TWK CHARACTERIZATION OF MOSFET WITH BSIM MODEL

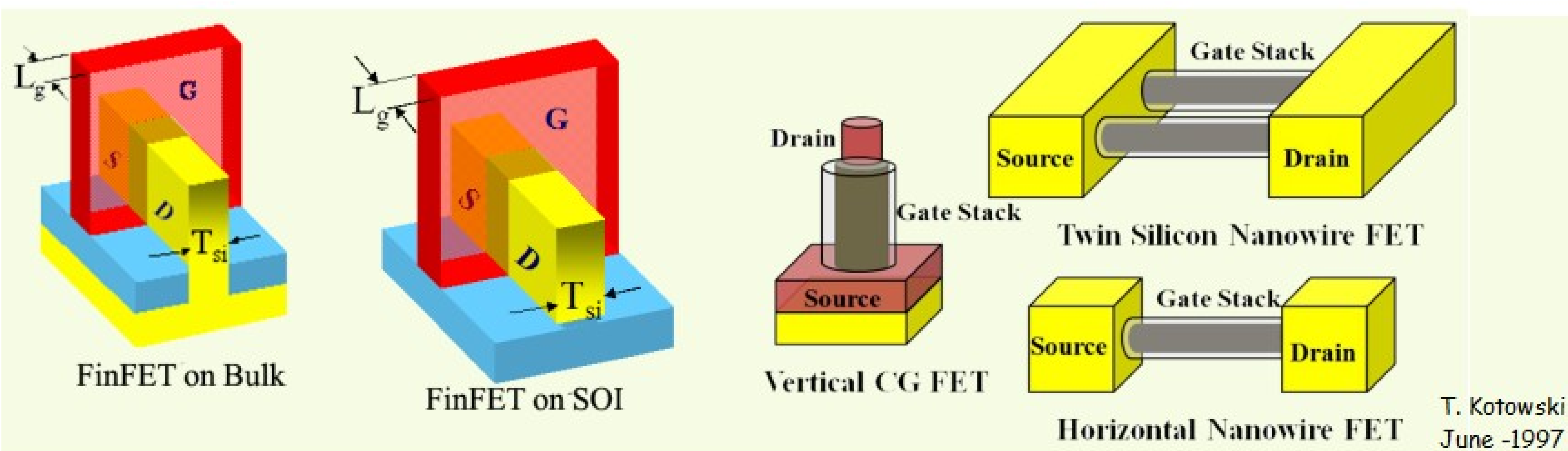
MOSFET Model Based on the BSIM Group University of California Berkeley

http://vxphysics.com/Integrated%20Ci/
http://bsim.berkeley.edu/models/bsimcmg/
http://www-device.eecs.berkeley.edu/~bsim3/

BSIM is the latest industry-standard MOSFET model for deep-submicron digital and analog circuit designs from the BSIM Group at the University of California at Berkeley. BSIM is based on its predecessor, BSIM3v3.1. Its many improvements and enhancements include

* A new intrinsic capacitance model (the Charge Thickness Model), considering the finite charge layer thickness determined by quantum effect, is introduced as capMod 3 It is very accurate in all operating regions.
* Modeling of C-V characteristics at the weak-to-inversion transition is improved.
* The T(ox) dependence is added into the threshold voltage model.
* The flat-band voltage is added as a new model parameter to accurately model MOSFET's with different gate materials.
* Substrate current dependence on the channel length is improved.
* The non-quasi-static (NQS) model is restructured to improve the model accuracy and simulation efficiency. NQS is added in the pole-zero analysis.
* The temperature dependence is added to the diode junction capacitance model.
* The DC junction diode model now supports a resistance-free diode model and a current-limiting feature.
* Option of using C-V inversion charge equations of capMod 0, 1, 2 or 3 to calculate the thermal noise when noiMod == 2 or 4 is added.
* The small negative capacitance of C(gs) and C(gd) in the accumulation-depletion regions is eliminated.
* A separate set of length/width-dependence parameters is introduced in the C-V model to better fit the capacitance data.

BSIM-CMG (Common Multi-Gate) Model



BSIM3v3.1 MOSFET SIMULATION

$P := READPRN("MNLPRN.prn")$

Note:Used Excel to import RMA's data file. Got records " a0=0.7, " into N columns of "name=data" and then into 2N columns by removing " = " as delimiters. Fill in empty cells to get rectangular matrix. Concat """ around text. Then copy into MathCad PRN file format with Rows and 2N Columns, e.g. examine files NCH.PRN or MNLPRN.PRN.

Feature Size:

$L := 0.35\cdot um$

$W := 0.6\cdot um$

$L := 4\cdot UDR$

$W := 4\cdot UDR$

$F(string) :=$
- for $j \in 0..(cols(P)\cdot .5) - 1$
  - for $i \in 0..rows(P) - 1$
    - if $string = \left(P^{\langle 2\cdot j\rangle}\right)_i$
      - $T \leftarrow \left(P^{\langle 2\cdot j+1\rangle}\right)_i$
      - break
- $T \leftarrow if\left[(T = 0)\cdot(i = rows(P) - 1), T_{11,1}, T\right]$

FUNCTION: Find parameters in P that match the string. Flag match failures.

DEFINE: VARIABLES = BSIM3 CHARACTERIZATION DATA EXTRACTED FROM MNL TRANSISTOR

$c2\_vs := cm^2\cdot(volt\cdot sec)^{-1}$	$wr := F("wr")$	$f\_m2 := farad\cdot m^{-2}$	$f\_m2v := farad\cdot m^{-2}\cdot volt^{-1}$
$a0 := F("a0")$	$a1 := F("a1")$		$ags := F("ags")\cdot volt^{-1}$
$alpha0 := F("alpha0")\cdot m\cdot V^{-1}$		$b0 := F("b0")\cdot m$	$b1 := F("b1")\cdot m$
$beta0 := F("beta0")\cdot volt$	$cdsc := F("cdsc")\cdot f\_m2$	$cdscb := F("cdscb")\cdot f\_m2v$	$cdscd := F("cdscd")\cdot f\_m2v$
$cgbo := F("cgbo")$	$a1 := F("a1")$	$a2 := F("a2")$	$cit := F("cit")\cdot f\_m2$
$cj := F("cj")$	$a1 := F("a1")$	$\delta := F("delta")\cdot volt$	$at := F("at")$
$diflens := F("diflens")$	$drout := F("drout")$	$dsub := F("dsub")$	$dvt0 := F("dvt0")$
$dvt0w := F("dvt0w")$	$dvt1 := F("dvt1")$	$dvt1w := F("dvt1w")\cdot m^{-1}$	$dvt2 := F("dvt2")\cdot volt^{-1}$
$dvt2w := F("dvt2w")\cdot volt^{-1}$	$dwb := F("dwb")\cdot m\cdot volt^{-0.5}$	$dwg := F("dwg")\cdot m\cdot volt^{-1}$	$eta0 := F("eta0")$
$etab := F("etab")\cdot volt^{-1}$	$k1 := F("k1")\cdot volt^{0.5}$	$k2 := F("k2")$	$js := F("js")$
$k3 := F("k3")$	$k3b := F("k3b")\cdot volt^{-1}$	$keta := F("keta")\cdot volt^{-1}$	$at := F("at")$
$kt11 := F("kt1l")$	$a1 := F("a1")$	$lint := F("lint")\cdot m$	$at := F("at")$
$mjsw := F("mjsw")$	$a1 := F("a1")$	$nch := F("nch")\cdot m^{-3}$	$nfactor := F("nfactor")$
$ngate := F("ngate")$	$nlx := F("nlx")\cdot m$	$nsub := F("nsub")\cdot m^{-3}$	$at := F("at")$
$pbsw := F("pbsw")$	$pclm := F("pclm")$	$pdiblc1 := F("pdiblc1")$	$pdiblc2 := F("pdiblc2")$
$pdiblcb := F("pdiblcb")\cdot volt^{-1}$	$a1 := F("a1")$	$prwb := F("prwb")\cdot V^{-0.5}$	$prwg := F("prwg")\cdot volt^{-1}$
$pscbe1 := F("pscbe1")\cdot \frac{volt}{m}$	$pscbe2 := F("pscbe2")\cdot \frac{m}{volt}$	$pvag := F("pvag")$	$rdsw := F("rdsw")\cdot ohm\cdot um^1$

$rsh := F("rsh")$ $a1 := F("a1")$ $a2 := F("a2")$ $at := F("at")$

$tc1s := F("tc1s")$ $a1 := F("a1")$ $a2 := F("a2")$ $tnom := F("tnom")$

$tox := F("tox")\cdot m$ $u0 := F("u0")\cdot c2\ \ vs$ $ua := F("ua")\cdot m\cdot V^{-1}$ $ua1 := F("ua1")\cdot m\cdot V^{-1}$

$ub := F("ub")\cdot m^2\cdot V^{-2}$ $ub1 := F("ub1")\cdot m^2\cdot V^{-2}$ $uc := F("uc")\cdot m\cdot V^{-2}$ $uc1 := F("uc1")\cdot m^2\cdot V^{-2}$

$ute := F("ute")$ $vbm := F("vbm")\cdot volt$ $vbx := F("vbx")\cdot volt$ $voff := F("voff")\cdot volt$

$vsat := F("vsat")\cdot\frac{m}{sec}$ $vth0 := F("vth0")\cdot volt$ $w0 := F("w0")\cdot m$ $wint := F("wint")\cdot m$

$wln := F("wln")$ $wl := F("wl")$ $wwn := F("wwn")$ $ww := F("ww")$

$wwlx := F("wwl")$ $xj := F("xj")\cdot m$ $at := F("at")$

$xt := 1.55\cdot 10^{-7}\cdot m$ $fox := 8500\cdot 10^{-10}\cdot m$ $dWeff := 0.3\cdot 10^{-6}\cdot m$ $dLeff := 0.25\cdot 10^{-6}\cdot m$ $wr = 1$ $wln = 1$

PHYSICAL CONSTANTS:

$lint = 1.17\times 10^{-7}\,m$ $wl := -1.46\times 10^{-13}\cdot m^2$

$\varepsilon_o := 8.854\cdot 10^{-14}\cdot\frac{farad}{cm}$ $q \equiv 1.602\cdot 10^{-19}\cdot coul$ $k := 1.380658\cdot 10^{-23}\cdot joule$ $ww = 1.51\times 10^{-14}$

$\varepsilon_{ox} := 3.9\cdot\varepsilon_o$ $\varepsilon_{si} := 11.9\cdot\varepsilon_o$ $Nc := 2.8\cdot 10^{19}\cdot cm^{-3}$ $Nv := 1.04\cdot 10^{19}\cdot cm^{-3}$ $wwn = 1$ $ww := ww\cdot m^2$

$wwlx = -6.02\times 10^{-20}$

DEVICE PARAMETERS:

$T := 300.15$ $V_{bs} := 0\cdot volt$ $nsub := 10^{20}\cdot m^{-3}$

$toxm := tox$ $dL := lint$ $nds := 10^{20}\cdot m^{-3}$ $\delta_1 := 0.001\cdot volt$ 2.2.26 $wwl := wwlx\cdot m^3$

CALCULATIONS:

$$\nu_t := k\cdot\frac{T}{q}\qquad E_{g0} := \left(1.16 - \frac{7.02\times 10^{-4}\cdot T^2}{T + 1108}\right)\cdot volt\qquad ni := 1.45\cdot 10^{10}\cdot\left(\frac{T}{300.15}\right)^{1.5}\exp\left(21.5565981 - \frac{E_{g0}\cdot q}{2k\cdot T}\right)\cdot cm^{-3}$$

$W = 1.4\times 10^{-6}\,m$

$L = 1.4\times 10^{-6}\,m$

$$dWp := wint + \frac{wl}{L^1} + \frac{ww}{\left(1.4\times 10^{-6}\,m\right)^1} + \frac{wwl}{\left(1.4\times 10^{-6}\,m\right)^1\cdot\left(1.4\times 10^{-6}\,m\right)^1}\qquad W_{effp} := W - 2\cdot dWp\qquad L_{eff} := L - 2\cdot lint$$

$$C_{ox} := \frac{\varepsilon_{ox}}{tox}\qquad \phi_s := 2\cdot\frac{k\cdot T}{q}\cdot\ln\left(\frac{nch}{ni}\right)\qquad V_{bx} := \phi_s - \frac{q\cdot nch\cdot xt^2}{2\cdot\varepsilon_{si}}\qquad V_{bi} := \frac{k\cdot T}{q}\cdot\ln\left(\frac{nch\cdot nds}{ni^2}\right)$$

$$\gamma_1 := \frac{\sqrt{2\cdot q\cdot\varepsilon_{si}\cdot nch}}{C_{ox}}\qquad \gamma_2 := \frac{\sqrt{2\cdot q\cdot\varepsilon_{si}\cdot nsub}}{C_{ox}}$$

Berkeley example defines k1 and k2

$$K_2 := \frac{(\gamma_1 - \gamma_2)\cdot\left(\sqrt{\phi_s - V_{bx}} - \sqrt{\phi_s}\right)}{\left[2\cdot\sqrt{\phi_s}\cdot\left(\sqrt{\phi_s - vbm} - \sqrt{\phi_s}\right)\right] + vbm}$$

$$K_1 := \gamma_2 - 2K_2\cdot\sqrt{\phi_s - vbm}$$

$$V_{bc} := 0.9\cdot\left[\phi_s - \left(\frac{K_1}{2\cdot K_2}\right)^2\right]$$

$$V_{bseff} := V_{bc} + 0.5\cdot\left[V_{bs} - V_{bc} - \delta_1 + \sqrt{\left(V_{bs} - V_{bc} - \delta_1\right)^2 - 4\cdot\delta_1\cdot V_{bc}}\right]$$

$$X_{depo} := \sqrt{\frac{2\cdot\varepsilon_{si}\cdot\phi_s}{q\cdot nch}}$$

2.1.17 B1.1

$$X_{dep} := \sqrt{\frac{\left[2\cdot\varepsilon_{si}\cdot\left(\phi_s - V_{bs}\right)\right]}{q\cdot nch}}$$

$$K_{lox} := K_1\cdot\frac{tox}{toxm}$$

$$l_{t0} := \sqrt{\frac{\varepsilon_{si}\cdot X_{depo}}{C_{ox}}}$$

$$l_t := \sqrt{\frac{\varepsilon_{si}\cdot X_{dep}}{C_{ox}}}\cdot\left(1 + dvt2\cdot V_{bseff}\right)$$

2.1.16

$$l_{tw} := \sqrt{\frac{\varepsilon_{si}\cdot X_{dep}}{C_{ox}}}\cdot\left(1 + dvt2w\cdot V_{bseff}\right)$$

$$C_d := \frac{\varepsilon_{si}}{X_{dep}}$$

$$V_{fb} := vth0 - \phi_s - K_1\cdot\sqrt{\phi_s}$$

A_{10}

$$V_{th0ox} := vth0 - K_1\cdot\sqrt{\phi_s}$$

$$K_{1ox} := K_1 \qquad K_{2ox} := K_2$$

Note: Circular defn. Weff is function of Vgsteff(Vth). Therefore Substituted Weffp for Weff in Dvtw.

$$Dvtw := -dvt0w\cdot\left(\exp\left(-dvt1w\cdot\frac{W_{effp}\cdot L_{eff}}{2\cdot l_{tw}}\right) + 2\cdot\exp\left(-dvt1w\cdot\frac{W_{effp}\cdot L_{eff}}{l_{tw}}\right)\right)\cdot\left(V_{bi} - \phi_s\right)$$

$$Dvtw = 7.152\times 10^{-3}\cdot volt$$

$$Dvt := -dvt0\cdot\left(\exp\left(-dvt1\cdot\frac{L_{eff}}{2\cdot l_t}\right) + 2\cdot\exp\left(-dvt1\cdot\frac{L_{eff}}{l_t}\right)\right)\cdot\left(V_{bi} - \phi_s\right)$$

$$Dvt = -0.233\cdot volt$$

$$eta0 = 0$$

$$D\left(V_{ds}\right) := -1\cdot\left(\exp\left(-dsub\cdot\frac{L_{eff}}{2\cdot l_{t0}}\right) + 2\cdot\exp\left(-dsub\cdot\frac{L_{eff}}{l_{t0}}\right)\right)\cdot\left(eta0 + etab\cdot V_{bseff}\right)\cdot V_{ds}$$

$$D(6\cdot V) = 0\cdot V$$

$$Do := K_{1ox}\cdot\left(\sqrt{1 + \frac{nlx}{L_{eff}}} - 1\right)\cdot\sqrt{\phi_s} + \left(k3 + k3b\cdot V_{bseff}\right)\cdot\frac{tox}{W_{effp} + w0}\cdot\phi_s$$

$$Do = -0.012\cdot volt$$

$$To := dvt2\cdot V_{bseff} \qquad To = 0$$

$$V_{th0ox} = 0.85\cdot volt$$

$$V_{th}\left(V_{ds}\right) := V_{th0ox} + K_{1ox}\cdot\sqrt{\phi_s - V_{bseff}} - K_{2ox}\cdot V_{bseff} + Do + Dvtw + Dvt + D\left(V_{ds}\right)$$

$$V_{th}(0\cdot V) = 0.638\cdot V$$

2.2.11

$$V_{thx}(V_{ds}) := \left[vth0 + K_1\cdot\left(\sqrt{\phi_s - V_{bs}} - \sqrt{\phi_s}\right)\right] - \left[K_2\cdot V_{bs} + K_1\cdot\left(\sqrt{1 + \frac{nlx}{L_{eff}}} - 1\right)\cdot\sqrt{\phi_s}\right] \qquad V_{thx}(0\cdot V) = 0.876\cdot V$$

$$temp4(V_{ds}) := nfactor\cdot\frac{C_d}{C_{ox}} + \frac{(cdsc + cdscd\cdot V_{ds} + cdscb\cdot V_{bseff})\cdot\left(exp\left(\frac{-dvt1\cdot L_{eff}}{2l_t}\right) + 2\cdot exp\left(\frac{-dvt1\cdot L_{eff}}{l_t}\right)\right)}{C_{ox}} + \frac{cit}{C_{ox}}$$

$$To(V_{ds}) := (3 + 8\cdot temp4(V_{ds}))^{-1} \qquad n2(V_{ds}) := (1 + 3\cdot temp4(V_{ds}))\cdot To(V_{ds})$$

$$n(V_{ds}) := if(temp4(V_{ds}) > -0.5, 1 - temp4(V_{ds}), n2(V_{ds})) \qquad n(3\cdot volt) = 0.384$$

$$V_{gsteff}(V_{gs}, V_{ds}) := \frac{2\cdot n(V_{ds})\cdot\nu_t\cdot ln\left(1 + exp\left(\frac{V_{gs} - V_{th}(V_{ds})}{2\cdot n(V_{ds})\cdot\nu_t}\right)\right)}{1 + 2\cdot n(V_{ds})\cdot C_{ox}\cdot\sqrt{\frac{2\cdot\phi_s}{q\cdot\varepsilon_{si}\cdot nch}}\cdot exp\left(\frac{-V_{gs} - V_{th}(V_{ds}) - 2\cdot voff}{2\cdot n(V_{ds})\cdot\nu_t}\right)}$$

$$dW(V_{gs}, V_{ds}) := dWp + dwg\cdot V_{gsteff}(V_{gs}, V_{ds}) + dwb\cdot\left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right)$$

$$W_{eff}(V_{gs}, V_{ds}) := W - 2\cdot dW(V_{gs}, V_{ds})$$

$$\mu_{eff}(V_{gs}, V_{ds}) := \frac{u0}{1 + (ua + uc\cdot V_{bseff})\cdot\left(\frac{V_{gs} + V_{th}(V_{ds})}{tox}\right) + ub\cdot\left(\frac{V_{gs} + V_{th}(V_{ds})}{tox}\right)^2}$$

$$\sigma(V_{gs}, V_{ds}) := \frac{W}{L}\cdot\mu_{eff}(V_{gs}, V_{ds})\cdot C_{ox} \qquad \theta_{th}(L) := exp\left(\frac{-L}{2\cdot l_t}\right) + 2\cdot exp\left(\frac{-L}{l_t}\right)$$

Velocity, ν, is not used explicitly in model

$$E_{sat}(V_{gs}, V_{ds}) := \frac{2\cdot vsat}{\mu_{eff}(V_{gs}, V_{ds})}$$

$$\upsilon := if\left[\frac{\mu_{eff}\cdot E_{eff}}{1 + \left(\frac{E_{eff}}{E_{sat}}\right)} > vsat, vsat, \frac{\mu_{eff}\cdot E_{eff}}{1 + \left(\frac{E_{eff}}{E_{sat}}\right)}\right]$$

$$E_{eff}(V_{gs}, V_{ds}) := \frac{V_{gs} + V_{th}(V_{ds})}{6\cdot tox}$$

$$A_{bulkx}(V_{gs},V_{ds}) := 1 - ags \cdot V_{gsteff}(V_{gs},V_{ds}) \cdot \left(\frac{L_{eff}}{L_{eff} + 2\cdot\sqrt{xj \cdot X_{dep}}}\right)^2$$

$$A_{bulk}(V_{gs},V_{ds}) := \left[1 + \frac{K_{lox}}{2\cdot\sqrt{\phi_s - V_{bseff}}} \cdot \left[\frac{a0 \cdot L_{eff}}{L_{eff} + 2\cdot\sqrt{xj \cdot X_{dep}}} \cdot \left(A_{bulkx}(V_{gs},V_{ds})\right) + \frac{b0}{W_{effp} + b1}\right]\right] \cdot \frac{1}{1 + keta \cdot V_{bseff}}$$

$$V_{dsat}(V_{gs},V_{ds}) := \frac{E_{sat}(V_{gs},V_{ds}) \cdot L_{eff} \cdot \left(V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t\right)}{A_{bulk}(V_{gs},V_{ds}) \cdot E_{sat}(V_{gs},V_{ds}) \cdot L_{eff} + \left(V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t\right)}$$

$$V_{dseff}(V_{gs},V_{ds}) := V_{dsat}(V_{gs},V_{ds}) - \frac{1}{2}\cdot\left[\left(V_{dsat}(V_{gs},V_{ds}) - V_{ds} - \delta\right) + \sqrt{\left(V_{dsat}(V_{gs},V_{ds}) - V_{ds} - \delta\right)^2 + 4\cdot\delta\cdot V_{dsat}(V_{gs},V_{ds})}\right]$$

$$l_{itl} := \sqrt{3 \cdot xj \cdot tox}$$

$$V_{aclm}(V_{gs},V_{ds}) := \frac{A_{bulk}(V_{gs},V_{ds}) \cdot E_{sat}(V_{gs},V_{ds}) \cdot L_{eff}}{pclm \cdot A_{bulk}(V_{gs},V_{ds}) \cdot E_{sat}(V_{gs},V_{ds}) \cdot l_{itl}} \cdot \left(V_{ds} - V_{dseff}(V_{gs},V_{ds})\right)$$

$$\theta_{rout} := pdiblc1 \cdot \left(\exp\left(-drout \cdot \frac{L_{eff}}{2 \cdot l_{t0}}\right) + 2\cdot\exp\left(-drout \cdot \frac{L_{eff}}{l_{t0}}\right)\right) + pdiblc2$$

$$wr = 1$$

$$R_{ds}(V_{gs},V_{ds}) := \frac{rdsw \cdot \left[1 + prwg \cdot V_{gsteff}(V_{gs},V_{ds}) + prwb \cdot \left(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s}\right)\right]}{{W_{effp}}^{1}}$$

$$V_{adiblc}(V_{gs},V_{ds}) := \frac{\left(V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t\right)}{\theta_{rout} \cdot \left(1 + pdiblcb \cdot V_{bseff}\right)} \cdot \left(1 - \frac{A_{bulk}(V_{gs},V_{ds}) \cdot V_{dsat}(V_{gs},V_{ds})}{A_{bulk}(V_{gs},V_{ds}) \cdot V_{dsat}(V_{gs},V_{ds}) + V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t}\right)$$

$$V_{Asat}(V_{gs},V_{ds}) := E_{sat}(V_{gs},V_{ds}) \cdot L_{eff} + V_{dsat}(V_{gs},V_{ds}) + 2\cdot R_{ds}(V_{gs},V_{ds}) \cdot vsat \cdot C_{ox} \cdot W_{eff}(V_{gs},V_{ds}) \cdot V_{gsteff}(V_{gs},V_{ds}) \cdot \left[1 - \frac{A_{bulk}(V_{gs},V_{ds}) \cdot V_{dsat}(V_{gs},V_{ds})}{2\cdot\left(V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t\right)}\right]$$

$$V_A(V_{gs},V_{ds}) := V_{Asat}(V_{gs},V_{ds}) + \left(1 + \frac{pvag \cdot V_{gsteff}(V_{gs},V_{ds})}{E_{sat}(V_{gs},V_{ds}) \cdot L_{eff}}\right) \cdot \left(\frac{1}{V_{aclm}(V_{gs},V_{ds})} + \frac{1}{V_{adiblc}(V_{gs},V_{ds})}\right)^{-1}$$

$$I_{dso}(V_{gs},V_{ds}) := \frac{W_{eff}(V_{gs},V_{ds})\cdot\mu_{eff}(V_{gs},V_{ds})\cdot C_{ox}\cdot V_{gsteff}(V_{gs},V_{ds})\cdot\left[1 - A_{bulk}(V_{gs},V_{ds})\cdot\frac{V_{dseff}(V_{gs},V_{ds})}{2\cdot\left(V_{gsteff}(V_{gs},V_{ds}) + 2\cdot\nu_t\right)}\right]\cdot V_{dseff}(V_{gs},V_{ds})}{L_{eff}\cdot\left(1 + \frac{V_{dseff}(V_{gs},V_{ds})}{E_{sat}(V_{gs},V_{ds})\cdot L_{eff}}\right)}$$

$$\frac{1}{V_{ascbe}} = \frac{pscbe2}{L_{eff}}\cdot\exp\left(\frac{-pscbe1\cdot l_{itl}}{V_{ds} - V_{dseff}}\right)$$

$alpha1 := 0\cdot volt^{-1}$ alpha1 added in BSIM3V3.2. Rouchoz has not yet extracted.

$$I_{sub}(V_{gs},V_{ds}) := \frac{alpha0 + alpha1\cdot L_{eff}}{L_{eff}}\cdot\left(V_{ds} - V_{dseff}(V_{gs},V_{ds})\right)\cdot\exp\left(\frac{-beta0}{V_{ds} - V_{dseff}(V_{gs},V_{ds})}\right)\cdot\frac{I_{dso}(V_{gs},V_{ds})}{1 + R_{ds}(V_{gs},V_{ds})\cdot\frac{I_{dso}(V_{gs},V_{ds})}{V_{dseff}(V_{gs},V_{ds})}}\cdot\left(1 + \frac{V_{ds} - V_{dseff}(V_{gs},V_{ds})}{V_A(V_{gs},V_{ds})}\right)$$

$$I_{ds}(V_{gs},V_{ds}) := \frac{I_{dso}(V_{gs},V_{ds})}{1 + \frac{R_{ds}(V_{gs},V_{ds})\cdot I_{dso}(V_{gs},V_{ds})}{V_{dseff}(V_{gs},V_{ds})}}\cdot\left(1 + \frac{V_{ds} - V_{dseff}(V_{gs},V_{ds})}{V_A(V_{gs},V_{ds})}\right)\cdot\left[1 + \left(V_{ds} - V_{dseff}(V_{gs},V_{ds})\right)\cdot\left(\frac{pscbe2}{L_{eff}}\cdot\exp\left(\frac{-pscbe1\cdot l_{itl}}{V_{ds} - V_{dseff}(V_{gs},V_{ds})}\right)\right)\right]\cdot\frac{10^3}{amp}$$

$Vgs := 0..6$ $Vds := 0, 0.5..9$ $R_{ds}(3\cdot volt, 4\cdot volt) = 601.46\cdot\Omega$ $I_{sub}(14\cdot V, 10\cdot V) = 2.407\times 10^{-4}A$

MSIM3V3 Model for MOS Transistor Drain Current (Id) versus Drain to Source Voltage (Vds)