BSIM4v4.7.0
Enhancements and Bug Fixes

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BSIM4v4.7.0 Bug-fix

Code inconsistency in files b4set.c and b4ld.c:

File b4set.c Line: 208

```
if (!model->BSIM4toxmGiven)
   model->BSIM4toxm = model->BSIM4toxe;
```

File b4temp.c Line: 134

```
else if ((!model->BSIM4toxeGiven) && (model->BSIM4toxpGiven))
{
    model->BSIM4toxe = model->BSIM4toxp + model->
BSIM4dtox;
if (!model->BSIM4toxmGiven)
      model->BSIM4toxm = model->BSIM4toxe; }
```

Reported by WENLI WANG, CADENCE

BSIM4v4.7.0 Bug-Fix

- **Source and Drain diode current shows unphysical and high values for Aseff=Pseff=Adeff=Pdeff=0, although it shows correct prediction for positive values of Aseff, Pseff, Adeff and Pdeff.**

- **Action:**
  - **If Aseff, Pseff, Adeff, Pdeff are negative, their values are set to '0' .**
  - **For Aseff && Pseff = 0, source side diode is turned off by setting SourceSaturationCurrent=0.0**
  - **For Adeff && Pdeff = 0, drain side diode is turned off by setting DrainSaturationCurrent=0.0**

(Code with red font is replaced by that with blue.)

Reported by Jushan Xie, CADENCE

Bug-fix Assistance: Jushan Xie, Samuel Mertens (ANSOFT)

BSIM4v4.7.0 Bug-Fix

```
if (here->BSIM4sourcePerimeterGiven)                    [Source side]
{ if (model->BSIM4perMod == 0)
here->BSIM4Pseff = here->BSIM4sourcePerimeter;
 else
here->BSIM4Pseff = here->BSIM4sourcePerimeter
- pParam->BSIM4weffCJ * here->BSIM4nf;
}  b4temp.c (1742-1748)

if (here->BSIM4sourcePerimeterGiven)                    [Source side]
{ if (here->BSIM4sourcePerimeter == 0.0)
here->BSIM4Pseff = 0.0;
else if (here->BSIM4sourcePerimeter < 0.0)
{ printf("Warning: Source Perimeter is specified as negative, it is set to zero.\n");
here->BSIM4Pseff = 0.0;}
else
{ if (model->BSIM4perMod == 0)
here->BSIM4Pseff = here->BSIM4sourcePerimeter;
Else
here->BSIM4Pseff = here->BSIM4sourcePerimeter - pParam->BSIM4weffCJ * here->BSIM4nf;
}
}
```

BSIM4v4.7.0 Bug-Fix

```
if (here->BSIM4drainPerimeterGiven)                    [Drain side]
{ if (model->BSIM4perMod == 0)
here->BSIM4Pdeff = here->BSIM4drainPerimeter;
 else
here->BSIM4Pdeff = here->BSIM4drainPerimeter
-pParam->BSIM4weffCJ * here->BSIM4nf;
}  b4temp.c (1758-1763)

if (here->BSIM4drainPerimeterGiven)                    [Drainside]
{ if (here->BSIM4drainPerimeter == 0.0)
here->BSIM4Pdeff = 0.0;
else if (here->BSIM4drainPerimeter < 0.0)
{ printf("Warning: Drain Perimeter is specified as negative, it is set to zero.\n");
here->BSIM4Pdeff = 0.0;}
else
{ if (model->BSIM4perMod == 0)
here->BSIM4Pdeff = here->BSIM4drainPerimeter;
Else
here->BSIM4Pdeff = here->BSIM4drainPerimeter - pParam->BSIM4weffCJ * here->BSIM4nf;
}
}
```

BSIM4v4.7.0 Bug-Fix

```
if ((here->BSIM4Aseff <= 0.0) && (here->BSIM4Pseff <= 0.0))        [Source side]
        {  SourceSatCurrent = 1.0e-14;
        }          b4ld.c (664-666), b4temp.c (1854-1856)

if ((here->BSIM4Aseff <= 0.0) && (here->BSIM4Pseff <= 0.0))        [Source side]
        {  SourceSatCurrent = 0.0;
        }

if ((here->BSIM4Adeff <= 0.0) && (here->BSIM4Pdeff <= 0.0))        [Drain side]
        {  DrainSatCurrent = 1.0e-14;
        }          b4ld.c (762-764), b4temp.c (1912-1914)

if ((here->BSIM4Adeff <= 0.0) && (here->BSIM4Pdeff <= 0.0))        [Drain side]
        {  DrainSatCurrent = 0.0;
        }
```

BSIM4v4.7.0 Bug-Fix

```
if (here->BSIM4Aseff < 0.0)
        here->BSIM4Aseff = 0.0;
```

b4temp.c (1778)

```
if (here->BSIM4Adeff < 0.0)
        here->BSIM4Adeff = 0.0;
```

b4temp.c (1785)

BSIM4v4.7.0 Bug-Fix

Redundant 'toxe' term appearing in the Igc formulation:

BSIM 4.6.4 users manual Equ 4.6.1

$$PIGCD = \frac{B \cdot TOXE}{V_{gsteff}^2}\left(1 - \frac{V_{dseff}}{2 \cdot V_{gsteff}}\right)$$

Code implementation:

pParam->BSIM4Bechvb = (model->BSIM4type == NMOS) ? 7.45669e11 : 1.16645e12; **b4temp.c (1276)**

pParam->BSIM4Bechvb *= -toxe; **b4temp.c (1285)**

T11 = pParam->BSIM4Bechvb * toxe; **b4ld.c (2387)**

Fix: T11 = -pParam-BSIM4Bechvb

Reported by Kyoon-Hyoung Kim, Hynix Semiconductor

BSIM4v4.7.0 Enhancements

Requested by

Wenwei Yang and Jung-Suk Goo
Globalfoundries

Enhancement of GIDL/GISL Model

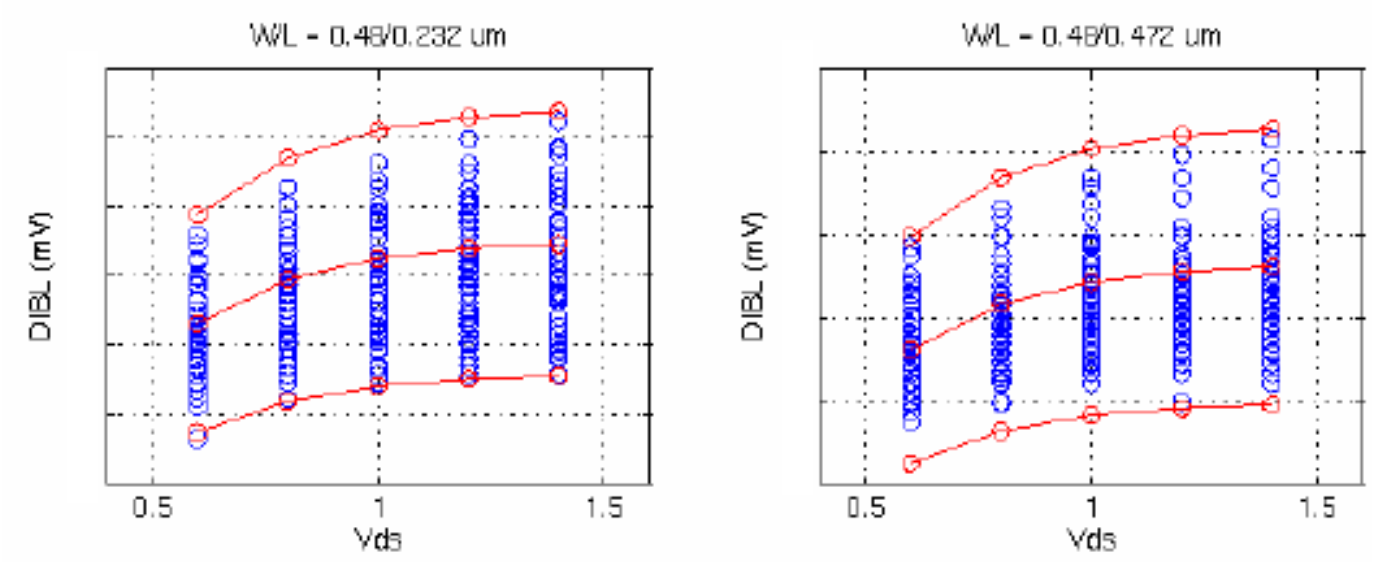
- **GIDLMOD=1 is introduced to decouple Vd from Vg through new parameters RGIDL, KGIDL and FGIDL (same for GISL)**

$$I_{GIDL} = AGIDL \cdot W_{diod} \cdot Nf \cdot \frac{V_{ds} - RGIDL \cdot V_{gse} - EGIDL + V_{fbsd}}{3 \cdot T_{oxe}} \cdot \exp\left(-\frac{3 \cdot T_{oxe} \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL}\right) \cdot \exp\left(\frac{KGIDL}{V_{ds} - FGIDL}\right)$$

- **Status:**
  - Binnable parameters RGIDL, KGIDL, FGIDL introduced with new Mod selector, gidlMod=1
  - Backward compatible

Enhancement of DIBL/Rout Model

- **Existing DIBL /Rout model in BSIMSOI is proposed to enhance with additional term DVTP5, to better capture Vds effect in long channel device**



- Current formulation cannot capture this asymmetric variation

Enhancement of DIBL/Rout Model

- **The tanh() function enables capturing the effect**
- **Proposal: Implement the enhanced model in BSIM4**

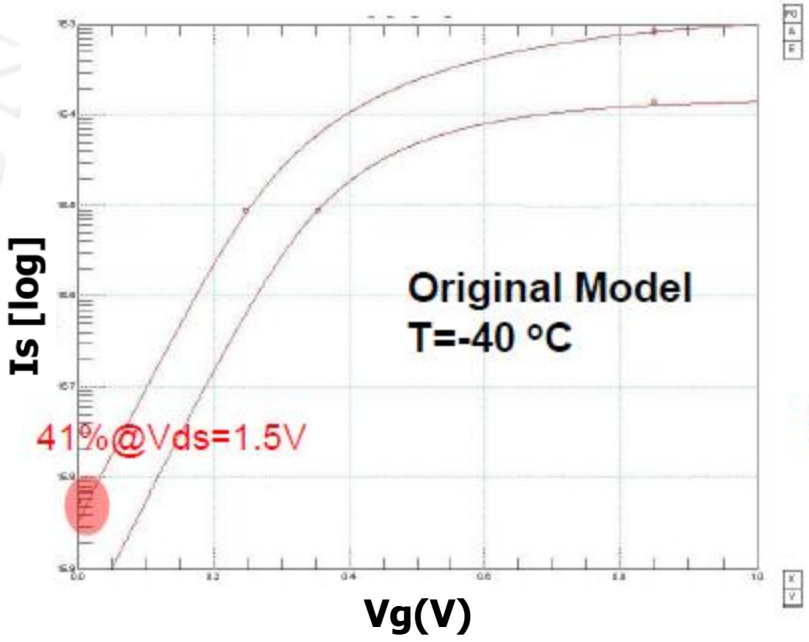
$$V_{th} = V_{th0} + ... - \left(DVTP5 + \frac{DVTP2}{L_{eff}^{DVTP3}} \right) \cdot \tanh\left(DVTP4 \cdot V_{ds} \right)$$

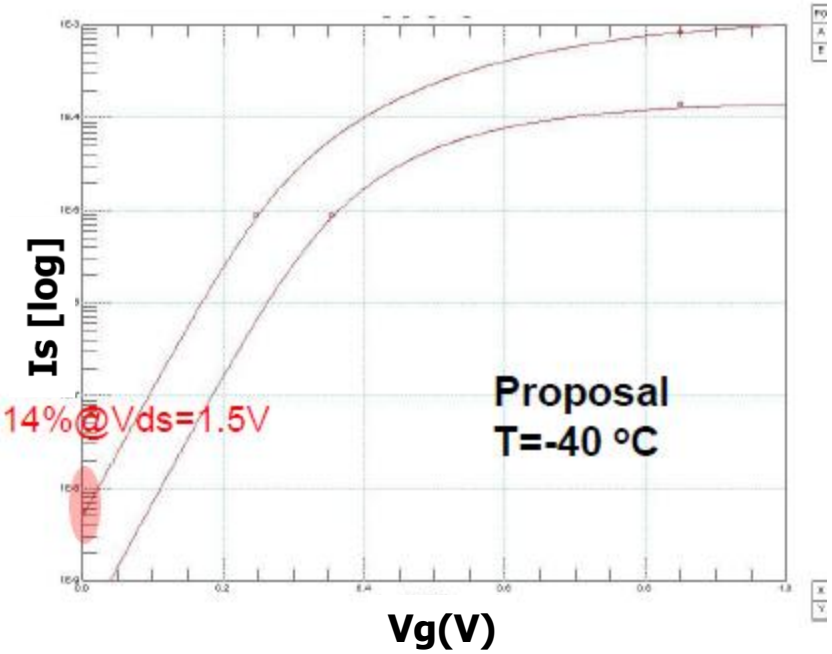
New term forBSIM4

- **Enhanecments:**
- **Proposed model implemented with Binnable parameters DVTP2, DVTP3, DVTP4, DVTP5**
- **Backward compatible**

Temperature Dependence of Sub-threshold Leakage Current

- **Improved formulations are suggested (reviewed by IBM) to capture temperature dependence of Leakage Current:**





Error = (Model-Si)/Si

Temperature Dependence of Subthreshold Leakage Current

- **Suggested equations:**
  - Nfactor(T)=nfactor(Tnom)+tnfactor*(T/Tnom-1)
  - ETA0(T)=ETA0(Tnom)+TETA0*(T/Tnom-1)
  - voffCV(T)=voffCV*(1.0+tvoffCV*(T-Tnom))
- **Enhancements**
  - **Suggested temperature dependence model has been implemented with new Binnable parameters (Red fonts)**
  - **Backward Compatible**

CODE MODIFICATIONS

- **List of code modification:**

Enhancements/ Bug-Fix	REPORTED BY	File	Line(s)
Code inconsistency	Wenli Wang, CADENCE	b4temp.c	134
Diode ‘off’ current	Jushan Xie, CADENCE	b4ld.c, b4temp.c	664, 762 1742,1758,1778,1785, 1854,1913
Igc formulation	Kyoon-Hyoung Kim HYNIX SEMI	b4ld.c	2387
New GIDL/GIDL	Wenwei Yang, Jung-Suk Goo GLOBAL-FOUNDRIES	b4.c, b4ld.c, b4mask.c, b4mpar.c, b4set.c, b4temp.c, bsim4def.h	Various locations
New DIBL/Rout			
Temp. Dependence of sub-threshold current			

Diode Ideality Factor

- Limit the minimum value of diode ideality factors NJD and NJS
  - Warning when these values are below 0.7.
  - Limit the minimum value to 0.1.

MOD Switch for mtrlMod=0,1 Compatibility

- New materials MOD (mtrlMod):
  - mtrlMod=0 and mtrlMod=1 behaves differently even with EOT=TOXE and EPSROX=3.9.
  - Reported by Wenwei Yang (GlobalFoundries)
  - **“mtrlCompatMod” added to make the two consistent**

Investigation and Fixing of mtrlMod=0,1 Discrepancy

- Physical oxide thickness calculation

  T_{oxp} is a complex function of EOT — for mtrlMod=1

  T_{oxp} = TOXE – DTOX — for mtrlMod=0

  Fix: New MOD switch mtrlCompatMod introduced

  T_{oxp} = EOT * EPSROX / 3.9 – DTOX when mtrlCompatMod=1 and mtrlMod=1

- Effective field for mobility calculation

  E_{eff} (V_{gsteff} + 2V_{th} - 2(V_{fb}+Φ_{st})) — for mtrlMod=1

  E_{eff} (V_{gsteff} + 2V_{th}) — for mtrlMod=0

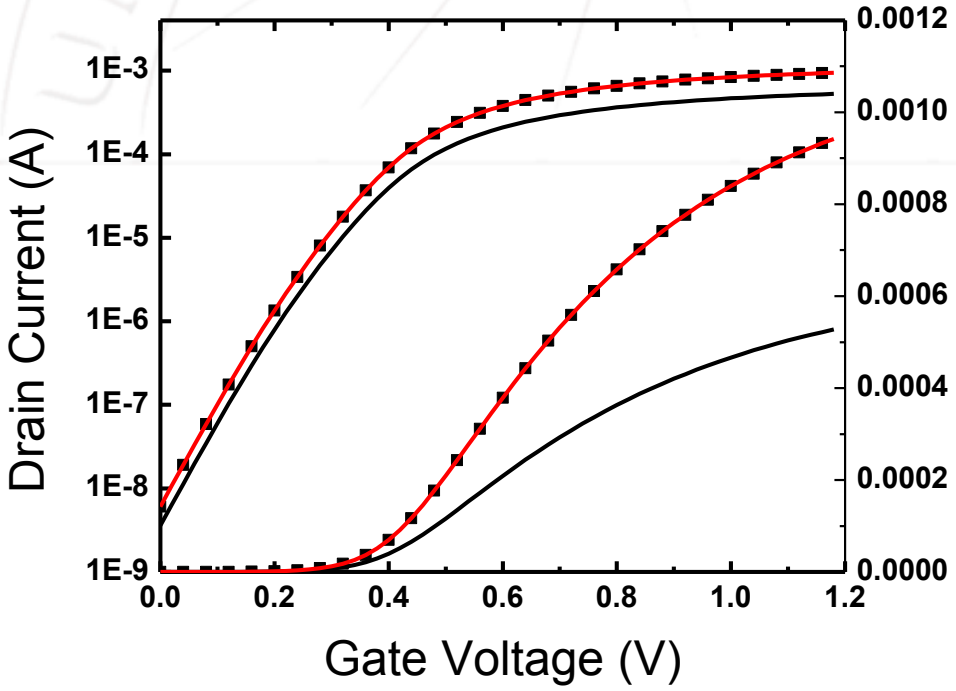
  Fig: 2(V_{fb}+Φ_{st}) is dropped when mtrlCompatMod=1

Ref: C. Hu, MOS Transistor," in Modern Semiconductor Devices for Integrated Circuits. Prentice Hall, 2009, ch. 6.

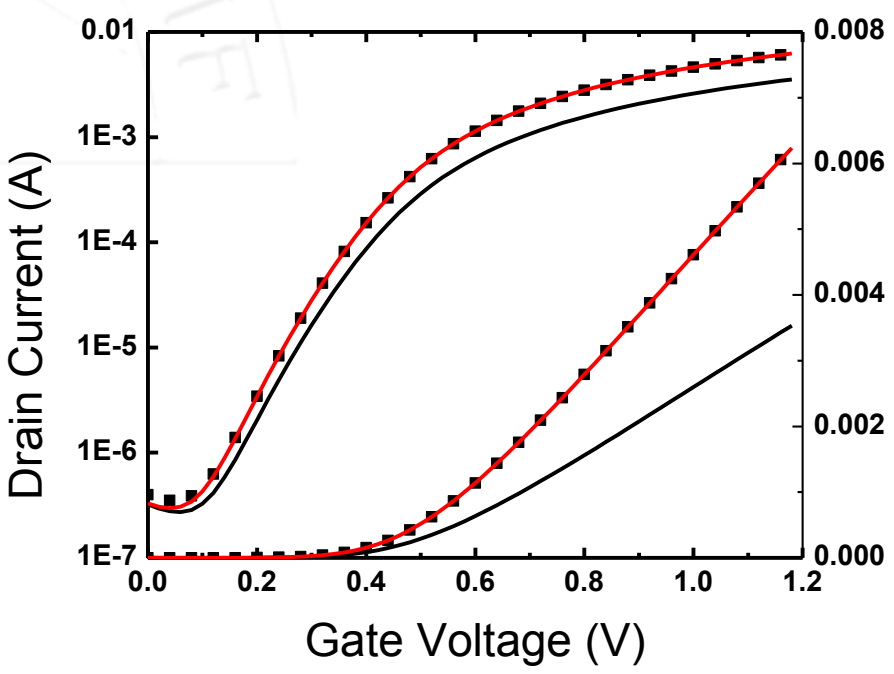
New switch "mtrlCompatMod" introduced to make mtrlMod=0 compatibile with mtrlMod=1

- Symbols: mtrlMod=0
- Lines: — mtrlMod=1; mtrlCompatMod=0
  — mtrlMod=1; mtrlCompatMod=1 (BSIM v4.7)

Idlin

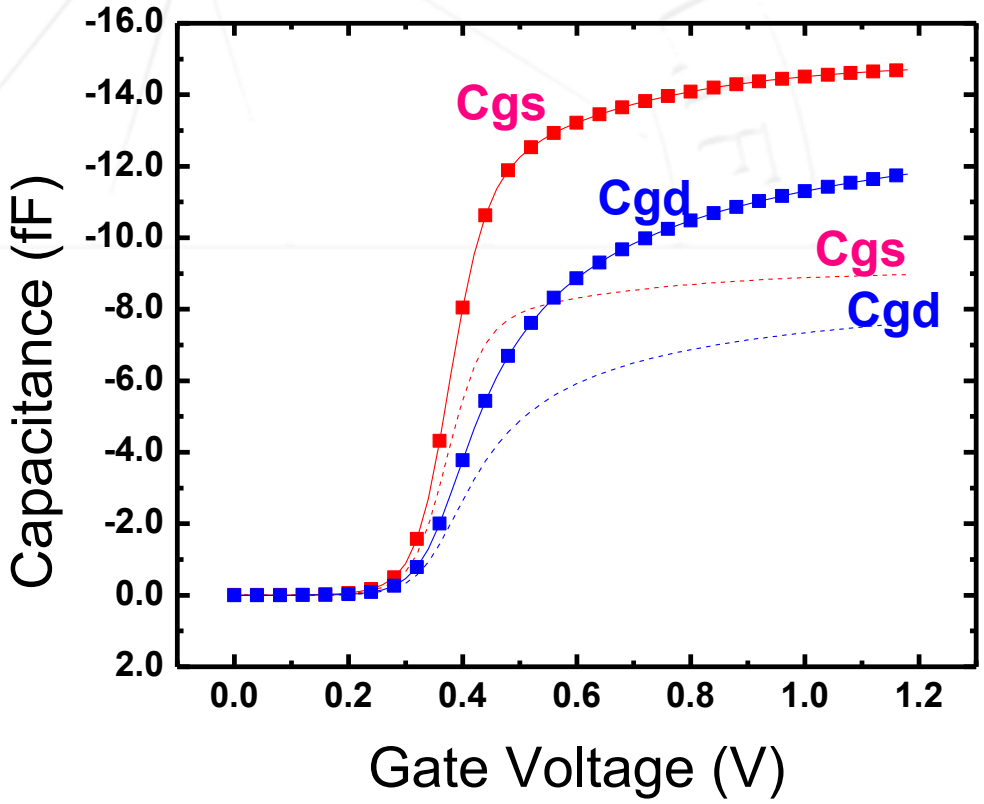


Idsat



C-V Discrepancy Also Fixed

- Symbols: mtrlMod=0
- Dashed Lines: mtrlMod=1; mtrlCompatMod=0
- **Solid Lines: mtrlMod=1; mtrlCompatMod=1 (BSIM4.7)**



Enhanced Thermal Noise Model for BSIM4

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tnoiMod=2 implemented in SPICE3

- New expressions for drain noise (S_{id}), induced gate noise (S_{ig}) and correlation coefficient (c):

$$S_{id} = 4kT \cdot \gamma \cdot g_{d0} \cdot \left(3 \cdot \beta_{tnoi}^2\right)$$

$$S_{ig0} = 4kT \cdot C_0^2 \cdot \omega^2 \cdot \frac{\delta}{g_{d0}} \cdot \left(\frac{15 \cdot \theta_{tnoi}^2}{4}\right)$$

$$c = -j\frac{\epsilon}{\sqrt{\gamma \cdot \delta}} \cdot \left(\frac{c_{tnoi}}{0.395}\right)$$

$$g_{d0} = NF \times \frac{\mu_{eff} C_{oxeff} \frac{W_{eff}}{L_{eff}} V_{gsteff}}{1 + gche \cdot R_{ds}}$$

$$C_0 = NF \times C_{oxeff} W_{eff,CV} L_{eff,CV}$$

$$\beta_{tnoi} = RNOIA \cdot \left[1 + TNOIA \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat} L_{eff}}\right)^2\right]$$

$$\theta_{tnoi} = RNOIB \cdot \left[1 + TNOIB \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat} L_{eff}}\right)^2\right]$$

$$c_{tnoi} = RNOIC \cdot \left[1 + TNOIC \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat} L_{eff}}\right)^2\right]$$

Default:

RNOIA=0.577

RNOIB=0.5164

RNOIC=0.395

Expressions for γ, δ and ε

$$\gamma = \frac{L}{L_{vsat}}\left[\frac{1+\eta}{2} + \frac{(1-\eta)^2}{6\left[(1+\eta)+\frac{2V_t\alpha}{V_{gsteff}}\right]}\right]$$

$$\delta = \frac{1}{6}\left(\frac{L_{vsat}}{L}\right)^3\left[\frac{1+\eta}{\left[(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right]^2} - \frac{\left[6(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right](1-\eta)^2}{15\left[(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right]^4} + \frac{(1-\eta)^4}{9\left[(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right]^5}\right]$$

$$\epsilon = \frac{1}{6}\cdot\frac{L_{vsat}}{L}\left[\frac{1-\eta}{\left[(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right]} + \frac{(1-\eta)^3}{3\left[(1+\eta)+\frac{2\alpha V_t}{V_{gsteff}}\right]^3}\right]$$

$$\alpha = A_{bulk}$$

$$\eta = 1 - \frac{V_{dseff}}{V_b}$$

$$L_{vsat} = L_{eff}\cdot\left[1 + \frac{V_{dseff}}{E_{sat}L_{eff}}\right]$$

$$V_b = \frac{V_{gsteff} + 2v_t}{A_{bulk}}$$

Summary of Code Changes

File	Line # (approx.)	Description
b4.c b4mask.c b4mpar.c b4set.c	1025 630 870 144	Entries for new parameters TNOIC, RNOIC added
b4check.c	719	Parameter checking for TNOIA, TNOIB, RNOIA and RNOIB are extended to tnoiMod=2,3
b4ld.c	1727	Definition of here->BSIM4Coxeff
	2890	Calculation of here->BSIM4noiGd0
b4noi.c	127	Definition of new noise source ".corl"
	248	Calcilation of Rs,Rd noise for tnoiMod=2,3
	390	Noise calculation for tnoiMod=2,3
bsim4def.h	164,440,977,1920	Definition new parameters & noise sources
makedefs	10	Entry for new source file nevalsrc2.c
nevalsrc2.c	**New source file**	New function for correlated noise source definition