Fundamentals, Computer Implementation and Applications of the Advanced Compact MOSFET (ACM) Model

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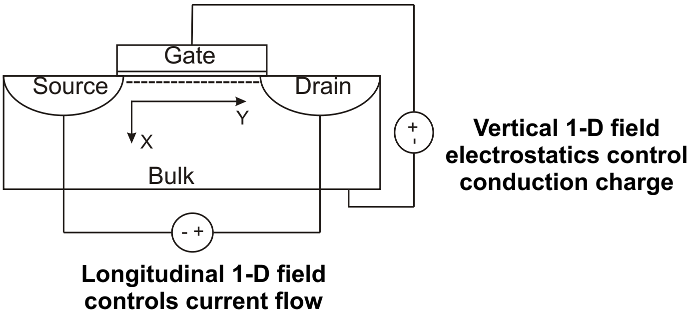
Gradual channel approximation

Considering $\frac{\partial F_x}{\partial x} \gg \frac{\partial F_y}{\partial y}$

We can separate one 2-D problem into two 1-D problems.



Pao-Sah current expression

Drain current expression

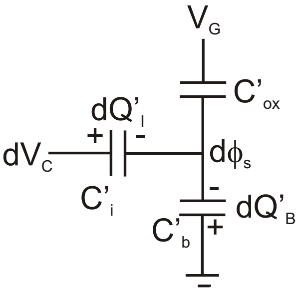
$$I_D = -\mu W Q_I' \frac{dV_c}{dy} \Longrightarrow I_D = \frac{W}{L}\int_{V_D}^{V_S} \mu(-Q_I')dV_C$$

$$I_D = \frac{W}{L}\int_{V_D}^{V_S} \mu(-Q_I')dV_C \begin{cases} I_D = -\mu\frac{W}{L}\int_{\phi_{s0}}^{\phi_{sL}} Q_I'(\phi_s)\frac{dV_C}{d\phi_s}d\phi_s \\ I_D = -\mu\frac{W}{L}\int_{Q_{IS}'}^{Q_{ID}'} Q_I'\frac{dV_C}{dQ_I'}dQ_I' \end{cases}$$

Small-signal output conductance

$$g_d = \left.\frac{\partial I_D}{\partial V_D}\right|_{V_G.V_S} = -\mu\frac{W}{L}Q_I'(V_D, V_G)$$

Capacitive model of the field-effect



$$\Rightarrow \begin{cases} C_i' = -\frac{dQ_I'}{d\phi_s} \cong -\frac{Q_I'}{\phi_t} \\ dQ_I' = C_i'(dV_C - d\phi_s) \end{cases}$$

$$\Downarrow$$

$$dV_C = d\phi_s - \frac{\phi_t}{Q_I'} dQ_I'$$

Drain current (including both drift and diffusion transport mechanisms)

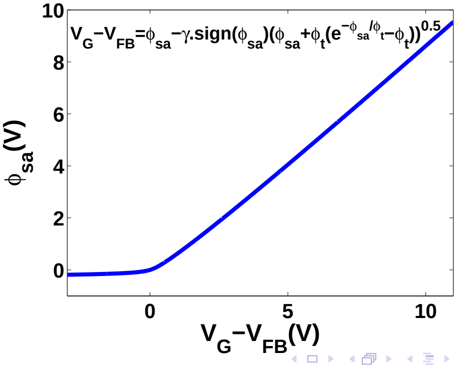
$$I_D = \mu W Q_I' \frac{dV_C}{dy} = -\mu W Q_I' \frac{d\phi_s}{dy} + \mu W \phi_t \frac{dQ_I'}{dy}$$

The ACM model - Fundamentals

$$Q'_I = -C'_{ox}(V_{GB} - V_{FB} - \phi_s) - Q'_B$$

Expanding in power series around $\phi_{sa} = \phi_s \Big|_{Q'_I=0}$ for V_G constant

$$Q'_I = nC'_{ox}(\phi_s - \phi_{sa}) \Rightarrow dQ'_I = nC'_{ox} d\phi_s$$



The ACM model 2 - Drain current

Drain current

$$I_D = -\mu W Q'_I \frac{d\phi_s}{dy} + \mu W \phi_t \frac{dQ'_I}{dy}$$

$$\Downarrow dQ'_I = nC'_{ox} d\phi_s$$

$$I_D = \frac{\mu W}{L}\left[\frac{{Q'_{IS}}^2 - {Q'_{ID}}^2}{2nC'_{ox}} - \phi_t(Q'_{IS} - Q'_{ID})\right]$$

Small-signal output conductance

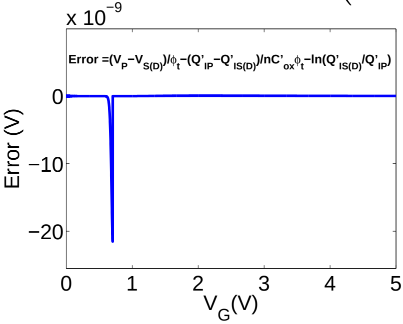
$$g_d = \frac{\partial I_D}{\partial V_D} = \frac{\mu W}{L}\left[\frac{-Q'_{ID}}{nC'_{ox}} + \phi_t\right]\frac{dQ'_{ID}}{dV_D} = -\frac{W}{L}\mu Q'_I(V_D, V_G)$$

The ACM model 3 - Charge evaluation

$$dQ'_{ID}\left(\frac{1}{nC'_{ox}} - \frac{\phi_t}{Q'_{ID}}\right) = dV_D$$

$$\Downarrow$$

$$\frac{V_P - V_{S(D)}}{\phi_t} = \frac{Q'_{IP} - Q'_{IS(D)}}{nC'_{ox}\phi_t} + ln\left(\frac{Q'_{IS(D)}}{Q'_{IP}}\right)$$



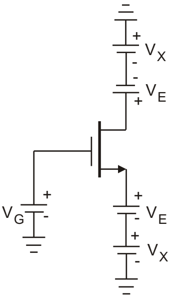
The ACM model 4 - Parameters

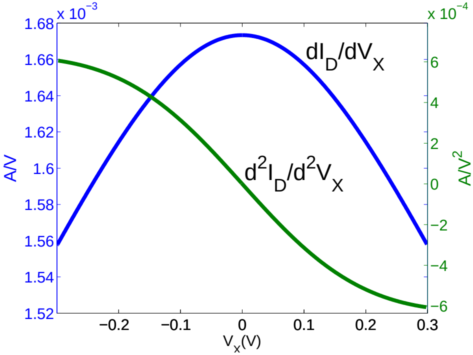
Parameters	Description	Unit
U0	Carrier mobility	m^2/Vs
TOX	Gate oxide thickness	m
VT0	Threshold voltage	V
NA	Acceptor densities	cm^{-3}
VFB	Flat-band voltage	V
GAMMA	Body effect factor	$\sqrt{V}$
LAMBDA	Channel length modulation factor	-
THETA	Mobility reduction factor	1/V
M	Temperature factor	-
VMAX	Velocity saturation	m/s
XJ	Junction depth	m
SIGMA	Drain-induced barrier lowering factor	m^2

Computer Implementation ELDO (Mentor Graphics)

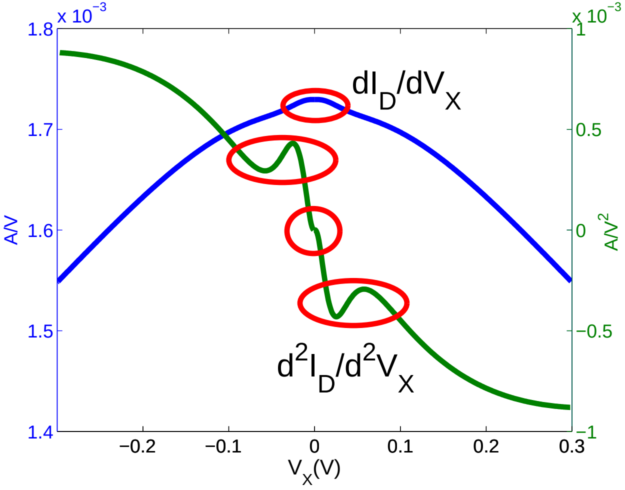
- Using the User Definable Model (UDM) tool.
- Algorithm used for the numerical calculation of the inversion charge in the UCCM obtains relative errors of less than $10^{-7} V$.
- Algorithm used for the numerical calculation of ϕ_{sa} obtains relative errors of less than $10^{-7} V$.
- The model code was written in C.
- It was implemented in ELDO version 6.6, release 2005.3.

Gummel symmetry test - ACM

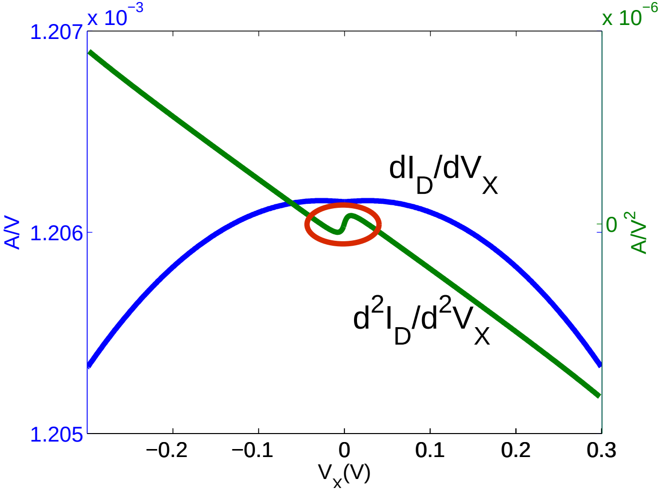




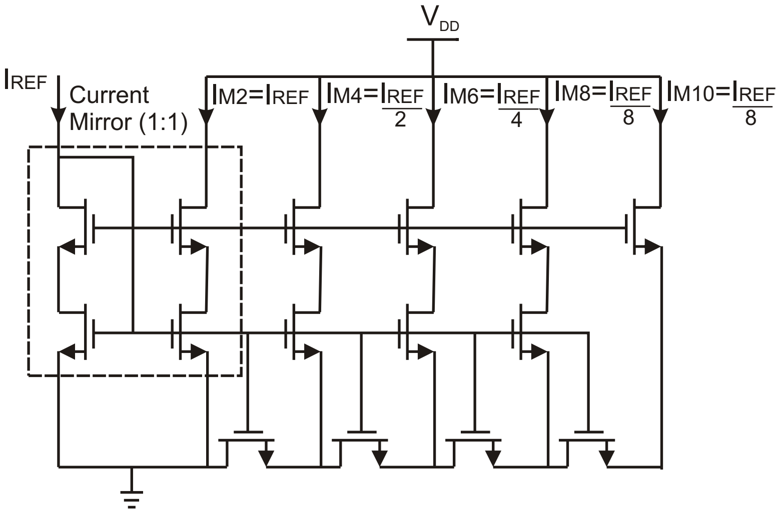
Gummel symmetry test - HiSIM



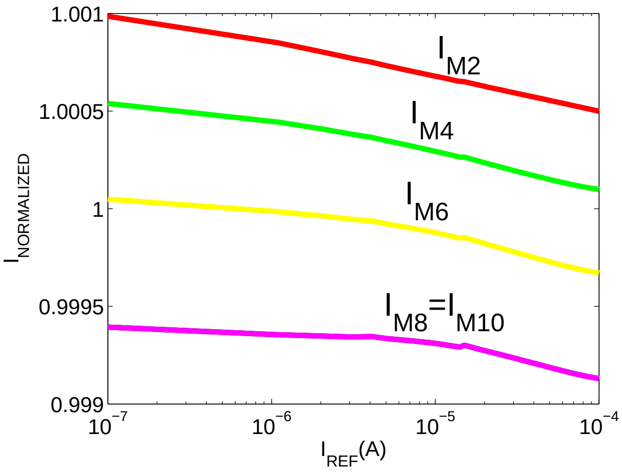
Gummel symmetry test - PSP



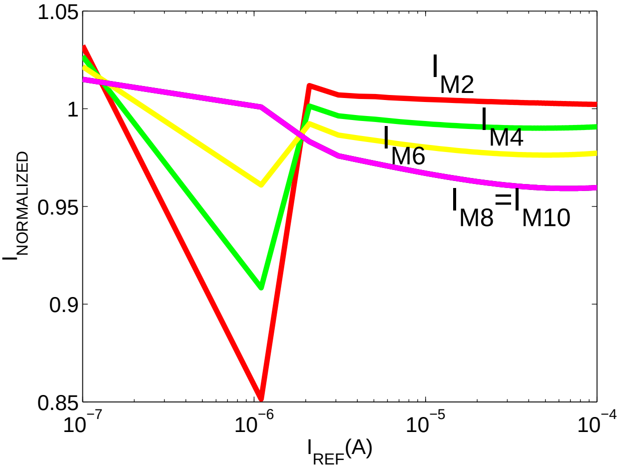
MOSFET binary current divider



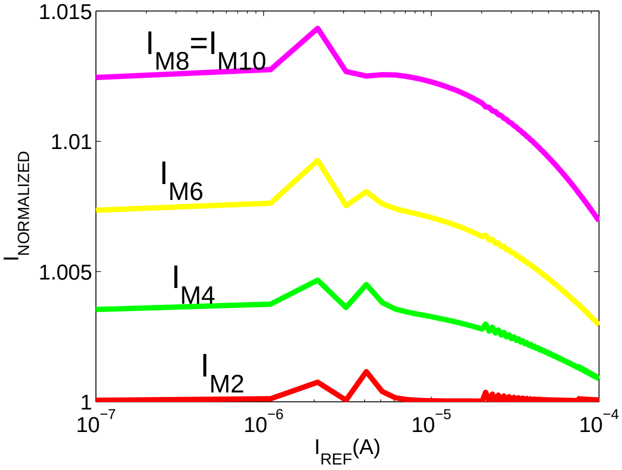
MOSFET binary current divider - ACM



MOSFET binary current divider - HiSIM



MOSFET binary current divider - PSP



Simulation times

Circuit	ACM_{cap}	ACM	EKV	MM11	HiSIM	PSP	BSIM4
schmitfast	1s580ms	1.02	0.84	2.14	1.63	1.87	1.16
schmitslow	2s430ms	1.00	0.70	1.75	1.60	1.93	1.28
g1310	640ms	0.98	0.92	1.28	1.23	1.31	1.19
hussamp	3s020ms	1.07	1.11	1.02	1.06	1.11	1.06
ab_ac	1s400ms	1.03	1.02	2.35	1.63	1.86	1.25
ab_integer	1s370ms	1.00	0.98	1.09	1.01	1.13	0.98

Conclusions

- ACM is a powerful and useful tool for simulation and design because it consists of simple, accurate and single equations (valid in all regions (including accumulation)) together with a small number of physical parameters.

Main references

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- F. N. Fritsch, R. E. Shafer, and W. P. Crowley, “Solution of the transcendental equation $we^w = x$,” Communications of the ACM, vol. 16, no.2, pp.123-124, 1973.