

Summary of Changes in BSIM-CMG110.0.0:

Corrected Bugs

- 2014bug12: T9 eqn in BULKMOD=1 code should use K1_t instead of K1
- 2014bug13: Charge term qis in thermal noise should be qia
- 2014bug14: In NOIMOD=1, max() should be applied to Vds/Ids instead of only Ids
- 2014bug15: Lower clamp limits on II model parms ALPHAI0 and ALPHAI1
- 2015bug1: Possible missing terms in Xpart/Qbul calculations
- 2015bug2: Add initialization to LK2SAT, NK2SAT, PK2SAT, LK2SAT1, NK2SAT1, PK2SAT1
- 2015bug3: Fix hidden variables Qdep_ov_Cins, qb_acc_s, qb_acc_d
- 2015bug4: Smooth clamp implemented on gate current to prevent large values
- 2015bug5: Update model parameter initialization
- 2015bug6: Update manual for K0 parameter limit
- 2015bug7: Update comment text on BULKMOD= 1,2 related model parameters
- 2015bug8: Code updated to account for missing mobility term in noise model
- 2015bug9: TNOIMOD=2 fix for divide by zero when ROIA or ROIB =0
- 2015bug11: Removal of Redundant variables from Model code
- 2015bug12: Removal of fatal warning message for PDIBL2_i
- 2015bug13: Removal of TNOIMOD = 1
- 2015bug14: For ASYMMOD=1, parameters such as MEXPR, UCR and their binning terms are updated.
- 2015bug15: NBODY_i is misplaced before Inv_L, Inv_NFIN, Inv_LNFIN are declared.
- 2015bug16: Theta_RSCE should not be put within the same begin/end block as Theta_DIBL.
- 2015bug17: Fix a typo of number with CIGD_i clamping.

Enhancements

- 2013enh20: A better modeling of body bias effects in I-V and C-V
- 2013enh21: Increase the model parameters to support the ASYMMOD=1
- 2014enh2: Use 'defines "macros" in place of conventional Verilog-A instance/model parameter definitions
- 2014enh4: Add optional temperture node for self-heating analysis
- 2014enh6: Add BSIM4-like support for VFBS in gate-channel tunneling current
- 2014enh8: Collapse bsimcmg_main.va into bsimcmg.va
- 2014enh9: DITS Implementation
- 2014enh11: NFIN Scaling of additional parameters: NFINNOM added as an instance parameter
- 2015enh1: Addition of output parameters: T_TOTAL_K, T_TOTAL_C, T_DELTA_SH
- 2015enh2: RTH Dependence on NFIN, FPITCH
- 2015enh3: Better description of parameters

Description of the changes:

Corrected Bugs

2014bug12: T9 eqn in BULKMOD=1 code should use K1_t instead of K1.

In BSIMCMG108.0.0, line#2628,

$T9 = (K1 / (2.0 * nVtm)) * \sqrt{Vtm}$;

In BSIM-CMG109.0.0 "K1_t" replaces "K1".

2014bug13: Charge term qis in thermal noise should be qia.

In BSIMCMG 108.0.0,

$T0 = qis / EsatL$

the charge term qis in T0 is replaced by qia in BSIM-CMG109.0.0.

2014bug14: In NOIMOD=1, max() should be applied to Vds/Ids instead of only Ids.

In BSIMCMG108.0.0, sid is defined as below:

```
sid = 4 * Vtm * `q * (T7 * T7 - T8 * T8) * Vdseff / max(ids, 1.0e-9)
```

In BSIMCMG109.0.0, the max() function is applied to Vds/Ids instead of only Ids

```
sid = 4 * Vtm * `q * (T7 * T7 - T8 * T8) / max(T9*IDS0MULT, 1.0e-9)
```

2014bug15: Lower clamp limits on II model parms ALPHAII0 and ALPHAII1.

In BSIMCMG108.0.0 the lower limit of hypmax is 1.0E-6

```
ALPHAII0_t = ALPHAII0_i + hypmax(ALPHAII01 * delTemp, -ALPHAII0_i, 1.0E-6)
ALPHAII1_t = ALPHAII1_i + hypmax(ALPHAII11 * delTemp, -ALPHAII1_i, 1.0E-6)
```

In BSIMCMG109.0.0 the lower limit of hypmax is reduced to 1.0E-25 and 1E-20, respectively for ALPHAII0_t and ALPHAII1_t

```
ALPHAII0_t = ALPHAII0_i + hypmax(ALPHAII01 * delTemp, -ALPHAII0_i, 1.0E-25)
ALPHAII1_t = ALPHAII1_i + hypmax(ALPHAII11 * delTemp, -ALPHAII1_i, 1.0E-20)
```

2015bug1: Possible missing terms in Xpart/Qbul calculations.

The variable Qbul has been removed in BSIMCMG109.0.0, while xdpert has been defined in BSIMCMG109.0.0 as below:

```
if(NQSMOD == 2) xdpert = qd / qg;  
else xdpert = 0;
```

2015bug2: Add initialization to LK2SAT, NK2SAT, PK2SAT, LK2SAT1, NK2SAT1, PK2SAT1.

In BSIMCMG109.0.0, these Binning parameters are set to zero in BSIMCMG109.0.0.

```
`MPRnb( LK2SAT , 0 , , , )  
`MPRnb( NK2SAT , 0 , , , )  
`MPRnb( PK2SAT , 0 , , , )  
  
`MPRnb( LK2SAT1 , 0 , , , )  
`MPRnb( NK2SAT1 , 0 , , , )  
`MPRnb( PK2SAT1 , 0 , , , )
```

2015bug3: Fix hidden variables Qdep_ov Cins, qb_acc_s, qb_acc_d.

Qdep_ov_Cins is declared and initialized, while qb_acc_s and qb_acc_d are removed in BSIMCMG109.0.0.

2015bug4: Smooth Clamp implemented on gate current to prevent large values.

Intermediate variables T1, T2 can flip signs resulting in extremely large gate currents and/or simulation non-convergence. This is fixed in BSIMCMG109.0.0 as shown below:

```
if(IGCLAMP ==1) begin
    T1 = hypsmooth((AIGS_t - BIGS_i * vgs_eff), 1e-6);
    if(CIGS_i < 0) CIGS_i = 0.01;
end else begin
    T1 = AIGS_t - BIGS_i * vgs_eff;
end
T2 = 1.0 + CIGS_i * vgs_eff;
T3 = -Bechvb * TOXG * POXEDGE_i * T1 * T2;
T4 = lexp(T3);
if(sigvds > 0) igs = igsd_mult * DLCIGS * vgs_noswap * vgs_eff * T4;
else           igd = igsd_mult * DLCIGS * vgs_noswap * vgs_eff * T4;
```

2015bug5: Update model parameter initialization.

In BSIMCMG109.0.0:

```
parameter real DVT1SS = DVT1; // Subthreshold Swing exponent coefficient, after binning should be in (0:inf)
```

```
parameter real LDVT1SS = 0;
parameter real NDVT1SS = 0;
parameter real PDVT1SS = 0;
```

In BSIMCMG109.0.0:

```
`MPRnb( DVT1SS ,DVT1 ,"" , "Subthreshold Swing exponent coefficient, after binning should be in (0:inf)" )
```

```
`MPRnb( LDVT1SS ,LDVT1 ,"" , "" )
`MPRnb( NDVT1SS ,NDVT1 ,"" , "" )
`MPRnb( PDVT1SS ,PDVT1 ,"" , "" )
```

2015bug6: Update manual for K0 parameter limit.

In the manual for BSIM-CMG 109, the K0 parameter limit is updated.

2015bug7: Update comment text on BULKMOD= 1,2 related model parameters

The comment text for parameters related to BULKMOD = 1, 2, is updated in BSIMCMG109.0.0 as shown below:

```
IPRcz( ASEJ ,0 , "m^2" , "Source junction area (BULKMOD=1 or 2)" )
IPRcz( ADEJ ,0 , "m^2" , "Drain junction area (BULKMOD=1 or 2)" )
IPRcz( PSEJ ,0 , "m" , "Source to substrate PN junction perimeter (BULKMOD=1 or 2)" )
IPRcz( PDEJ ,0 , "m" , "Drain to substrate PN junction perimeter (BULKMOD=1 or 2)" )
```

2015bug8: Code Updated to account for missing mobility term in noise model

The Mobility term is missing in noise model as shown below

```
T9 = beta * ids0_ov_dqi * Moc / (Dmob * Dvsat * Dr);  
sid = 4 * Vtm * `q * (T7 * T7 - T8 * T8) / max(T9 * NFINTotal * Mob * Mnud  
* IDS0MULT, 1.0e-9);
```

This is included in the BSIMCMG109.0.0 code as shown below:

```
T9 = NFINTotal * beta * ids0_ov_dqi * Moc * Mnud / (Dmob * Dvsat * Dr);  
sid = 4 * Vtm * `q * (T7 * T7 - T8 * T8) / max(T9*IDS0MULT*Mob, 1.0e-9);
```

2015bug9: TNOIMOD=2 fix for divide by zero when ROIA or ROIB =0

The variable sf becomes NaN when ROIA or ROIB = 0 when TNOIMOD = 2. This is fixed in BSIMCMG109.0.0, as shown below:

```
if (gamma > 0 && delta>0) begin  
    I(N) <+ V(N) * sf * SCALEN;  
    I(N) <+ white_noise(sid/(sf*sf*SCALEN*SCALEN));  
--  
if (gamma > 0 && delta > 0) begin  
    sf = (noiGd0+1e-15)/sqrt(delta/gamma);  
end else begin  
    sf = 0.0 ;
```

2015bug11: Removal of Redundant variables from Model code

The following bugs are fixed in BSIMCMG109.0.0:

- Redundant variables: R, T13, T14, phibulk, psiavg are removed from the code.
- Correction of Units, ensuring consistency of units, alignment of Parameters, proper and consistent Unit descriptions, addition of op-pt parameters, fixing code indentation.
- Removal of redundant parameters from modelcard.nmos.1 (NIGC, ALPHAII), modelcard.nmos, modelcard.pmos (NIGC, PCLMGCV, PRWG, VASAT, VASATCV)

2015bug12: Removal of fatal warning message for PDIBL2_i

Fatal warning message for PDIBL2_i is removed.

2015bug13: Removal of TNOIMOD = 1

In all previous versions of BSIMCMG we have had TNOIMOD = 0, 1 and 2, respectively. However, from this version (BSIMCMG109.0.0) of BSIMCMG onwards, TNOIMOD = 1 is not supported and has been removed. Therefore, from the current version of BSIMCMG, only TNOIMOD = 0 and 2 will be supported, similar to BSIM6. While TNOIMOD = 0 is the same as before, TNOIMOD = 2 is equivalent to TNOIMOD = 1 in previous versions of BSIM-CMG. TNOIMOD=2 is a correlated thermal noise model where both drain and gate noise are implemented as current sources in this thermal noise model. The correlation between two sources is independently controllable and can be tuned using RNOIC parameter.

2015bug14: For ASYMMOD=1, parameters such as MEXPR, UCR and their binning terms are updated

For ASYMMOD=1, parameters such as MEXPR, UCR and their binning terms are updated so that their default values are equal to their "forward" model parameters. In addition, the binning terms for PCLMCV are also updated such that their default values are equal to their "forward" model parameters.

```
MPRnb( LMEXPR      , LMEXP      , ""      , "" )
MPRnb( NMEXPR      , NMEXP      , ""      , "" )
MPRnb( PMEXPR      , PMEXP      , ""      , "" )
```

```
MPRnb( UCR          , UC          , ""      , "Reverse-mode Body effect for mobility degradation parameter - BULKMOD=1 or 2" )
```

```
MPRnb( LPCLMCV      , LPCLM      , ""      , "" )
MPRnb( NPCLMCV      , NPCLM      , ""      , "" )
MPRnb( PPCLMCV      , PPCLM      , ""      , "" )
```


2015bug15: NBODY_i is misplaced before Inv_L, Inv_NFIN, Inv_LNFIN are declared.

Binning variables Inv_L, Inv_NFIN, Inv_LNFIN are defined after NBODY_i definition. This causes them to be undefined in Ln. 1271 where their default values of zero are used. This error causes NBODY_i = NBODY at all times.

In BSIMCMG109.0.1, definition of Inv_L, Inv_NFIN, Inv_LNFIN and related variable Leff1 are moved before NBODY_i definition.

Ln. 1270–1271

```
// Nbody Binning Equation for UFCM Parameters
NBODY_i = NBODY + Inv_L * LNBDY + Inv_NFIN * NNBDY + Inv_LNFIN * PNBDY;
```

Ln. 1403–1406

```
// Binning
Inv_L = 1.0e-6 / (Leff1);
Inv_NFIN = 1.0 / NFIN;
Inv_LNFIN = 1.0e-6 / (Leff1 * NFIN);
```

2015bug16: Theta_RSCE should not be put within the same begin/end block as Theta_DIBL.

Theta_RSCE is misplaced within the same begin/end block with Theta_DIBL.

```
if (!$param_given(THETADIBL)) begin
    tmp = DSUB_i * Leff / scl + 1.0e-6;
    if (tmp < 40.0) begin
        Theta_DIBL = 0.5 / (cosh(tmp) - 1.0);
    end else begin
        Theta_DIBL = exp(-tmp);
    end
end else begin
    Theta_DIBL = THETADIBL;
    Theta_RSCE = sqrt(1.0 + LPE0_i / Leff) - 1.0;
end
```

This is an error since Theta_RSCE should not be dependent on Theta_DIBL. The code is corrected as below:

Guideline document for changes in BSIMCMG110.0.0 compared to BSIMCMG108.0.0

UC Berkeley, BSIM Group

Sourabh Khandelwal (sourabh@berkeley.edu), Aditya Sankar Medury, Juan Pablo Duarte

```
if (!$param_given(THETADIBL)) begin
    tmp = DSUB_i * Leff / scl + 1.0e-6;
    if (tmp < 40.0) begin
        Theta_DIBL = 0.5 / (cosh(tmp) - 1.0);
    end else begin
        Theta_DIBL = exp(-tmp);
    end
end else begin
    Theta_DIBL = THETADIBL;
end

Theta_RSCE = sqrt(1.0 + LPE0_i / Leff) - 1.0;
```

2015bug17: Fix a typo of number with CIGD_i clamping.

CIGD_i clamping at 0.01 has a typo inside the if condition.

```
if (CIGD_i < 0.0) begin
    CIGD_i = 0.01;
end
```

It is fixed as below:

```
if (CIGD_i < 0.01) begin
    CIGD_i = 0.01;
end
```


Enhancements

2013enh20: A better modeling of body bias effects in I-V and C-V

Better modeling of body bias effects in I-V and C-V in BSIMCMG109.0.0 by using BULKMOD = 2.

```
// *** Body- effect factor for BULKMOD = 2 ***
if(BULKMOD == 2) begin
    T0      = hypsmooth((K2_t + K2SAT_t * vdsx), 1.0E-6);
    T1      = T0 / (max(0, K2SI_t + K2SISAT_t * dqi * dqi) * qia + 2.0 * nVtm);
    T3      = sqrt(PHIBE_i - veseff) - sqrt(PHIBE_i);
    Mob     = lexp(- T1 * T3);
end else
    Mob = 1.0;
```

2013enh21: Increase the model parameters to support the ASYMMOD=1

PCLM, PDIBL2, VSAT, KSATIV, DVTSHIFT, CIT, mobility model parameters (U0, UA, UD, UC, EU) are model parameters included in 109beta2 to support ASYMMOD = 1.

2014enh2: User 'defined "macros" in place of conventional Verilog-A instance/model parameter definitions

User defined macros in BSIMCMG109.0.0 to replace the conventional Verilog-A instance/model parameter definitions.

Parameter declaration in 109.0.0 beta

```
parameter real EPSROX = 3.9 from [1:inf]; // Relative dielectric constant of the gate dielectric
```

Parameter declaration in BSIMCMG109.0.0

```
`MPRco( EPSROX ,3.9 ,"" ,1 ,inf ,"Relative dielectric constant of the gate dielectric" )
```

2014enh4: Add optional temperture node for self-heating analysis

The Temperature Node option is added to the module declaration as shown below:

Guideline document for changes in BSIMCMG110.0.0 compared to BSIMCMG108.0.0

UC Berkeley, BSIM Group

Sourabh Khandelwal (sourabh@berkeley.edu), Aditya Sankar Medury, Juan Pablo Duarte

```
module bsimcmg(d, g, s, e, t);
  inout    g, d, s, e, t;
  electrical g, d, s, e;
  electrical si, di;

  ifdef __NQSMOD1__
    electrical gi;
  endif

  ifdef __NQSMOD2__
    electrical q;
  endif

  ifdef __RGATEMOD__
    electrical ge;
  endif

  ifdef __SHMOD__
    thermal t;
    branch (t) rth_branch;
    branch (t) ith_branch;
  else
    thermal t;
  endif

  // Internal node controlled by Correlated Thermal Noise Switch
  ifdef __TNOIMOD2__
    electrical N;
  endif

  include "bsimcmg_body.include"

endmodule
```

If SHMOD =0 or if SHMOD is not defined, then even if the temperature node is present, warning messages are strobed as shown below:

Guideline document for changes in BSIMCMG110.0.0 compared to BSIMCMG108.0.0

UC Berkeley, BSIM Group

Sourabh Khandelwal (sourabh@berkeley.edu), Aditya Sankar Medury, Juan Pablo Duarte

```
if ($port_connected(t) == 1) begin
  `ifdef SHMOD
    if (SHMOD == 0) begin
      if (SH_WARN == 1) begin
        $strobe("The optional 5th terminal is present but not active because SHMOD=0.");
      end
    end
  `else
    Temp(t) <+ 0.0;
    if (SH_WARN == 1) begin
      $strobe("The optional 5th terminal is present but not active because the model was not compiled with self-heating enabled
    _SHMOD_ was not activated).");
    end
  `endif
end
```

2014enh6: Add BSIM4-like support for VFBS in gate-channel tunneling current

In BSIMCMG109.0.0, VFBS and VFBSDCV are included as a model parameter, as shown below.

```
`MPRnb( VFBS , 0.0 , "V" , "Flat band voltage for S/D region" )
```

```
`MPRnb( VFBSDCV , VFBS , "V" , "Flat band voltage for S/D region for C-V calculations" )
```

2014enh8: Collapse bsimcmg_main.va into bsimcmg.va

In BSIMCMG109.0.0, bsimcmg_main.va is collapsed into bsimcmg.va. This eliminates one Verilog-A file.

2014enh9: DITS Implementation

For more flexibility, a new DITS term will be included in BSIMCMG109.0.0. This approach is backward compatible with previous version.

$$\Delta V_{th,DIBL} = \left(\frac{-0.5 ETA_0}{\cosh\left(\frac{DSUB \times L_{eff}}{\lambda}\right) - 1} \right) V_{dsx} + \frac{DVTP0 \times V_{dsx}^{DVTP1}}{\left(1 + DVTP2 \left(\cosh\left(\frac{DSUB \times L_{eff}}{\lambda}\right) - 2\right)\right)}$$

$$DVTP0[L] = DVTP0 + ADVTP0 \exp(-L_{eff}/BDVTP0)$$

$$DVTP1[L] = DVTP1 + ADVTP1 \exp(-L_{eff}/BDVTP1)$$

Default settings for DITS model parameters:

DVTP0: 0 ADVTP0: 0 BDVTP0: 100.0e-9

DVTP1: 0 ADVTP1: 0 BDVTP1: 100.0e-9

DVTP2: 0 (backward compatible)

2014enh11: NFIN Dependency

L dependences for PHIG, ETA0, U0 cross-coupled with NFIN dependency are included in 109beta2.

BSIMCMG108.0.0:

$$\text{PHIG}_i = \text{PHIG}_i * (1.0 + \text{PHIGN1}/\text{NFIN} * \ln(1.0 + \text{NFIN}/\text{PHIGN2}))$$

BSIMCMG109.0.0:

$$\text{PHIG}_i = \text{PHIG}_i * (1.0 + \text{PHIGN1}/\text{NFIN} * \ln(1.0 + \text{NFIN}/\text{PHIGN2})) * (1.0 + (\text{NFIN} - \text{NFINNOM}) * \text{PHIGLT} * \text{Leff})$$

NFINNOM added as instance parameter with a default value of 1.

2015enh1: Addition of output parameters: T_TOTAL_K, T_TOTAL_C, T_DELTA_SH

Additional output parameters added to the model code: _output parameters: T_TOTAL_K, T_TOTAL_C, T_DELTA_SH.

2015enh2: RTH Dependence on NFIN, FPITCH

An Expression for thermal resistance taking NFIN, FPITCH dependence into account has been implemented. This expression is backward compatible via the model parameters.

$$R_{th} = \frac{RTH0}{(WTH0 \cdot NF^{BSHEXP} + FPITCH \cdot NFIN_{total}^{ASHEXP})}$$

By setting **BSHEXP = 0**, the above implementation becomes the same as Samsung. **By setting ASHEXP = 1, BSHEXP = 1**, the above implementation is backward compatible.

2015enh3: Better description of parameters

Parameters K2SAT1, DLACC, UC etc..., are updated as shown below:

```
MPRnb( K2SAT1 , 0.0 , "" , "Temperature dependence of K2SAT" )
```

```
MPRnb( UC , 0.0 , "(1e-6 * cm/MV^2)^EU" , "Body effect for mobility degradation parameter - BULKMOD=1 or 2" )
```