_t$	50% drop (relative to the peak) in the g_m/I_D curve	$2\phi_F + V_C + \phi_t \ln\left(\frac{n}{n-1}\right)$	$-nC'_{ox}\phi_t$
Extrapolated drain current	No clear physical meaning	Dependent on operating point	Not well defined
$\max\left(\frac{dg_m}{\partial V_G}\right)$	Peak on the second derivative curve	$2\phi_F + V_C + \phi_t \ln\left[\frac{n}{2(n-1)}\right]$	$-nC'_{ox}\frac{\phi_t}{2}$
Constant current	Equal drift and diffusion components of I_D	$2\phi_F + V_C + \phi_t \ln\left(\frac{n}{n-1}\right)$	$-nC'_{ox}\phi_t$