CHAPTER 8: Noise Modeling

8.1 Flicker Noise

8.1.1 Parameters

There exist two models for flicker noise modeling. One is called SPICE2 flicker noise model; the other is BSIM3 flicker noise model [35-36]. The flicker noise model parameters are listed in Table 8-1.

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit
Noia	noia	Noise parameter A	(NMOS) 1e20 (PMOS) 9.9e18	none
Noib	noib	Noise parameter B	(NMOS) 5e4 (PMOS) 2.4e3	none
Noic	noic	Noise parameter C	(NMOS) -1.4e-12 (PMOS) 1.4e-12	none
Em	em	Saturation field	4.1e7	V/m
Af	af	Flick noise exponent	1	none
Ef	ef	Flicker noise frequency exponent	1	none
Kf	kf	Flicker noise coefficient	0	none
LINTNOI	lintnoi	Length Reduction Parameter Offset	0.0	m

Table 8-1. Flicker noise model parameters.

8.1.2 Formulations

1. For SPICE2 model

(8.1)

$$Noisedensity = \frac{K_f I_{ds}{}^{af}}{C_{ox} L_{eff}{}^2 f^{ef}}$$

where f is the frequency.

2. For BSIM3 model

If $V_{gs} > V_{th} + 0.1$

(8.2)

$$S_{id,inv}(f) = \frac{k_B T q^2 \mu_{eff} I_{ds}}{C_{oxe}(L_{eff} - 2 \cdot LINTNOI)^2 A_{bulk} f^{ef} \cdot 10^8} \left(NOIA \cdot \log\left(\frac{N_0 + 2 \times 10^{14}}{N_l + 2 \times 10^{14}} \right) + NOIB \cdot (N_0 - N_l) + \frac{NOIC}{2}\left(N_0{}^2 - N_l{}^2\right) \right)$$
$$+ \frac{k_B T I_{ds}{}^2 \Delta L_{clm}}{W_{eff} \cdot (L_{eff} - 2 \cdot LINTNOI)^2 f^{ef} \cdot 10^8} \cdot \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l{}^2}{\left(N_l + N^*\right)^2}$$

where V_{tm} is the thermal voltage, μ_{eff} is the effective mobiity at the given bias condition, and L_{eff} and W_{eff} are the effective channel length and width, respectively. The parameter N_0 is the charge density at the source side given by

(8.3)

$$N_0 = \frac{C_{ox}\left(V_{gs} - V_{th}\right)}{q}$$

The parameter N_l is the charge density at the drain end given by

(8.4)

$$N_l = \frac{C_{ox}\left(V_{gs} - V_{th} - \min\left(V_{ds}, V_{dsat}\right)\right)}{q}$$

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

(8.5)

$$\Delta L_{\mathrm{clm}} = \begin{cases} Litl \cdot \log\left(\dfrac{\dfrac{V_{ds} - V_{dsat}}{Litl} + E_m}{E_{sat}}\right) & \left(\text{for } V_{ds} > V_{dsat}\right) \\ 0 & \left(\text{otherwise}\right) \end{cases}$$

$$E_{sat} = \frac{2 \times v_{sat}}{m_{eff}}$$

where

$$Litl = \sqrt{3X_j T_{ox}}$$

Otherwise

(8.6)

$$Noisedensity = \frac{S_{\mathrm{limit}} \times S_{\mathrm{wi}}}{S_{\mathrm{limit}} + S_{\mathrm{wi}}}$$

Where, S_{limit} is the flicker noise calculated at $V_{gs} = V_{th} + 0.1$ and S_{wi} is given by

$$S_{\mathrm{wi}} = \frac{Noia \cdot V_{tm} \cdot I_{ds}{}^{2}}{W_{eff} L_{eff} \cdot f^{ef} \cdot 4 \times 10^{36}} \tag{8.7}$$

8.2 Channel Thermal Noise

There also exist two models for channel thermal noise modeling. One is called SPICE2 thermal noise model. The other is BSIM3v3 thermal noise model. Each of these can be toggled through the model flag, **noiMod**.

1. For SPICE2 thermal noise model

$$\frac{8k_B T}{3}\left(G_m + G_{mbs} + G_{ds}\right) \tag{8.8}$$

where G_m, G_{mbs} and G_{ds} are the transconductances.

2. For BSIM3v3 thermal noise model [37]

$$\frac{4 \boldsymbol{k}_{\boldsymbol{B}} \boldsymbol{T} \Delta \boldsymbol{f} \mu_{\boldsymbol{eff}}}{\mu_{\boldsymbol{eff}} \left|\boldsymbol{Q}_{\boldsymbol{inv}}\right| \boldsymbol{R}_{\boldsymbol{ds}}(\boldsymbol{V}) + \boldsymbol{L}_{\boldsymbol{eff}}{}^{2}} \left|\boldsymbol{Q}_{\boldsymbol{inv}}\right| \tag{8.9}$$

Q_{inv} is the inversion channel charge computed from the capacitance models (**capMod** = 0, 1, 2 or 3).

3. New SPICE2 thermal noise model

$$\frac{8}{3} \boldsymbol{kT}\left(\boldsymbol{g}_{\boldsymbol{m}} + \boldsymbol{g}_{\boldsymbol{ds}} + \boldsymbol{g}_{\boldsymbol{mbs}}\right)\left[\frac{3}{2} - \frac{\mathbf{min}(\boldsymbol{Vds}, \boldsymbol{Vdsat})}{2\boldsymbol{Vdsat}}\right] \tag{8.10}$$

8.3 Noise Model Flag

A model flag, **noiMod**, is used to select different combination of flicker and thermal noise models discussed above with possible optoins described in Table 8-2.

noimod flag	Flicker noise model	Thermal noise model
1	SPICE2	SPICE2
2	BSIM3v3	BSIM3v3
3	BSIM3v3	SPICE2
4	SPICE2	BSIM3v3
5	SPICE2	SPICE2new
6	BSIM3v3	SPICE2new

Table 8-2. noiMod flag for differnet noise models.