Chapter 8 BSIMSOI Noise Model

8.1 Flicker noise models

BSIMSOI4.0 provides two flicker noise models. When the model selector fnoiMod is set to 0, a simple flicker noise model which is convenient for hand calculation is invoked. A unified physical flicker noise model, which is the default model, will be used if fnoiMod=1. These two modes come from BSIMSOI3.1, but the unified model has many improvements. For instance, it is now smooth over all bias regions and considers the bulk charge effect.

- fnoiMod = 0 (simple model)

The noise density is:

$$S_{id}(f) = \left(\frac{W_{eff}}{W0FLK} \right)^{1-AF} \cdot \frac{KF \cdot I_{ds}^{AF}}{C_{ox} L_{eff}^{BF} \cdot f^{EF}}$$

- fnoiMOd = 1 (unified model)

The physical mechanism for the flicker noise is trapping/de-trapping related charge fluctuation in oxide traps, which results in fluctuations of both mobile carrier numbers and mobility in the channel. The unified flicker noise model captures this physical process.

The noise density in inversion region is given by:

$$S_{id,inv}(f) = \frac{k_B T q^2 m_{eff} I_{ds}}{C_{oxe} L_{eff}^2 A_{bulk} f^{ef} \cdot 10^{10}} \left(NOIA \log\left(\frac{N_0 + N^*}{N_l + N^*} \right) + NOIB\left(N_0 - N_l\right) + \frac{NOIC}{2}\left(N_0^2 - N_l^2\right) \right)$$
$$+ \frac{k_B T I_{ds}^2 \Delta L_{clm}}{W_{eff} L_{eff}^2 f^{ef} \cdot 10^{10}} \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l^2}{\left(N_l + N^*\right)^2}$$

Where m_{eff} is the effective mobility at the given bias condition, and L_{eff} and W_{eff} are the effective length and width respectively. The parameter N_0 is the charge density at the source side given by:

$$N_0 = \frac{C_{ox} V_{gsteff}}{q}$$

The parameter N_l is the charge density at the source side given by:

$$N_l = \frac{C_{ox} V_{gsteff}}{q} \left(1 - \frac{A_{bulk} V_{dseff}}{V_{gsteff} + 2v_t} \right)$$

N^* is given by:

$$N^* = {k_B T \cdot (C_{ox} + C_d + CIT)} \big/ {q^2}$$

where CIT is a model parameter from DC IV and C_d is the depletion capacitance.

ΔL_{clm} is the channel length reduction due to channel length modulation and given by:

$$\Delta L_{clm} = Litl \cdot \log \left(\frac{\frac{V_{ds} - V_{dseff}}{Litl} + EM}{E_{sat}} \right)$$

$$E_{sat} = \frac{2VSAT}{m_{eff}}$$

In the subthreshold region, the noise density is written as:

$$S_{id,subVt}(f) = \frac{NOIA \cdot k_B T \cdot I_{ds}^2}{W_{eff} L_{eff} f^{EF} {N^*}^2 \cdot 10^{10}}$$

The total flicker noise density is given by

$$S_{id}(f) = \frac{S_{id,inv}(f) \times S_{id,subvt}(f)}{S_{id,inv}(f) + S_{id,subvt}(f)}$$

8.2 Thermal noise models

There are three channel thermal noise models in BSIMSOI4.0 beta version. One is the charge based model (default) similar to that used in BSIMSOI3.1. The second is the BSIM4 compatible holistic thermal noise model. The simple SPICE2 thermal noise model is also provided in BSIMSOI4.0. These three models can be selected through the model selector tnoiMod.

- tnoiMod = 0 (charge based model)

The noise current is given by

$$\overline{i_d^2} = \frac{4k_B T\Delta f}{R_{ds} + \dfrac{L_{eff}^2}{m_{eff}\left|Q_{inv}\right|}} \cdot NTNOI\ ,$$

where R_{ds} is the source/drain resistance, and the parameter $NTNOI$ is introduced fro more accurate fitting of short-channel devices. Q_{inv} is the inversion channel charge computed from the capacitance models

- tnoiMod = 1 (holistic model)

In this thermal noise model, all the short-channel effects and velocity saturation effect incorporated in the IV model are automatically included, hence the name "holistic thermal noise model". In addition, the amplification of the channel thermal noise through G_m and G_{mbs} as well as the induced-gate noise with partial correlation to the channel thermal noise are all captured in the new "noise partition" model.

The noise voltage source partitioned to the source side is given by:

$$\overline{v_d^2} = 4k_B T \cdot q_{tnoi}^2 \cdot \frac{V_{dseff}\Delta f}{I_{ds}}$$

and the noise current source put in the channel region with gate and body amplification is given by:

$$\overline{i_d^2} = 4k_B T \frac{V_{dseff}\Delta f}{I_{ds}} [G_{ds} + b_{tnoi} \cdot (G_m + G_{mbs})]^2 - \overline{v_d^2} \cdot (G_m + G_{ds} + G_{mbs})^2$$

where

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

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

- tnoiMod = 2 (SPICE2 model)

$$\overline{i_d^2} = \frac{8k_B T \Delta f}{3} \cdot NTNOI \cdot (G_m + G_{mbs} + G_{ds})$$

The parameter NTNOI is added to give the flexibility to tune the magnitude of noise density.

8.3 Other improvement on noise model

In BSIMSOI4.0, some other improvements on noise model are made as following

1. Body contact resistance induced thermal noise is introduced.
2. Thermal noise induced by the body resistance network is introduced as RBODYMOD=1.
3. Shut noises induced by Ibs and Ibd are equal in BSIMSOI3.2 and BSIMPD. In BSIMSOI4.0, these two noises are separated.