CHAPTER 6: Parameter Extraction

Parameter extraction is an important part of model development. Many different extraction methods have been developed [23, 24]. The appropriate methodology depends on the model and on the way the model is used. A combination of a local optimization and the group device extraction strategy is adopted for parameter extraction.

6.1 Optimization strategy

There are two main, different optimization strategies: global optimization and local optimization. Global optimization relies on the explicit use of a computer to find one set of model parameters which will best fit the available experimental (measured) data. This methodology may give the minimum average error between measured and simulated (calculated) data points, but it also treats each parameter as a "fitting" parameter. Physical parameters extracted in such a manner might yield values that are not consistent with their physical intent.

In local optimization, many parameters are extracted independently of one another. Parameters are extracted from device bias conditions which correspond to dominant physical mechanisms. Parameters which are extracted in this manner might not fit experimental data in all the bias conditions. Nonetheless, these extraction methodologies are developed specifically with respect to a given parameter's physical meaning. If properly executed, it should, overall, predict device performance quite well. Values extracted in this manner will now have some physical relevance.

6.2 Extraction Strategies

Two different strategies are available for extracting parameters: the single device extraction strategy and group device extraction strategy. In single device extraction strategy, experimental data from a single device is used to extract a complete set of model parameters. This strategy will fit one device very well but will not fit other devices with different geometries. Furthermore, single device extraction strategy can not guarantee that the extracted parameters are physical. If only one set of channel length and width is used, parameters related to channel length and channel width dependencies can not be determined.

BSIM3v3 uses group device extraction strategy. This requires measured data from devices with different geometries. All devices are measured under the same bias conditions. The resulting fit might not be absolutely perfect for any single device but will be better for the group of devices under consideration.

6.3 Extraction Procedure

6.3.1 Parameter Extraction Requirements

One large size device and two sets of smaller-sized devices are needed to extract parameters, as shown in Figure 6-1.

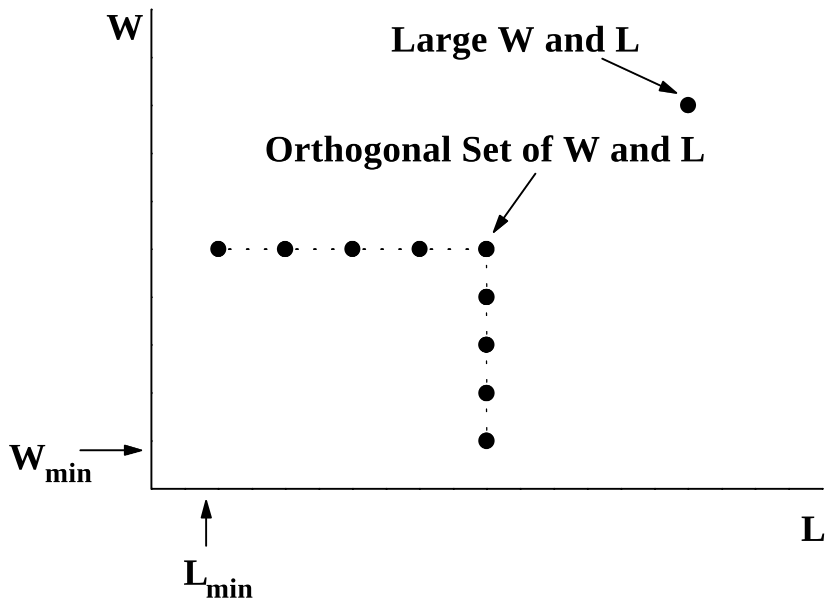

Figure 6-1. Device geometries used for parameter extraction

The large-sized device (W ≥ 10µm, L ≥ 10µm) is used to extract parameters which are independent of short/narrow channel effects and parasitic resistance. Specifically, these are: mobility, the large-sized device threshold voltage V_{Tideal}, and the body effect coefficients K_1 and K_2 which depend on the vertical doping concentration distribution. The set of devices with a fixed large channel width but different channel lengths are used to extract parameters which are related to the short channel effects. Similarly, the set of devices with a fixed, long channel length but different channel widths are used to extract parameters which are related to narrow width effects. Regardless of device geometry, each device will have to be measured under four, distinct bias conditions.

(1) I_{ds} vs. V_{gs} @ $V_{ds} = 0.05V$ with different V_{bs}.

(2) I_{ds} vs. V_{ds} @ $V_{bs} = 0V$ with different V_{gs}.

(3) I_{ds} vs. V_{gs} @ $V_{ds} = V_{dd}$ with different V_{bs}. (V_{dd} is the maximum drain voltage).

(4) I_{ds} vs. V_{ds} @ $V_{bs} = V_{bb}$ with different V_{gs}. ($|V_{bb}|$ is the maximum body bias).

6.3.2 Optimization

The optimization process recommended is a combination of Newton-Raphson's iteration and linear-squares fit of either one, two, or three variables. This methodology was discussed by M. C. Jeng [18]. A flow chart of this optimization process is shown in Figure 6-2. The model equation is first arranged in a form suitable for Newton-Raphson's iteration as shown in Eq. (6.3.1):

$$f_{\exp}(P_{10},P_{20},P_{30}) - f_{sim}(P_1^{(m)},P_2^{(m)},P_3^{(m)}) = \frac{\partial f_{sim}}{\partial P_1}\Delta P_1^m + \frac{\partial f_{sim}}{\partial P_2}\Delta P_2^m + \frac{\partial f_{sim}}{\partial P_3}\Delta P_3^m \tag{6.3.1}$$

The variable $f_{sim}()$ is the objective function to be optimized. The variable $f_{exp}()$ stands for the experimental data. P_{10}, $P_{20,}$ and P_{30} represent the desired extracted parameter values. $P_1^{(m)}$, $P_2^{(m)}$ and $P_3^{(m)}$ represent parameter values after the mth iteration.

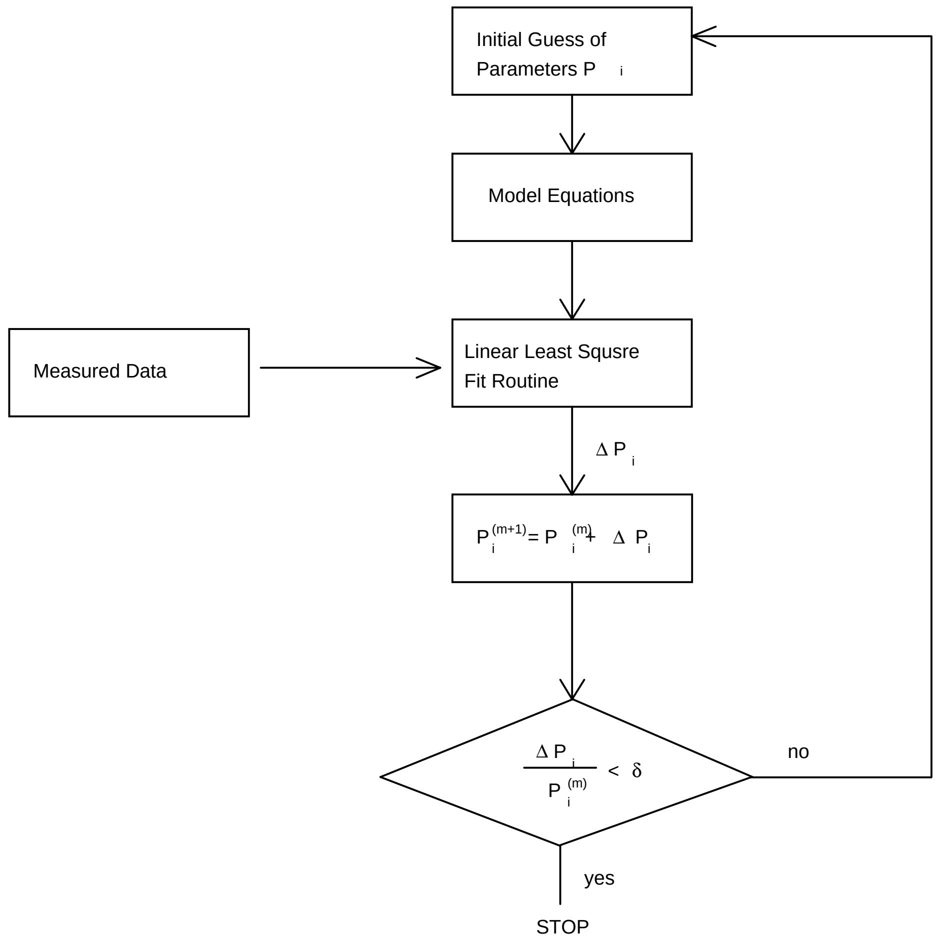

Figure 6-2. Optimization flow.

To change Eq. (6.3.1) into a form that a linear least-squares fit routine can be used (i.e. in a form of $y = a + bx1 + cx2$), both sides of the Eq. (6.3.1) are divided by $\partial f_{sim} / \partial P_1$. This gives the change in P_1, $\Delta P_1^{(m)}$, for the next iteration such that:

$$P_i^{(m+1)} = P_i^{(m)} + \Delta P_i^{(m)} \tag{6.3.2}$$

where i=1, 2, 3 for this example. The (m+1) parameter values for P_2 and P_3 are obtained in an identical fashion. This process is repeated until the incremental parameter change in parameter values $\Delta P_i^{(m)}$ are smaller than a pre-determined value. At this point, the parameters P_1, P_2, and P_3 have been extracted.

6.3.3 Extraction Routine

Before any model parameters can be extracted, some process parameters have to be provided. They are listed below in Table 6-1:

Input Parameters Names	Physical Meaning
T_{ox}	Gate oxide thickness
N_{ch}	Doping concentration in the channel
T	Temperature at which the data is taken
L_{drawn}	Mask level channel length
W_{drawn}	Mask level channel width
X_j	Junction depth

Table 6-1. Prerequisite input parameters prior to extraction process.

The parameters are extracted in the following procedure. These procedures are based on a physical understanding of the model and based on local optimization. (Note: *Fitting Target Data* refers to measurement data used for model extraction.)

Step 1

Extracted Parameters & Fitting Target Data	Device & Experimental Data
V_{th0}, K_1, K_2 Fitting Target Exp. Data: $V_{th}(V_{bs})$	Large Size Device (Large W & L). I_{ds} vs. V_{gs} @ V_{ds} = 0.05V at Different V_{bs} Extracted Experimental Data $V_{th}(V_{bs})$

Step 2

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
μ_0, U_a, U_b, U_c Fitting Target Exp. Data: Strong Inversion region $I_{ds}(V_{gs}, V_{bs})$	Large Size Device (Large W & L). I_{ds} vs. V_{gs} @ V_{ds} = 0.05V at Different V_{bs}

Step 3

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$Lint$, $R_{ds}(R_{dsw}, W, V_{bs})$ Fitting Target Exp. Data: Strong Inversion region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{gs} @ V_{ds} = 0.05V at Different V_{bs}

Step 4

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$Wint$, $R_{ds}(R_{dsw}, W, V_{bs})$ Fitting Target Exp. Data: Strong Inversion region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed L & Different W). I_{ds} vs. V_{gs} @ V_{ds} = 0.05V at Different V_{bs}

Step 5

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$R_{dsw}, Prwb, Wr$ Fitting Target Exp. Data: $R_{ds}(R_{dsw}, W, V_{bs})$	$R_{ds}(R_{dsw}, W, V_{bs})$

Step 6

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$D_{vt0}, D_{vt1}, D_{vt2}, Nlx$ Fitting Target Exp. Data: $V_{th}(V_{bs}, L, W)$	One Set of Devices (Large and Fixed W & Different L). $V_{th}(V_{bs}, L, W)$

Step 7

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
D_{vt0w}, D_{vt1w}, D_{vt2w} Fitting Target Exp. Data: $V_{th}(V_{bs}, L, W)$	One Set of Devices (Large and Fixed L & Different W). $V_{th}(V_{bs}, L, W)$

Step 8

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
K_3, K_{3b}, W_0 Fitting Target Exp. Data: $V_{th}(V_{bs}, L, W)$	One Set of Devices (Large and Fixed L & Different W). $V_{th}(V_{bs}, L, W)$

Step 9

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
V_{off}, $Nfactor$, C_{dsc}, C_{dscb} Fitting Target Exp. Data: Subthreshold region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{gs} @ V_{ds} = 0.05V at Different V_{bs}

Step 10

Extracted Parameters & Fitting Target Data	Devices & Experimental Data

C_{dscd} Fitting Target Exp. Data: Subthreshold region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{gs} @ $V_{bs} = V_{bb}$ at Different V_{ds}

Step 11

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
dWb Fitting Target Exp. Data: Strong Inversion region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{gs} @ $V_{ds} = 0.05\text{V}$ at Different V_{bs}

Step 12

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
v_{sat}, A_0, A_{gs} Fitting Target Exp. Data: $I_{sat}(V_{gs}, V_{bs})/W$ A_1, A_2 (PMOS Only) Fitting Target Exp. Data $V_{asat}(V_{gs})$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{ds} @ $V_{bs} = 0\text{V}$ at Different V_{gs}

Step 13

Extracted Parameters & Fitting Target Data	Devices & Experimental Data

$B0$, $B1$ Fitting Target Exp. Data: $I_{sat}(V_{gs}, V_{bs})/W$	One Set of Devices (Large and Fixed L & Different W). I_{ds} vs. V_{ds} @ V_{bs} = 0V at Different V_{gs}

Step 14

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
dWg Fitting Target Exp. Data: $I_{sat}(V_{gs}, V_{bs})/W$	One Set of Devices (Large and Fixed L & Different W). I_{ds} vs. V_{ds} @ V_{bs} = 0V at Different V_{gs}

Step 15

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
P_{scbe1}, P_{scbe2} Fitting Target Exp. Data: $R_{out}(V_{gs}, V_{ds})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{ds} @ V_{bs} = 0V at Different V_{gs}

Step 16

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
P_{clm}, $\theta(D_{rout}$, P_{diblc1}, P_{diblc2}, $L)$, $Pavg$ Fitting Target Exp. Data: $R_{out}(V_{gs}, V_{ds})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{ds} @ V_{bs} = 0V at Different V_{gs}

Step 17

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
D_{rout}, P_{dibl1c}, P_{diblc2} Fitting Target Exp. Data: $\theta(D_{rout}$, P_{diblc1}, P_{diblc2}, $L)$	One Set of Devices (Large and Fixed W & Different L). $\theta(D_{rout}$, P_{diblc1}, P_{diblc2}, $L)$

Step 18

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$P_{dibl1cb}$ Fitting Target Exp. Data: $\theta(D_{rout}$, P_{diblc1}, P_{diblc2}, L, $V_{bs})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{gs} @ fixed V_{gs} at Different V_{bs}

Step 19

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
$\theta_{dibl}(Eta0, Etab, Dsub, L)$ Fitting Target Exp. Data: Subthreshold region $I_{ds}(V_{gs}, V_{bs})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{gs} @ $V_{ds} = V_{dd}$ at Different V_{bs}

Step 20

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
*Eta*0, *Etab*, *Dsub* Fitting Target Exp. Data: $\theta_{dibl}(Eta0, Etab, L)$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{gs} @ $V_{ds} = V_{dd}$ at Different V_{bs}

Step 21

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
Keta Fitting Target Exp. Data: $I_{sat}(V_{gs}, V_{bs})/W$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{ds} @ $V_{bs} = V_{bb}$ at Different V_{gs}

Step 22

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
α_0, α_1, β_0 Fitting Target Exp. Data: $I_{sub}(V_{gs}, V_{bs})/W$	One Set of Devices (Large and Fixed *W* & Different *L*). I_{ds} vs. V_{ds} @ $V_{bs} = V_{bb}$ at Different V_{ds}

6.4 Notes on Parameter Extraction

6.4.1 Parameters with Special Notes

Below is a list of model parameters which have special notes for parameter extraction.

Symbols used in SPICE	Description	Default Value	Unit	Notes
Vth0	Threshold voltage for large W and L device @ Vbs=0V	0.7 (NMOS) -0.7 (PMOS)	V	nI-1
K1	First order body effect coefficient	0.5	$V^{1/2}$	nI-2
K2	Second order body effect coefficient	0	none	nI-2
Vbm	Maximum applied body bias	-3	V	nI-2
Nch	Channel doping concentration	1.7E17	$1/cm^3$	nI-3
gamma1	Body-effect coefficient near interface	calculated	$V^{1/2}$	nI-4
gamma2	Body-effect coefficient in the bulk	calculated	$V^{1/2}$	nI-5
Vbx	Vbs at which the depletion width equals xt	calculated	V	nI-6
Cgso	Non-LDD source-gate overlap capacitance per channel length	calculated	F/m	nC-1
Cgdo	Non-Ldd drain-gate overlap capacitance per channel length	calculated	F/m	nC-2
CF	Fringing field capacitance	calculated	F/m	nC-3

Table 6-2. Parameters with notes for extraction.

6.4.2 Explanation of Notes

nI-1. If V_{th0} is not specified, it is calculated by

$$V_{th0} = V_{FB} + \Phi_s + K_1\sqrt{\Phi_s}$$

where the model parameter V_{FB}=-1.0. If V_{th0} is specified, V_{FB} defaults to

$$V_{FB} = V_{th0} - \Phi_s - K_1\sqrt{\Phi_s}$$

nI-2. If K_1 and K_2 are not given, they are calculated based on

$$K_1 = \gamma_2 - 2K_2\sqrt{\Phi_s - V_{bm}}$$

$$K_2 = \frac{(\gamma_1 - \gamma_2)\left(\sqrt{\Phi_s - V_{bx}} - \sqrt{\Phi_s}\right)}{2\sqrt{\Phi_s}\left(\sqrt{\Phi_s - V_{bm}} - \sqrt{\Phi_s}\right) + V_{bm}}$$

where Φ_s is calculated by

$$\Phi_s = 2V_{tm0}\ln\left(\frac{N_{ch}}{n_i}\right)$$

$$V_{tm0} = \frac{k_B T_{nom}}{q}$$

$$n_i = 1.45\times 10^{10}\left(\frac{T_{nom}}{300.15}\right)^{1.5}\exp\left(21.5565981-\frac{E_{g0}}{2V_{tm0}}\right)$$

$$E_{g0} = 1.16-\frac{7.02\times 10^{-4}T_{nom}^{\ 2}}{T_{nom}+1108}$$

where E_{g0} is the energy bandgap at temperature T_{nom}.

nI-3. If N_{ch} is not given and γ_1 is given, N_{ch} is calculated from

$$N_{ch} = \frac{\gamma_1^{\ 2}C_{ox}^{\ 2}}{2q\varepsilon_{si}}$$

If both γ_1 and N_{ch} are not given, N_{ch} defaults to 1.7e23 m^{-3} and γ_1 is calculated from N_{ch}.

nI-4. If γ_1 is not given, it is calculated by

$$\gamma_1 = \frac{\sqrt{2q\varepsilon_{si}N_{ch}}}{C_{ox}}$$

nI-5. If γ_2 is not given, it is calculated by

$$\gamma_2 = \frac{\sqrt{2q\varepsilon_{si}N_{sub}}}{C_{ox}}$$

nI-6. If V_{bx} is not given, it is calculated by

$$\frac{qN_{ch}X_t^{\ 2}}{2\varepsilon_{si}} = \Phi_s - V_{bx}$$

nC-1. If *Cgso* is not given, it is calculated by

if (*dlc* is given and is greater 0),
    Cgso = *dlc* * *Cox* - *Cgs*1
    if (*Cgso* < 0)
    Cgso = 0
else *Cgso* = 0.6 *Xj* * *Cox*

nC-2. If *Cgdo* is not given, it is calculated by

if (*dlc* is given and is greater than 0),
    Cgdo = *dlc* * *Cox* - *Cgd*1
    if (*Cgdo* < 0)
    Cgdo = 0
else *Cgdo* = 0.6 *Xj* * *Cox*

nC-3. If *CF* is not given then it is calculated usin by

$$CF = \frac{2\varepsilon_{ox}}{\pi}\ln\left(1+\frac{4\times 10^{-7}}{Tox}\right)$$