Chapter 13: Parameter Extraction Methodology

Parameter extraction is an important part of model development. The extraction 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.

13.1 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.

13.2 Extraction Strategy

Two different strategies are available for extracting parameters: 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.

It is suggested that BSIM4 use 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. In the following, a general extraction methodology is proposed for basic BSIM4 model parameters. Thus, it will not cover other model parameters, such as those of the gate tunneling current model and RF models, etc.

13.3 Extraction Procedure

13.3.1 Extraction Requirements

One large size device and two sets of smaller-sized devices are needed to extract parameters, as shown in Figure 13-1.

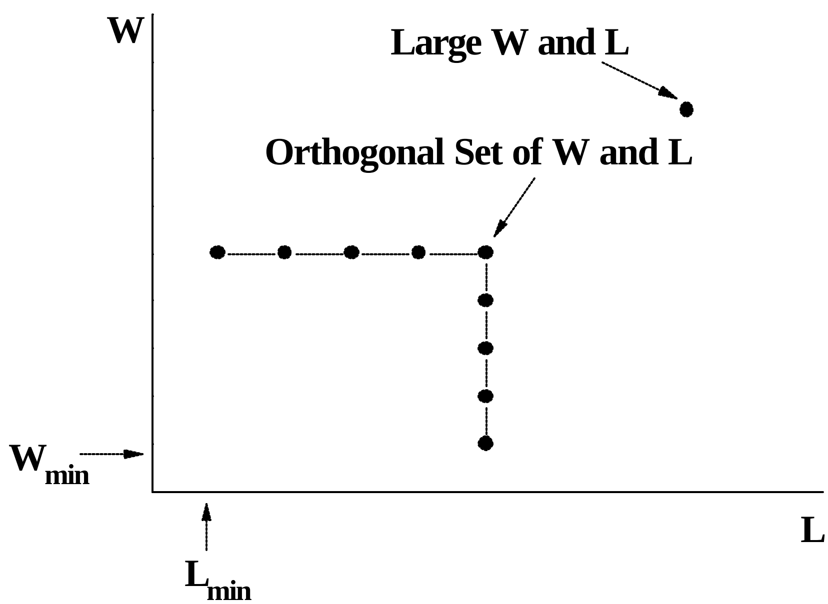

Figure 13-1. Device geometries used for parameter extraction

The large-sized device ($W \geq 10\mu m$, $L \geq 10\mu m$) 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 *VTH*0, 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}.

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

13.3.2 Optimization

The optimization process recommended is a combination of Newton-Raphson's iteration and linear-squares fit of either one, two, or three variables. A flow chart of this optimization process is shown in Figure 13-2. The model equation is first arranged in a form suitable for Newton-Raphson's iteration as shown in (13.3.1):

$$f_{\exp}(P_{10},P_{20},P_{30}) - f_{sim}(P_1^{(m)},P_2^{(m)},P_3^{(m)}) = \frac{\partial f_{sim}}{\partial P_1}\Delta P_1^m + \frac{\partial f_{sim}}{\partial P_2}\Delta P_2^m + \frac{\partial f_{sim}}{\partial P_3}\Delta P_3^m \qquad (13.3.1)$$

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.

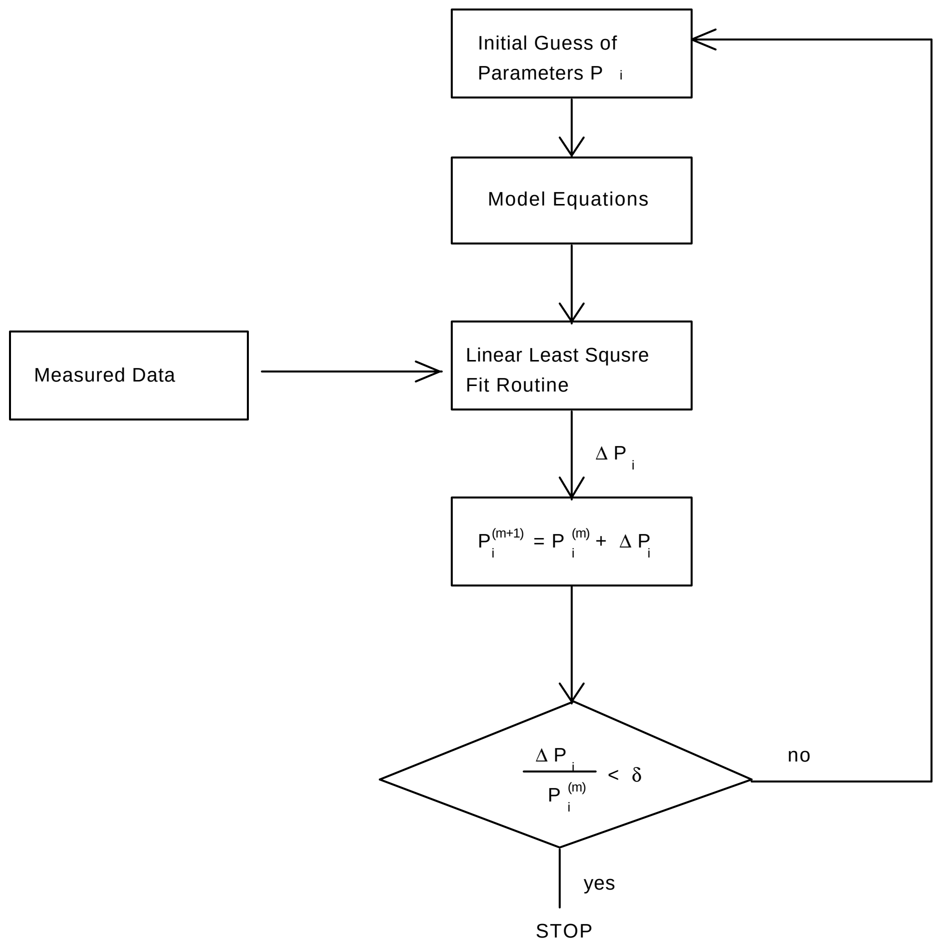

Figure 13-2. Optimization flow.

To change (13.3.1) 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 (13.3.1) are divided by ∂f_{sim} / ∂P_1. This gives the change in P_1, $\Delta P_1^{(m)}$, for the next iteration such that:

$$P_i^{(m+1)} = P_i^{(m)} + DP_i^{(m)} \tag{13.3.2}$$

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.

13.3.3 Extraction Routine

Before any model parameters can be extracted, some process parameters have to be provided. They are listed below in Table 13-1:

Input Parameters Names	Physical Meaning
TOXE, TOXP, DTOX, or EPSROX	Gate oxide thickness and dielectric constant
NDEP	Doping concentration in the channel
TNOM	Temperature at which the data is taken
L_{drawn}	Mask level channel length
W_{drawn}	Mask level channel width
XJ	Junction depth

Table 13-1. 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
VTH0, K1, K2 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
UA, UB, UC, EU 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}(RDSW, 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}(RDSW, 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
RDSW, PRWG, PRWB, WR Fitting Target Exp. Data: R_{ds}(RDSW, W, V_{gs}, V_{bs})	R_{ds}(RDSW, W, V_{gs}, V_{bs})

Step 6

Extracted Parameters & Fitting Target Data	Devices & Experimental Data

DVT0, DVT1, DVT2, LPE0, LPEB 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
DVT0W, DVT1W, DVT2W 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
K3, K3B, W0 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
MINV, VOFF, VOFFL, NFACTOR, CDSC, CDSCB 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
CDSCD 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} = 0.05V at Different V_{bs}

Step 12

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
VSAT, A0, AGS Fitting Target Exp. Data: $I_{sat}(V_{gs}, V_{bs})/W$ A1, A2 (PMOS Only) Fitting Target Exp. Data $V_{dsat}(V_{gs})$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{ds} @ V_{bs} = 0V 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
PSCBE1, PSCBE2 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

PCLM, θ(DROUT, PDIBLC1, PDIBLC2, *L*), PVAG, FPROUT, DITS, DITSL, DITSD 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
DROUT, PDIBLC1, PDIBLC2 Fitting Target Exp. Data: θ(DROUT, PDIBLC1, PDIBLC2, *L*)	One Set of Devices (Large and Fixed *W* & Different *L*). θ(DROUT, PDIBLC1, PDIBLC2, *L*)

Step 18

Extracted Parameters & Fitting Target Data	Devices & Experimental Data
PDIBLCB Fitting Target Exp. Data: θ(DROUT, PDIBLC1, PDIBLC2, *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

θ_{DIBL}(ETA0, ETAB, DSUB, DVTP0, DVTP1, 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
ETA0, ETAB, DSUB Fitting Target Exp. Data: θ_{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

ALPHA0, ALPHA1, BETA0 Fitting Target Exp. Data: $I_{ii}(V_{gs}, V_{bs})/W$	One Set of Devices (Large and Fixed W & Different L). I_{ds} vs. V_{ds} @ $V_{bs} = V_{bb}$ at Different V_{ds}