Leti-UTSOI 2.2.0 User's Manual

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1 Introduction

Leti-UTSOI2 is the second version of the Leti-UTSOI model, compact model dedicated to Fully-Depleted on Silicon-On-Insulator (FDSOI) technologies with low-doped channel, developed at CEA-LETI. The device architecture described by this model is illustrated in Figure 1.1.

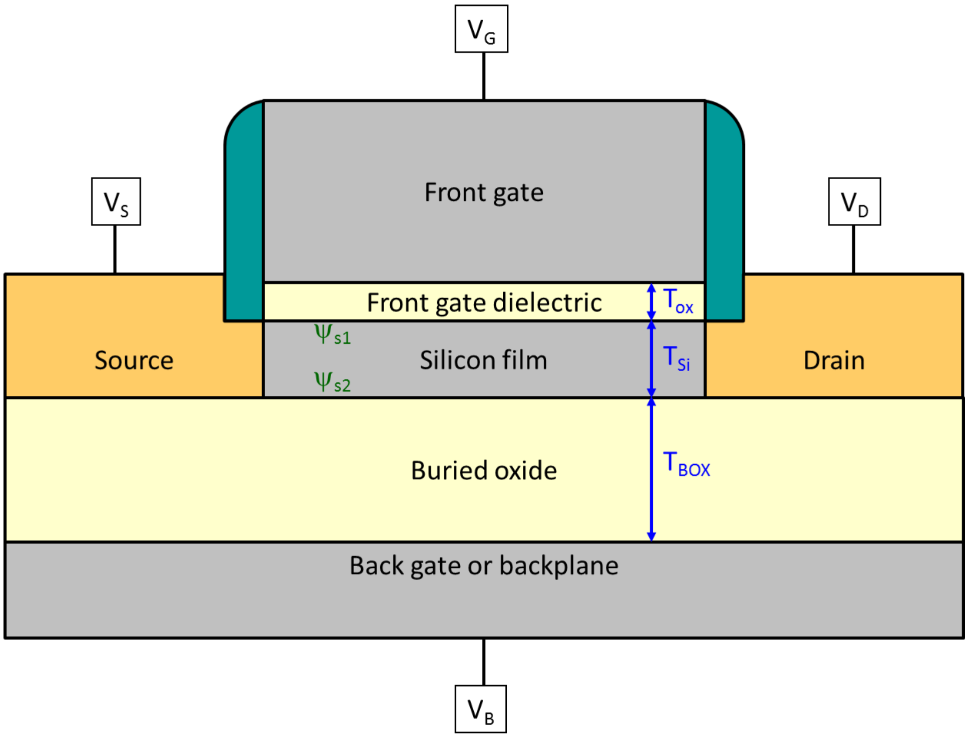

Figure 1.1- Schematic cross-section of a FDSOI transistor, describing the characteristic thicknesses and the surface potentials at the front (ψ_{s1}) and back (ψ_{s2}) interfaces.

1.1 Model structure

As described in Figure 1.2, the model structure is the same as in the different versions of Leti-UTSOI1 [1] [2] and, thus, similar to PSP [3] [4]. It is based on a hierarchical construction featuring two levels of parameter set:

- A local mode, in which the knowledge of the device geometry (channel length and width) is not needed. In this mode, the local parameter values are directly obtained from the model cards.
- A global mode, in which the local parameters are computed from the global model card and the device geometry through scaling laws (see paragraph 3.1). The so-computed local parameters are then used to compute the model equations. In this mode, some local parameters can also be modified according to the stress model (see paragraph 3.2).

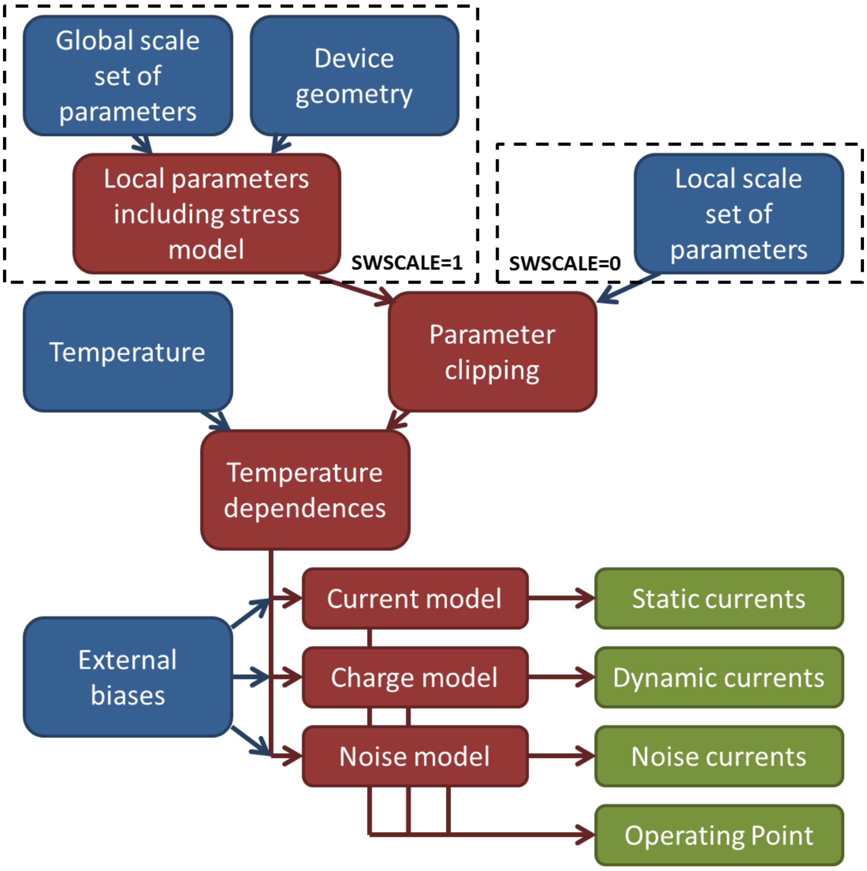

Figure 1.2- Model structure, showing the two scale levels of parameter set: local (SWSCALE=0) and global (SWSCALE=1).

1.2 Device physics

In terms of device physics, all the features included in Leti-UTSOI1 are also present in Leti-UTSOI2, but Leti-UTSOI2 includes some additional ingredients.

First, Leti-UTSOI2 has been developed with the aim of being able to describe device operations with a strongly inverted back interface. Thus, an original analytical procedure has been developed to calculate the exact values of the surface potentials at front and back interfaces in all operating conditions (see **Error! Reference source not found.**). Besides this surface potential calculation, new drain current (paragraph 4.4) and intrinsic charge (paragraph 4.8) models have also been developed. It should be noticed that this new model core is valid not only for FDSOI technologies, but more generally for all Independent Double Gate device architectures. An overview of Leti-UTSOI2 can be found in [5] and detailed description of the model core in [6] [7] [8].

Second, in Leti-UTSOI2 is introduced the effect of backplane depletion (paragraph 4.3), computed through a bulk MOSFET like surface potential calculation. This effect can be activated or not through the value of the SWSUBDEP flag. If the flag is set to 0, the backplane is assumed metallic, as in UTSOI1.

Third, Leti-UTSOI2 offers the possibility to define two different junctions at source and drain sides, as done in PSP. Junction related parameters are thus duplicated, the drain related parameters having the same name as their source side counterparts plus a final “D”. This possible junction asymmetry can be activated or not thanks to the SWJUNASYM flag. When it is de-activated, drain related parameters are ignored (see paragraph 3.3).

Finally, it should be noticed that the Leti-UTSOI1 possibility to switch from external to internal series resistance through the SWRSMOD flag is no longer included in Leti-UTSOI2.

Note that, from version 2.1.0, the temperature node of the transistor (Tnode), that gives channel temperature elevation induced by self-heating, is accessible from the circuit netlist (i.e. declared as “inout”). So, from version 2.1.0, transistor instantiation accepts 5 nodes: drain, gate, source, bulk and internal temperature.

Model evolutions from UTSOI 2.0.0 version are detailed in part 9.

1.3 Output currents

Figure 1.3 describes how the quantities calculated afterwards in this documentation are sent as output currents in the different branches. Static currents are in blue, dynamic currents in red and noise currents in green. It should be noticed that a multiplication parameter $Mult_f$ = MULTxNF is applied to all the output quantities specified in Figure 1.3.

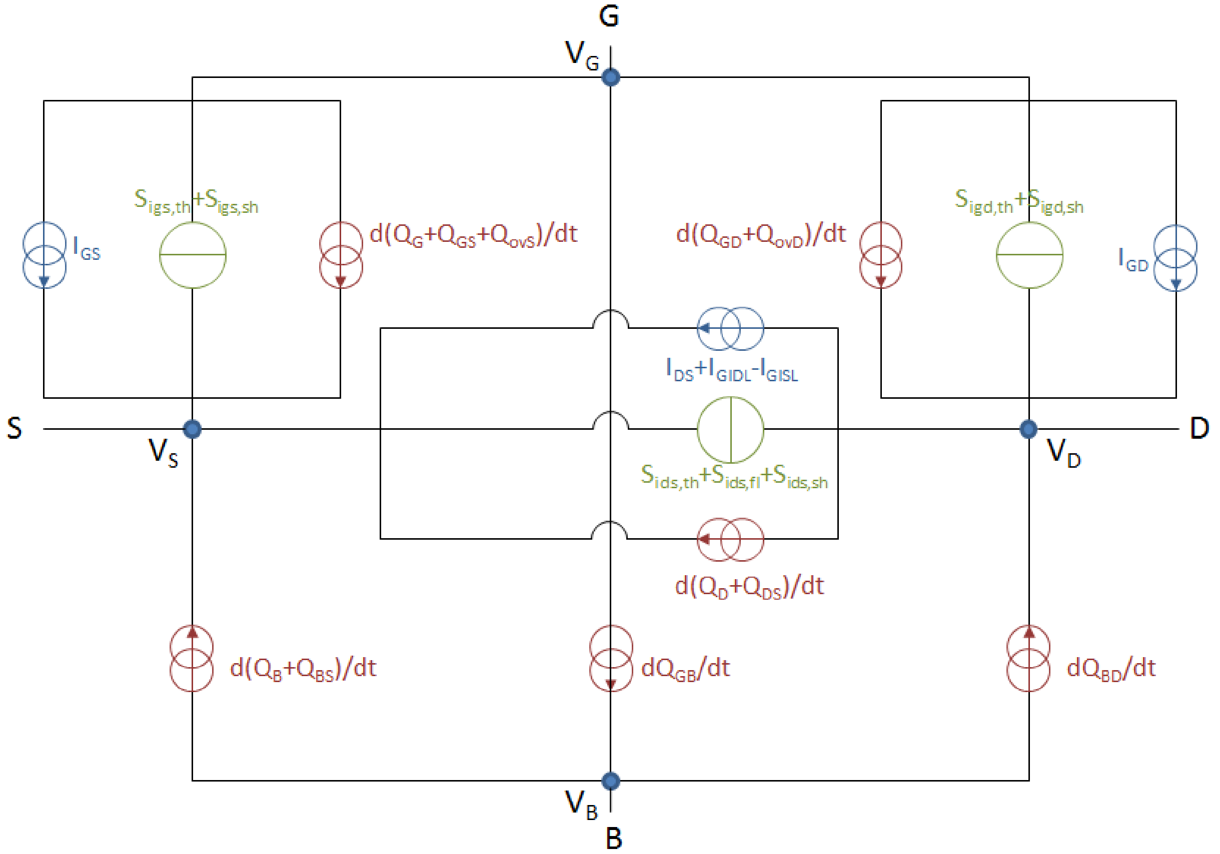

Figure 1.3- Description of the output currents in the device branches. All quantities are multiplied by $Mult_f$.

2 Constants and parameters

2.1 Constants

The following tables detail the signification and the values of the constants used in the model.

Symbol	Unit	Description	Value
k_B	J/K	Boltzmann constant	$1.3806488\ 10^{-23}$
ħ	J s	Reduced Planck constant	$1.054571726\ 10^{-34}$
q	C	Elementary charge	$1.602176565\ 10^{-19}$
m_0	kg	Electron intrinsic mass	$9.10938291\ 10^{-31}$
QM_N	$V^{1/3}nm^{2/3}$	Constant for quantum confinement of electrons	1.27520989
QM_P	$V^{1/3}nm^{2/3}$	Constant for quantum confinement of holes	1.54120870

QM_N and QM_P are equal to $\left(\frac{9\pi\hbar}{4\sqrt{2qm_{conf}}}\right)^{2/3}$ with $m_{conf}=0.918m_0$ for electrons and $m_{conf}=0.52m_0$ for holes.

Symbol	Unit	Description	Value
ε_{ox}	F/m	Permittivity of silicon dioxide (relative value is 3.9)	$3.45313\ 10^{-11}$
ε_{Si}	F/m	Permittivity of silicon (relative value is 11.8)	$1.04479\ 10^{-10}$
ε_{Ge}	F/m	Permittivity of germanium (relative value is 16.2)	$1.43438\ 10^{-10}$
$E_{g0,Si}$	V	Bandgap voltage for silicon at 0K	1.17
$E_{g0,Ge}$	V	Bandgap voltage for germanium at 0K	0.744
α_{Si}	V/K	First bandgap temperature dependence for silicon	$4.730\ 10^{-4}$
α_{Ge}	V/K	First bandgap temperature dependence for germanium	$4.774\ 10^{-4}$
β_{Si}	K	Second bandgap temperature dependence for silicon	636
β_{Ge}	K	Second bandgap temperature dependence for germanium	235
C_G	---	Non linearity coefficient for SiGe bandgap	-0.4
$n_{i,fact,300}$	m^{-3}	Intrinsic concentration pre-factor for silicon at 300K	$4.05\ 10^{25}$

2.2 Model selection, effect activation switches and reference temperature

The table below details the parameters used for model selection, the flags used to activate different physical effects, the selection of the transistor type and the reference temperature. Except for QMC, the value of the flags is 0 (effect de-activated) or 1 (effect activated). QMC parameter is used to adjust quantum confinement effects and can take other values than 0 or 1.

Name	Unit	Definition	Default	Min	Max
SWSCALE	---	Scale level: 0 = Local, 1 = Global	0	---	---
VERSION	---	Model version	2.20	---	---
SWCLIPCHK	---	Flag for warnings about parameter clipping	0	---	---
SWSUBDEP	---	Flag for backplane depletion effect	0	---	---
SWIGATE	---	Flag for gate current model	0	---	---
SWGIDL	---	Flag for gate induced source/drain leakage model	0	---	---
SWSHE	---	Flag for self-heating effect	0	---	---
SWIGN	---	Flag for induced gate noise model	1	---	---
SWJUNASYM	---	Flag for source/drain junction asymmetry	0	---	---
QMC	---	Quantum confinement coefficient	1.0	0.0	---
TYPE	---	Channel type: +1 = NMOS, -1 = PMOS	1	---	---
TR	°C	Temperature of parameter extraction	21.0	-273.0	---

Warning: Parameter **TYPE** defines the transistor type for the VerilogA version of the model. To define the transistor type when using an implemented version of Leti-UTSOI2 in a SPICE simulator, please refer to the corresponding simulator documentation.

2.3 Instance parameters

The following table describes the instance parameters.

Name	Unit	Definition	Default	Min	Max
L	m	Drawn channel length	10^{-6}	10^{-9}	---
W	m	Drawn channel width	10^{-6}	10^{-9}xNF	---
ASOURCE	m^2	Source region area	10^{-12}	0.0	---
ADRAIN	m^2	Drain region area	10^{-12}	0.0	---
PSOURCE	m	Source region perimeter	10^{-6}	0.0	---
PDRAIN	m	Drain region perimeter	10^{-6}	0.0	---
SA	m	Distance between active edge and poly at source side	0.0	0.0	---
SB	m	Distance between active edge and poly at drain side	0.0	0.0	---
SD	m	Distance between neighbouring fingers	0.0	0.0	---
NF	---	Number of fingers	1	1	---
MULT	---	Number of devices in parallel	1	0	---
DELVTO	V	Threshold voltage shift parameter	0.0	---	---
FACTUO	---	Low field mobility pre-factor	1.0	0.0	---

2.4 Scaling parameters

In the following table are given the geometrical parameters that link drawn, physical and electrical transistor dimensions.

Name	Unit	Definition	Default	Min	Max
LVARO	m	Long channel difference between physical and drawn gate lengths	0.0	---	---
LVARL	---	Length dependence of physical to drawn gate length difference	0.0	---	---
LVARW	---	Width dependence of physical to drawn gate length difference	0.0	---	---
LAP	m	Effective channel length reduction per side	0.0	---	---
WVARO	m	Wide channel difference between physical and drawn active width	0.0	---	---
WVARL	---	Length dependence of physical to drawn active width difference	0.0	---	---
WVARW	---	Width dependence of physical to drawn active width difference	0.0	---	---
WOT	m	Effective channel width reduction per side	0.0	---	---
DLQ	m	Effective channel length additional offset for charge model	0.0	---	---
DWQ	m	Effective channel width additional offset for charge model	0.0	---	---

2.5 Stress model parameters

Besides the existing STI-based stress model, a new stress model dedicated to strained-FDSOI technologies has been introduced in Leti-UTSOI from version 2.2.0. Selection between the two models is done through **SWSTRESS** flag: 1 for STI-based model, 2 for strained-SOI model. Stress effect can be de-activated by setting the flag to 0.

Name	Unit	Definition	Default	Min	Max
SWSTRESS	---	Stress model selection flag	1	---	---
SAREF	m	Reference distance between active edge and poly from one side	10^{-6}	10^{-9}	---
SBREF	m	Reference distance between active edge and poly from other side	10^{-6}	10^{-9}	---

2.5.1 Parameters for SWSTRESS=1

The next table describes the parameters used for the STI-stress model. This model comes originally from BSIM4.4 and has been slightly modified in PSP.

Name	Unit	Definition	Default	Min	Max
WLOD	m	Width parameter	0.0	---	---
KUO	m	Mobility degradation/enhancement coefficient	0.0	---	---

KVSAT	---	Saturation velocity degradation/enhancement coefficient	0.0	-1.0	1.0
TKUO	---	Temperature dependence of KUO	0.0	---	---
LKUO	$m^{LLODKUO}$	Length dependence of KUO	0.0	---	---
WKUO	$m^{WLODKUO}$	Width dependence of KUO	0.0	---	---
PKUO	$m^{sumLODKUO}$	Cross-term dependence of KUO	0.0	---	---
LLODKUO	---	Length parameter for mobility stress effect	0.0	0.0	---
WLODKUO	---	Width parameter for mobility stress effect	0.0	0.0	---
KVTHO	Vm	Threshold voltage shift parameter	0.0	---	---
LKVTHO	$m^{LLODVTH}$	Length dependence of KVTHO	0.0	---	---
WKVTHO	$m^{WLODVTH}$	Width dependence of KVTHO	0.0	---	---
PKVTHO	$m^{sumLODVTH}$	Cross-term dependence of KVTHO	0.0	---	---
LLODVTH	---	Length parameter for threshold voltage stress effect	0.0	0.0	---
WLODVTH	---	Width parameter for threshold voltage stress effect	0.0	0.0	---
STETAO	m	ETAO shift factor related to threshold voltage change	0.0	---	---
LODETAO	---	ETAO shift modification factor	1.0	0.0	---

Note: sumLODKUO and sumLODVTH refer to LLODKUO+WLODKUO and LLODVTH+WLODVTH respectively.

2.5.2 Parameters for SWSTRESS=2

The next table describes the parameters used for the strained-SOI dedicated model.

Name	Unit	Definition	Default	Min	Max
STRLAMBDA	m	Strain relaxation characteristic length	10^{-7}	10^{-9}	10^{-5}
STRALPHA	---	Strain relaxation asymmetry parameter	3.0	0.5	---
STRDVFBO	V	Threshold shift parameter	0.0	---	---
STRWDVFBO	---	Width dependence of threshold shift parameter	0.0	---	---
STRDCFL	---	DIBL variation parameter	0.0	---	---
STRRUO	---	Mobility degradation/enhancement coefficient	0.0	---	---
STRTRUO	---	Temperature dependence of STRRUO	0.0	---	---
STRRVSAT	---	Saturation velocity degradation/enhancement coefficient	0.0	---	---

2.6 Process parameters

In the following tables are given all the local model parameters, in bold. Each local parameter is immediately followed by its related global scale parameters, in italic.

Name	Unit	Definition	Default	Min	Max
TOXE	m	Front gate equivalent oxide thickness (EOT)	$2\ 10^{-9}$	$3\ 10^{-10}$	10^{-6}
TOXEO	*m*	*Geometry independent global scale parameter for TOXE*	$2\ 10^{-9}$	$3\ 10^{-10}$	10^{-6}
TSI	m	Silicon or SiGe film thickness	10^{-8}	$3\ 10^{-9}$	$2\ 10^{-8}$
TSIO	*m*	*Geometry independent global scale parameter for TSI*	10^{-8}	$3\ 10^{-9}$	$2\ 10^{-8}$
XGE	---	Fraction of germanium content in the channel	0.0	0.0	1.0
XGEO	---	*Geometry independent global scale parameter for XGE*	*0.0*	*0.0*	*1.0*
TBOX	m	Back gate equivalent oxide thickness (EOT)	10^{-7}	$3\ 10^{-10}$	10^{-6}
TBOXO	*m*	*Geometry independent global scale parameter for TBOX*	10^{-7}	$3\ 10^{-10}$	10^{-6}
NCH	cm^{-3}	Thin film doping: positive = p-type, negative = n-type	0.0	0.0	10^{19}
NCHO	cm^{-3}	*Geometry independent global scale parameter for NCH*	*0.0*	*0.0*	10^{19}
NSUB	cm^{-3}	Backplane doping level: positive = p-type, negative = n-type	$3\ 10^{18}$	10^{16}	10^{21}
NSUBO	cm^{-3}	*Geometry independent global scale parameter for NSUB*	$3\ 10^{18}$	10^{16}	10^{21}
CT	---	Interface states factor	0.0	0.0	---
CTO	---	*Geometry independent global scale parameter for CT*	*0.0*	*0.0*	---
TOXP	m	Front gate physical oxide thickness	$2\ 10^{-9}$	$3\ 10^{-10}$	10^{-6}
TOXPO	*m*	*Geometry independent global scale parameter for TOXP*	$2\ 10^{-9}$	$3\ 10^{-10}$	10^{-6}
NOV	cm^{-3}	Effective doping level of overlap-LDD regions	10^{20}	10^{15}	10^{21}
NOVO	cm^{-3}	*Geometry independent global scale parameter for NOV*	10^{20}	10^{15}	10^{21}
NOVD	cm^{-3}	Effective doping level of overlap-LDD regions at drain side	10^{20}	10^{15}	10^{21}

NOVDO	*cm^{-3}*	*Geometry independent global scale parameter for NOVD*	*10^{20}*	*10^{15}*	*10^{21}*
VFB	V	Front gate workfunction referenced to Si midgap at TR	0.0	---	---
VFBO	*V*	*Long and wide channel value of VFB*	*0.0*	*---*	*---*
VFBL	*V*	*Channel length scaling parameter of VFB*	*0.0*	*---*	*---*
VFBLEXP	*---*	*Channel length scaling exponent of VFB*	*2.0*	*---*	*---*
VFBL2	*---*	*Second order channel length dependence of VFB*	*0.0*	*0.0*	*---*
VFBLEXP2	*---*	*Second order channel length scaling exponent of VFB*	*2.0*	*---*	*---*
VFBW	*V*	*Channel width scaling parameter of VFB*	*0.0*	*---*	*---*
VFBLW	*---*	*Channel area scaling parameter of VFB*	*0.0*	*---*	*---*
VFBB	V	Back gate workfunction offset at TR	0.0	---	---
VFBBO	*V*	*Long and wide channel value of VFBB*	*0.0*	*---*	*---*
VFBLBO	*---*	*Back to front interface asymmetry factor applied to VFBL*	*0.0*	*0.0*	*---*
STVFB	V/K	Temperature dependence of VFB and VFBB	0.0	---	---
STVFBO	*V/K*	*Long and wide channel value of STVFB*	*0.0*	*---*	*---*
STVFBL	*---*	*Channel length scaling parameter of STVFB*	*0.0*	*---*	*---*
STVFBW	*---*	*Channel width scaling parameter of STVFB*	*0.0*	*---*	*---*
STVFBLW	*---*	*Channel area scaling parameter of STVFB*	*0.0*	*---*	*---*

2.7 Gate to interface coupling parameters

Name	Unit	Definition	Default	Min	Max
CICF	---	Long channel front interface coupling coefficient	1.0	0.1	10.0
CICFO	*---*	*Geometry independent global scale parameter for CICF*	*1.0*	*0.1*	*10.0*
CIC	---	Long channel back interface coupling coefficient	1.0	0.1	10.0
CICO	*---*	*Geometry independent global scale parameter for CIC*	*1.0*	*0.1*	*10.0*
PSCE	---	Short channel coupling attenuation parameter	0.0	0.0	5.0
PSCEL	*---*	*Channel length scaling parameter of PSCE*	*0.0*	*---*	*---*
PSCELEXP	*---*	*Channel length scaling exponent of PSCE*	*2.0*	*---*	*---*
PSCEW	*---*	*Channel width scaling parameter of PSCE*	*0.0*	*---*	*---*
PSCEB	---	Short channel back to front interface asymmetry factor	1.0	0.0	---
PSCEBO	*---*	*Geometry independent global scale parameter for PSCEB*	*1.0*	*0.0*	*---*
NSDDC	cm^{-3}	Source/drain effective doping level for DC model	10^{22}	10^{18}	10^{22}
NSDDCO	*cm^{-3}*	*Geometry independent global scale parameter for NSDDC*	*10^{22}*	*10^{18}*	*10^{22}*
PSCEDLB	---	Back bias dependence of short channel effect modulation	0.0	0.0	---
PSCEDLBO	*---*	*Geometry independent global scale parameter for PSCEDLB*	*0.0*	*0.0*	*---*
PNCE	---	Narrow channel effect on body factor	0.0	-1.0	1.0
PNCEW	*---*	*Channel width scaling parameter of PNCE*	*0.0*	*---*	*---*

2.8 Drain Induced Barrier Lowering parameters

Name	Unit	Definition	Default	Min	Max
CF	---	DIBL parameter at TR	0.0	0.0	---
CFL	*---*	*Channel length scaling parameter of CF*	*0.0*	*---*	*---*
CFLEXP	*---*	*Channel length scaling exponent of CF*	*2.0*	*---*	*---*
CFW	*---*	*Channel width scaling parameter of CF*	*0.0*	*---*	*---*
CFB	---	DIBL back to front interface asymmetry factor	1.0	0.0	---
CFBO	*---*	*Geometry independent global scale parameter for CFB*	*1.0*	*0.0*	*---*
STCF	K^{-1}	Temperature dependence of CF	0.0	---	---
STCFL	*K^{-1}*	*Channel length scaling parameter for STCF*	*0.0*	*---*	*---*
CFD	V	Drain voltage dependence parameter of DIBL	0.2	0.05	---
CFDO	*V*	*Geometry independent global scale parameter for CFD*	*0.2*	*0.05*	*---*
CFDL	---	DIBL modulation due to Leff dependence on biases	0.0	---	---
CFDLL	*---*	*Channel length scaling parameter of CFDL*	*0.0*	*---*	*---*
CFDLW	*---*	*Channel width scaling parameter of CFDL*	*0.0*	*---*	*---*
CFDLB	---	Back bias dependence of DIBL modulation	0.0	0.0	---
CFDLBO	*---*	*Geometry independent global scale parameter for CFDLB*	*0.0*	*0.0*	*---*

2.9 Mobility parameters

Name	Unit	Definition	Default	Min	Max
BETN	m^2/Vs	Front channel aspect ratio times low field mobility at TR	0.05	10^{-10}	---
UO	*m^2/Vs*	*Front channel low field mobility at TR*	*0.05*	---	---
FBET1	---	*First length dependence modulation of BETN*	*0.0*	---	---
FBET1W	---	*Width dependence of FBET1*	*0.0*	---	---
LP1	*m*	*First characteristic length of BETN scaling*	10^{-8}	10^{-10}	---
LP1W	---	*Width dependence of LP1*	*0.0*	---	---
FBET2	---	*Second length dependence modulation of BETN*	*0.0*	---	---
LP2	*m*	*Second characteristic length of BETN scaling*	10^{-8}	10^{-10}	---
BETW1	---	*First width dependence modulation of BETN*	*0.0*	---	---
BETW2	---	*Second width dependence modulation of BETN*	*0.0*	---	---
WBET	*m*	*Characteristic width of BETN scaling*	10^{-8}	10^{-10}	---
BETNB	---	Back channel over front channel low field mobility ratio	1.0	0.1	10.0
BETNBO	---	*Geometry independent global scale parameter for BETNB*	*1.0*	*0.1*	*10.0*
STBET	---	Temperature dependence exponent of BETN	1.5	---	---
STBETO	---	*Long and wide channel value of STBET*	*1.5*	---	---
STBETL	---	*Channel length scaling parameter of STBET*	*0.0*	---	---
STBETW	---	*Channel width scaling parameter of STBET*	*0.0*	---	---
STBETLW	---	*Channel area scaling parameter of STBET*	*0.0*	---	---
CS	---	Coulomb scattering parameter at TR	0.0	0.0	---
CSO	---	*Long and wide channel value of CS*	*0.0*	---	---
CSL	---	*Channel length scaling parameter of CS*	*0.0*	---	---
CSLEXP	---	*Geometry independent global scale parameter for CS*	*1.0*	---	---
CSW	---	*Channel width scaling parameter of CS*	*0.0*	---	---
CSLW	---	*Channel area scaling parameter of CS*	*0.0*	---	---
CSFI	---	Field dependence of Coulomb scattering at front interface	0.0	0.0	---
CSFIO	---	*Geometry independent global scale parameter for CSFI*	*0.0*	*0.0*	---
CSBI	---	Field dependence of Coulomb scattering at back interface	0.0	0.0	---
CSBIO	---	*Geometry independent global scale parameter for CSBI*	*0.0*	*0.0*	---
STCS	---	Temperature dependence exponent of CS	0.0	---	---
STCSO	---	*Long and wide channel value of STCS*	*0.0*	---	---
STCSL	---	*Channel length scaling parameter of STCS*	*0.0*	---	---
STCSW	---	*Channel width scaling parameter of STCS*	*0.0*	---	---
STCSLW	---	*Channel area scaling parameter of STCS*	*0.0*	---	---
THECS	---	Coulomb scattering exponent at TR	1.5	0.0	---
THECSO	---	*Geometry independent global scale parameter for THECS*	*1.5*	*0.0*	---
STTHECS	---	Temperature dependence exponent of THECS	0.0	---	---
STTHECSO	---	*Geometry independent global scale parameter for STTHECS*	*0.0*	---	---
CSTHR	---	Coulomb scattering threshold level	2.0	0.001	---
CSTHRO	---	*Geometry independent global scale parameter for CSTHR*	*2.0*	*0.001*	---
CSTHRB	---	Coulomb scattering threshold asymmetry parameter	1.0	0.1	---
CSTHRBO	---	*Geometry independent global scale parameter for CSTHRB*	*1.0*	*0.1*	---
MUE	cm/MV	High field mobility reduction coefficient at TR	0.0	0.0	---
MUEO	*cm/MV*	*Geometry independent global scale parameter for MUE*	*0.0*	*0.0*	---
STMUE	---	Temperature dependence exponent of MUE	0.0	---	---
STMUEO	---	*Geometry independent global scale parameter for STMUE*	*0.0*	---	---
THEMU	---	High field mobility reduction exponent at TR	1.5	0.0	---
THEMUO	---	*Geometry independent global scale parameter for THEMU*	*1.5*	*0.0*	---
STTHEMU	---	Temperature dependence exponent of THEMU	0.0	---	---
STTHEMUO	---	*Geometry independent global scale parameter for STTHEMU*	*0.0*	---	---
XCOR	V^{-1}	High field mobility non universality factor at TR	0.0	---	---
XCORO	V^{-1}	*Long and wide channel value of XCOR*	*0.0*	---	---
XCORL	---	*Channel length scaling parameter of XCOR*	*0.0*	---	---
XCORLEXP	---	*Channel length scaling exponent of XCOR*	*1.0*	---	---
XCORW	---	*Channel width scaling parameter of XCOR*	*0.0*	---	---

XCORLW	---	*Channel area scaling parameter of XCOR*	*0.0*	---	---
XCORB	---	Asymmetry term of non-universality factor	1.0	---	---
XCORBO	---	*Geometry independent global scale parameter for XCORB*	*1.0*	---	---
STXCOR	---	Temperature dependence exponent of XCOR	0.0	---	---
STXCORO	---	*Geometry independent global scale parameter for STXCOR*	*0.0*	---	---
FETA	---	Transverse effective field parameter	1.0	0.0	---
FETAO	---	*Geometry independent global scale parameter for FETA*	*1.0*	*0.0*	---

2.10 Series resistance parameters

Name	Unit	Definition	Default	Min	Max
RS	Ω	Source/drain series resistance at TR	30.0	0.0	---
RSW1	*Ω*	*Source/drain series resistance for a WEN width at TR*	*30.0*	---	---
RSW2	---	*Second order width scaling parameter of RS*	*0.0*	---	---
RSIG	---	Source/drain extension resistance coefficient	0.0	0.0	---
RSIGO	---	*Geometry independent global scale parameter for RSIG*	*0.0*	*0.0*	---
STRS	---	Temperature dependence exponent of RS	0.0	---	---
STRSO	---	*Geometry independent global scale parameter for STRS*	*0.0*	---	---
RSG	---	Transverse electric field dependence of RS	0.0	-0.5	---
RSGO	---	*Geometry independent global scale parameter for RSG*	*0.0*	*-0.5*	---
RSB	---	Back bias dependence of RS	0.0	---	---
RSBO	---	*Geometry independent global scale parameter for RSB*	*0.0*	---	---
THERSG	---	Transverse electric field exponent of RS	2.0	---	---
THERSGO	---	*Geometry independent global scale parameter for THERSG*	*2.0*	---	---

2.11 Velocity saturation parameters

Name	Unit	Definition	Default	Min	Max
THESAT	V^{-1}	Velocity saturation parameter at TR	0.0	0.0	---
THESATO	V^{-1}	*Long and wide channel parameter for THESAT*	*0.0*	*0.0*	---
THESATL	s/m^2	*Channel length scaling parameter of THESAT*	*0.0*	---	---
THESATLEXP	---	*Channel length scaling exponent of THESAT*	*1.0*	---	---
THESATW	---	*Channel width scaling parameter of THESAT*	*0.0*	---	---
THESATLW	---	*Channel area scaling parameter of THESAT*	*0.0*	---	---
STTHESAT	---	Temperature dependence exponent of THESAT	-0.1	---	---
STTHESATO	---	*Long and wide channel value of STTHESAT*	*-0.1*	---	---
STTHESATL	---	*Channel length scaling parameter of STTHESAT*	*0.0*	---	---
STTHESATW	---	*Channel width scaling parameter of STTHESAT*	*0.0*	---	---
STTHESATLW	---	*Channel area scaling parameter of STTHESAT*	*0.0*	---	---
THESATG	---	Front gate bias dependence of velocity saturation	0.0	-0.5	---
THESATGO	---	*Geometry independent global scale parameter for THESATG*	*0.0*	*-0.5*	---
THESATB	---	Back gate bias dependence of velocity saturation	0.0	-0.5	---
THESATBO	---	*Geometry independent global scale parameter for THESATB*	*0.0*	*-0.5*	---

2.12 Saturation and Channel Length Modulation parameters

Name	Unit	Definition	Default	Min	Max
AX	---	Linear/saturation transition exponent	8.0	1.0	16.0
AXO	---	*Long and wide channel value of AX*	*8.0*	---	---
AXL	---	*Channel length scaling parameter of AX*	*0.0*	*0.0*	---
AXLEXP	---	*Channel length scaling exponent of AX*	*1.0*	---	---
ALP	---	Channel length modulation pre-factor	0.0	0.0	---
ALPL1	---	*Channel length scaling parameter of ALP*	*0.0*	---	---
ALPLEXP	---	*Channel length scaling exponent of ALP*	*1.0*	---	---
ALPL2	---	*Second order channel length dependence of ALP*	*0.0*	*0.0*	---
ALPLEXP2	---	*Second order channel length scaling exponent of ALP*	*2.0*	---	---

ALPW	---	*Channel width scaling parameter of ALP*	*0.0*	---	---
ALP1	V	Channel length modulation enhancement above threshold	0.0	0.0	---
ALP1L1	---	*Channel length scaling parameter of ALP1*	*0.0*	---	---
ALP1LEXP	---	*Channel length scaling exponent of ALP1*	*0.5*	---	---
ALP1L2	---	*Second order channel length dependence of ALP1*	*0.0*	*0.0*	---
ALP1LEXP2	---	*Second order channel length scaling exponent of ALP1*	*1.5*	---	---
ALP1W	---	*Channel width scaling parameter of ALP1*	*0.0*	---	---
ALPB	---	Back bias dependence of channel length modulation	0.0	---	---
ALPBO	---	*Geometry independent global scale parameter for ALPB*	*0.0*	---	---
VP	V	Channel length modulation logarithm dependence factor	0.05	10^{-10}	---
VPO	*V*	*Geometry independent global scale parameter for VP*	*0.05*	10^{-10}	---
VPG	---	Tranverse field dependence of CLM logarithm factor	0.0	0.0	---
VPGO	---	*Geometry independent global scale parameter for VPG*	*0.0*	*0.0*	---

2.13 Gate current parameters

Name	Unit	Definition	Default	Min	Max
GCO	---	Gate tunneling energy adjustment in inversion mode	0.0	-10.0	10.0
GCOO	---	*Geometry independent global scale parameter for GCO*	*0.0*	*-10.0*	*10.0*
IGINV	A	Gate to channel current pre-factor	0.0	0.0	---
IGINVLW	*A*	*IGINV value for a LEN.WEN area*	*0.0*	*0.0*	---
IGOVINV	A	Gate-overlap current pre-factor in inversion	0.0	0.0	---
IGOVINVW	*A*	*IGOVINV value for a WEN width*	*0.0*	*0.0*	---
IGOVINVD	A	Gate-overlap current pre-factor in inversion at drain side	0.0	0.0	---
IGOVINVDW	*A*	*IGOVINVD for a WEN width*	*0.0*	*0.0*	---
IGOVACC	A	Gate-overlap current pre-factor in accumulation	0.0	0.0	---
IGOVACCW	*A*	*IGOVACC value for a WEN width*	*0.0*	*0.0*	---
IGOVACCD	A	Gate-overlap current pre-factor in accumulation at drain side	0.0	0.0	---
IGOVACCDW	*A*	*IGOVACCD value for a WEN width*	*0.0*	*0.0*	---
STIG	---	Temperature dependence of all gate current pre-factors	0.0	---	---
STIGO	---	*Geometry independent global scale parameter for STIG*	*0.0*	---	---
GC2CH	---	Gate to channel current slope factor	0.375	0.0	10.0
GC2CHO	---	*Geometry independent global scale parameter for GC2CH*	*0.375*	*0.0*	*10.0*
GC3CH	---	Gate to channel current curvature factor	0.063	-2.0	2.0
GC3CHO	---	*Geometry independent global scale parameter for GC3CH*	*0.063*	*-2.0*	*2.0*
GC2OVINV	---	Gate-overlap current slope factor in inversion	0.375	0.0	10.0
GC2OVINVO	---	*Geometry independent global scale parameter for GC2OVINV*	*0.375*	*0.0*	*10.0*
GC3OVINV	---	Gate-overlap current curvature factor in inversion	0.063	-2.0	2.0
GC3OVINVO	---	*Geometry independent global scale parameter for GC3OVINV*	*0.063*	*-2.0*	*2.0*
GC2OVACC	---	Gate-overlap current slope factor in accumulation	0.375	0.0	10.0
GC2OVACCO	---	*Geometry independent global scale parameter for GC2OVACC*	*0.375*	*0.0*	*10.0*
GC3OVACC	---	Gate-overlap current curvature factor in accumulation	0.063	-2.0	2.0
GC3OVACCO	---	*Geometry independent global scale parameter for GC3OVACC*	*0.063*	*-2.0*	*2.0*
GCDOV	V^{-1}	High drain voltage dependence of overlap gate current	0.0	---	---
GCDOVL	V^{-1}	*GCDOV value for a LEN length*	*0.0*	---	---
GCVDOV	V	Threshold of high drain voltage effect on overlap gate current	1.0	---	---
GCVDOVO	*V*	*Geometry independent global scale parameter for GCVDOV*	*1.0*	---	---
CHIB	V	Tunneling barrier height	3.1	1.0	---
CHIBO	*V*	*Geometry independent global scale parameter for CHIB*	*3.1*	*1.0*	---
NIGINV	---	Gate tunneling slope adjustment in subthreshold regime	0.0	0.0	---
NIGINVO	---	*Geometry independent global scale parameter for NIGINV*	*0.0*	*0.0*	---

2.14 Gate Induced Drain/Source Leakage (GIDL/GISL) parameters

Name	Unit	Definition	Default	Min	Max
AGIDL	A/V^3	GIDL/GISL current pre-factor	0.0	0.0	---
AGIDLW	A/V^3	*AGIDL value for a WEN width*	*0.0*	*0.0*	---

AGIDLD	A/V^3	GIDL current pre-factor at drain side	0.0	0.0	---
AGIDLDW	*A/V^3*	*AGIDLD value for a WEN width*	*0.0*	*0.0*	---
BGIDL	V	GIDL/GISL probability factor at TR	41.0	0.0	---
BGIDLO	*V*	*Geometry independent global scale parameter for BGIDL*	*41.0*	*0.0*	---
BGIDLD	V	GIDL probability factor at TR at drain side	41.0	0.0	---
BGIDLDO	*V*	*Geometry independent global scale parameter for BGIDLD*	*41.0*	*0.0*	---
STBGIDL	V/K	Temperature dependence of BGIDL	0.0	---	---
STBGIDLO	*V/K*	*Geometry independent global scale parameter for STBGIDL*	*0.0*	---	---
STBGIDLD	V/K	Temperature dependence of BGIDLD	0.0	---	---
STBGIDLDO	*V/K*	*Geometry independent global scale parameter for STBGIDLD*	*0.0*	---	---
CGIDL	V^{-1}	Substrate bias dependence of GIDL/GISL	0.0	---	---
CGIDLO	*V^{-1}*	*Geometry independent global scale parameter for CGIDL*	*0.0*	---	---
CGIDLD	V^{-1}	Substrate bias dependence of GIDL at drain side	0.0	---	---
CGIDLDO	*V^{-1}*	*Geometry independent global scale parameter for CGIDLD*	*0.0*	---	---
DGIDL	V^{-1}	High longitudinal field dependence of GIDL/GISL	0.0	---	---
DGIDLL	*V^{-1}*	*DGIDL value for a LEN length*	*0.0*	---	---
DGIDLD	V^{-1}	High longitudinal field dependence of GIDL at drain side	0.0	---	---
DGIDLDL	*V^{-1}*	*DGIDLD value for a LEN length*	*0.0*	---	---

2.15 Charge model parameters

Name	Unit	Definition	Default	Min	Max
AREAQ	m^2	Effective channel area for intrinsic charge model	10^{-12}	10^{-18}	---
CGBOV	F	Oxide capacitance for gate to substrate overlap	0.0	0.0	---
CGBOVO	*F*	*Geometry independent global scale parameter for CGBOV*	*0.0*	---	---
CGBOVL	*F*	*Gate length scaling parameter of CGBOV*	*0.0*	---	---
NSDAC	cm^{-3}	Source/drain effective doping level for AC model	10^{22}	10^{18}	10^{22}
NSDACO	*cm^{-3}*	*Geometry independent global scale parameter for NSDAC*	10^{22}	10^{18}	10^{22}
FIF	---	Inner fringe capacitance pre-factor	0.0	0.0	---
FIFW	---	*FIF value for a WEN width*	*0.0*	*0.0*	---
FSCEAC	---	Short channel effect adjustment factor for charge model	0.0	0.0	---
FSCEACO	---	*Geometry independent global scale parameter for FSCEAC*	*0.0*	*0.0*	---
COV	F	Overlap capacitance per side	0.0	0.0	---
LOVO	*m*	*Overlap length for gate/source-drain overlap capacitance*	*0.0*	*0.0*	---
COVD	F	Overlap capacitance at drain side	0.0	0.0	---
LOVDO	*m*	*Overlap length for gate/drain overlap capacitance*	*0.0*	*0.0*	---
COVDL	---	Overlap capacitance modulation due to Leff bias-dependence	0.0	---	---
COVDLO	---	*Wide channel parameter for COVDL*	*0.0*	---	---
COVDLW	---	*Channel width scaling parameter of COVDL*	*0.0*	---	---
COVDLB	---	Overlap capacitance modulation with back bias	0.0	---	---
COVDLBO	---	*Geometry independent global scale parameter for COVDLB*	*0.0*	---	---
DVFBOV	V	Overlap capacitance flat-band voltage adjustment	0.0	---	---
DVFBOVO	*V*	*Geometry independent global scale parameter for DVFBOV*	*0.0*	---	---
CFR	F	Outer fringe capacitance per side	0.0	0.0	---
CFRO	*F*	*Corner related outer fringe capacitance*	*0.0*	---	---
CFRW	*F*	*Outer fringe capacitance per side for a WEN width*	*0.0*	---	---
CFRD	F	Outer fringe capacitance at drain side	0.0	0.0	---
CFRDO	*F*	*Corner related outer fringe capacitance at drain side*	*0.0*	---	---
CFRDW	*F*	*Outer fringe capacitance at drain side for a WEN width*	*0.0*	---	---
CSD	F	Drain to source direct capacitance	1.04 10^{-18}	0.0	---
CSDO	---	*Drain to source direct capacitance correction factor*	*1.0*	*0.0*	---
CSDBP	F/m	Drain/source to substrate perimeter capacitance	0.0	0.0	---
CSDBPO	*F/m*	*Geometry independent global scale parameter for CSDBP*	*0.0*	*0.0*	---

2.16 Self-heating parameters

Name	Unit	Definition	Default	Min	Max

RTH	K/W	Thermal resistance	10^4	10^{-6}	---
RTHO	*K/W*	*Geometry independent global scale parameter for RTH*	*10^5*	---	---
RTHL	---	*Channel length scaling parameter of RTH and CTH*	*1.5*	---	---
RTHW	---	*Channel width scaling parameter of RTH and CTH*	*3.0*	---	---
RTHLW	---	*Channel area scaling parameter of RTH and CTH*	*4.5*	---	---
STRTH	---	Temperature dependence of RTH	0.0	---	---
STRTHO	---	*Geometry independent global scale parameter for STRTH*	*0.0*	---	---
CTH	J/K	Thermal capacitance	10^{-11}	0.0	---
CTHO	*J/K*	*Geometry independent global scale parameter for CTH*	*10^{-12}*	---	---
LAMBTHO	*m*	*Characteristic length of thermal coupling for multifinger devices*	*10^{-7}*	*10^{-9}*	---
FTHO	---	*First neighbour thermal coupling factor for multifinger devices*	*0.0*	*0.0*	---

2.17 Noise model parameters

Name	Unit	Definition	Default	Min	Max
FNT	---	Thermal noise coefficient	1.0	0.0	---
FNTO	---	*Geometry independent global scale parameter for FNT*	*1.0*	*0.0*	---
NFA	$V^{-1}m^{-4}$	First coefficient of flicker noise	$8\ 10^{22}$	0.0	---
NFALW	*$V^{-1}m^{-4}$*	*NFA value for a LEN.WEN area*	*$8\ 10^{22}$*	*0.0*	---
NFB	$V^{-1}m^{-2}$	Second coefficient of flicker noise	$3\ 10^{7}$	0.0	---
NFBLW	*$V^{-1}m^{-2}$*	*NFB value for a LEN.WEN area*	*$3\ 10^{7}$*	*0.0*	---
NFC	V^{-1}	Third coefficient of flicker noise	0.0	0.0	---
NFCLW	*V^{-1}*	*NFC value for a LEN.WEN area*	*0.0*	*0.0*	---
NFE	---	Front interface transverse field effect coefficient	0.0	-1.0	1.0
NFEO	---	*Geometry independent global scale parameter for NFE*	*0.0*	*-1.0*	*1.0*
NFEB	---	Back interface transverse field effect coefficient	0.0	-1.0	1.0
NFEBO	---	*Geometry independent global scale parameter for NFEB*	*0.0*	*-1.0*	*1.0*
EF	---	Frequency dependence exponent of flicker noise	1.0	0.1	---
EFO	---	*Geometry independent global scale parameter for EF*	*1.0*	*0.1*	---

3 Geometrical dependences, stress effects and junction asymmetry

In this section, the global parameters are used to calculate local parameter values as a function of device geometry. These calculations includes geometrical scaling, modification of some parameters through the stress model and symmetrization of the source/drain junctions when the **SWJUNASYM** flag is set to 0.

3.1 Scaling equations

In this part are detailed the calculation of local parameters from the global parameter set. These calculations are carried out when the scaling flag **SWSCALE** is set to 1.

3.1.1 Effective dimensions

Introduction of the number of fingers

$$W_f = W/\mathbf{NF} \tag{3.1}$$

$$A_{source,f} = \mathbf{ASOURCE}/\mathbf{NF} \tag{3.2}$$

$$A_{drain,f} = \mathbf{ADRAIN}/\mathbf{NF} \tag{3.3}$$

$$P_{source,f} = \mathbf{PSOURCE}/\mathbf{NF} \tag{3.4}$$

$$P_{drain,f} = \mathbf{PDRAIN}/\mathbf{NF} \tag{3.5}$$

$$Mult_f = \mathbf{MULT} \times \mathbf{NF} \tag{3.6}$$

Effective length and width for current model

$$L_{EN} = 10^{-6} \tag{3.7}$$

$$W_{EN} = 10^{-6} \tag{3.8}$$

$$\Delta L_{PS} = \mathbf{LVARO}\left(1 + \mathbf{LVARL}\frac{L_{EN}}{L}\right)\left(1 + \mathbf{LVARW}\frac{W_{EN}}{W_f}\right) \tag{3.9}$$

$$\Delta W_{OD} = \mathbf{WVARO}\left(1 + \mathbf{WVARL}\frac{L_{EN}}{L}\right)\left(1 + \mathbf{WVARW}\frac{W_{EN}}{W_f}\right) \tag{3.10}$$

$$L_E = L + \Delta L_{PS} - 2 \times \mathbf{LAP} \tag{3.11}$$

$$W_E = W_f + \Delta W_{OD} - 2 \times \mathbf{WOT} \tag{3.12}$$

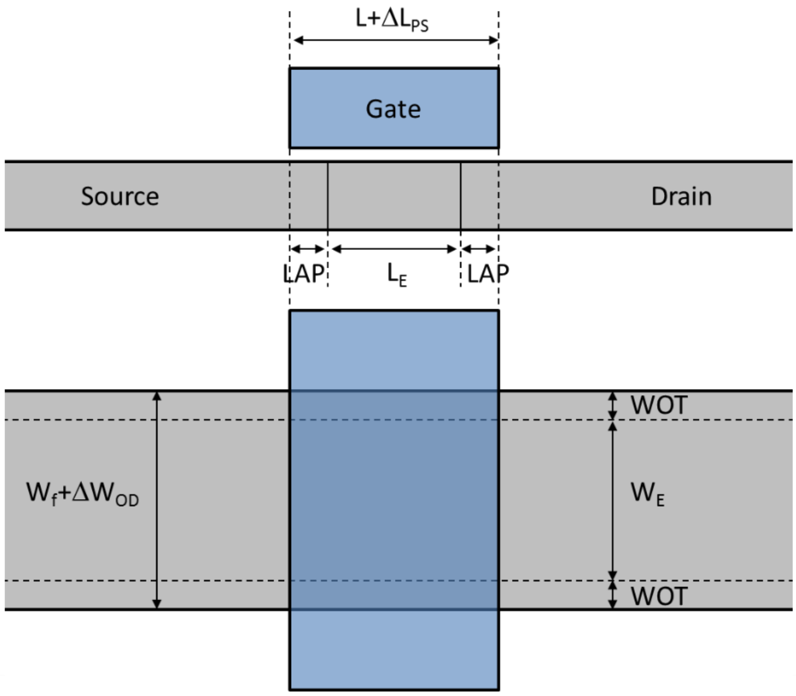

Figure 3.1- Description of transistor active and gate dimensions on a cross-section (top) and a top-view (bottom).

Effective length and width for charge model

$$L_{E,CV} = L + \Delta L_{PS} - 2 \times \mathbf{LAP} + \mathbf{DLQ} \tag{3.13}$$

$$W_{E,CV} = W_f + \Delta W_{OD} - 2 \times \mathbf{WOT} + \mathbf{DWQ} \tag{3.14}$$

Physical length and width for parasitic charges and self-heating

$$L_{phy} = L + \Delta L_{PS} \tag{3.15}$$

$$W_{phy} = W_f + \Delta W_{OD} \tag{3.16}$$

3.1.2 Process parameters

$$\mathbf{TOXE} = \mathbf{TOXEO} \tag{3.17}$$

$$\mathbf{TSI} = \mathbf{TSIO} \tag{3.18}$$

$$\mathbf{XGE} = \mathbf{XGEO} \tag{3.19}$$

$$\mathbf{TBOX} = \mathbf{TBOXO} \tag{3.20}$$

$$\mathbf{NCH} = \mathbf{NCHO} \tag{3.21}$$

$$\mathbf{NSUB} = \mathbf{NSUBO} \tag{3.22}$$

$$\mathbf{CT} = \mathbf{CTO} \tag{3.23}$$

$$\mathbf{TOXP} = \mathbf{TOXPO} \tag{3.24}$$

$$\mathbf{NOV} = \mathbf{NOVO} \tag{3.25}$$

$$\mathbf{NOVD} = \mathbf{NOVDO} \tag{3.26}$$

$$\mathbf{VFB} = \mathbf{VFBO} + \mathbf{VFBL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{VFBLEXP}} \Bigg/ \left(1 + \mathbf{VFBL2}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{VFBLEXP2}}\right) + \mathbf{VFBW}\frac{W_{EN}}{W_E} + \mathbf{VFBLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E} \tag{3.27}$$

$$\mathbf{VFBB} = \mathbf{VFBBO} + \mathbf{VFBLBO} \times \frac{\mathbf{TBOX}}{\mathbf{TOXE}} \times \mathbf{VFBL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{VFBLEXP}} \Bigg/ \left(1 + \mathbf{VFBL2}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{VFBLEXP2}}\right) \tag{3.28}$$

$$\mathbf{STVFB} = \mathbf{STVFBO}\left(1 + \mathbf{STVFBL}\frac{L_{EN}}{L_E}\right)\left(1 + \mathbf{STVFBW}\frac{W_{EN}}{W_E}\right)\left(1 + \mathbf{STVFBLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \tag{3.29}$$

3.1.3 Gate to interface coupling parameters

$$\mathbf{CICF} = \mathbf{CICFO} \tag{3.30}$$

$$\mathbf{CIC} = \mathbf{CICO} \tag{3.31}$$

$$\lambda_{2D} = \sqrt{\frac{\varepsilon_{Si}(1 - \mathbf{XGE}) + \varepsilon_{Ge}\mathbf{XGE}}{\varepsilon_{ox}} \times \mathbf{TSI} \times \left(\mathbf{TOXE} + 4 \times 10^{-10}\right)} \tag{3.32}$$

$$\mathbf{PSCE} = 2 \times \mathbf{PSCEL}\left(\frac{\lambda_{2D}}{L_E}\right)^{\mathbf{PSCELEXP}}\left(1 + \mathbf{PSCEW}\frac{W_{EN}}{W_E}\right) \tag{3.33}$$

$$\mathbf{PSCEB} = \mathbf{PSCEBO} \tag{3.34}$$

$$\mathbf{NSDDC} = \mathbf{NSDDCO} \tag{3.35}$$

$$\mathbf{PSCEDLB} = \mathbf{PSCEDLBO} \tag{3.36}$$

$$\mathbf{PNCE} = \mathbf{PNCEW}\frac{W_{EN}}{W_E} \tag{3.37}$$

3.1.4 Drain Induced Barrier Lowering parameters

$$\mathbf{CF} = \mathbf{CFL}\left(\frac{\lambda_{2D}}{L_E}\right)^{\mathbf{CFLEXP}}\left(1 + \mathbf{CFW}\frac{W_{EN}}{W_E}\right) \tag{3.38}$$

$$\mathbf{CFB} = \mathbf{CFBO} \tag{3.39}$$

$$\mathbf{STCF} = \mathbf{STCFL}\left(\frac{\lambda_{2D}}{L_E}\right)^{\mathbf{CFLEXP}}\left(1 + \mathbf{CFW}\frac{W_{EN}}{W_E}\right) \tag{3.40}$$

$$\mathbf{CFD} = \mathbf{CFDO} \tag{3.41}$$

$$\mathbf{CFDL} = \mathbf{CFDLL}\frac{L_{EN}}{L_E} \Bigg/ \max\left(1 + \mathbf{CFDLW}\frac{W_{EN}}{W_E}, 10^{-3}\right) \tag{3.42}$$

$$\mathbf{CFDLB} = \mathbf{CFDLBO} \tag{3.43}$$

3.1.5 Mobility parameters

$$L_{P1eff} = \mathbf{LP1} \times \max\left(1 + \mathbf{LP1W}\frac{W_{EN}}{W_E}, 10^{-3}\right) \tag{3.44}$$

$$G_{PE} = \max\left(1 + \mathbf{FBET1}\left(1 + \mathbf{FBET1W}\frac{W_{EN}}{W_E}\right)\frac{1 - \exp\left(-L_E/L_{P1eff}\right)}{L_E/L_{P1eff}} + \mathbf{FBET2}\frac{1 - \exp\left(-L_E/\mathbf{LP2}\right)}{L_E/\mathbf{LP2}}, 10^{-6}\right) \tag{3.45}$$

$$G_{WE} = \max\left(1 + \mathbf{BETW1}\frac{W_{EN}}{W_E} + \mathbf{BETW2}\frac{W_{EN}}{W_E}\ln\left(1 + \frac{W_E}{\mathbf{WBET}}\right), 10^{-6}\right) \tag{3.46}$$

$$G_E = \mathbf{UO}\frac{G_{WE}}{G_{PE}} \tag{3.47}$$

Note that, unlike in UTSOI1, **UO** is integrated into G_E. This changes the signification of the **THESAT** related global parameters, as detailed in the velocity saturation parameters part.

$$\mathbf{BETN} = G_E \frac{W_E}{L_E} \quad (3.48)$$

$$\mathbf{BETNB} = \mathbf{BETNBO} \quad (3.49)$$

$$\mathbf{STBET} = \mathbf{STBETO}\left(1+\mathbf{STBETL}\frac{L_{EN}}{L_E}\right)\left(1+\mathbf{STBETW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{STBETLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.50)$$

$$\mathbf{CS} = \left(\mathbf{CSO}+\mathbf{CSL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{CSLEXP}}\right)\left(1+\mathbf{CSW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{CSLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.51)$$

$$\mathbf{CSFI} = \mathbf{CSFIO} \quad (3.52)$$

$$\mathbf{CSBI} = \mathbf{CSBIO} \quad (3.53)$$

$$\mathbf{STCS} = \mathbf{STCSO}\left(1+\mathbf{STCSL}\frac{L_{EN}}{L_E}\right)\left(1+\mathbf{STCSW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{STCSLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.54)$$

$$\mathbf{THECS} = \mathbf{THECSO} \quad (3.55)$$

$$\mathbf{STTHECS} = \mathbf{STTHECSO} \quad (3.56)$$

$$\mathbf{CSTHR} = \mathbf{CSTHRO} \quad (3.57)$$

$$\mathbf{CSTHRB} = \mathbf{CSTHRBO} \quad (3.58)$$

$$\mathbf{MUE} = \mathbf{MUEO} \quad (3.59)$$

$$\mathbf{STMUE} = \mathbf{STMUEO} \quad (3.60)$$

$$\mathbf{THEMU} = \mathbf{THEMUO} \quad (3.61)$$

$$\mathbf{STTHEMU} = \mathbf{STTHEMUO} \quad (3.62)$$

$$\mathbf{XCOR} = \left(\mathbf{XCORO}+\mathbf{XCORL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{XCORLEXP}}\right)\left(1+\mathbf{XCORW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{XCORLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.63)$$

$$\mathbf{XCORB} = \mathbf{XCORBO} \quad (3.64)$$

$$\mathbf{STXCOR} = \mathbf{STXCORO} \quad (3.65)$$

$$\mathbf{FETA} = \mathbf{FETAO} \quad (3.66)$$

3.1.6 Series resistance parameters

$$\mathbf{RS} = \mathbf{RSW1}\frac{W_{EN}}{W_E}\left(1+\mathbf{RSW2}\frac{W_{EN}}{W_E}\right) \quad (3.67)$$

$$\mathbf{RSIG} = \mathbf{RSIGO} \quad (3.68)$$

$$\mathbf{STRS} = \mathbf{STRSO} \quad (3.69)$$

$$\mathbf{RSG} = \mathbf{RSGO} \quad (3.70)$$

$$\mathbf{THERSG} = \mathbf{THERSGO} \quad (3.71)$$

$$\mathbf{RSB} = \mathbf{RSBO} \quad (3.72)$$

3.1.7 Velocity saturation parameters

$$\mathbf{THESAT} = G_E\left(\mathbf{THESATO}+\mathbf{THESATL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{THESATLEXP}}\right)\left(1+\mathbf{THESATW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{THESATLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.73)$$

Since **UO** has been included in G_E (see (3.47)), **THESATL** is, in Leti-UTSOI2, closely related to the saturation velocity itself.

$$\mathbf{STTHESAT} = \mathbf{STTHESATO}\left(1+\mathbf{STTHESATL}\frac{L_{EN}}{L_E}\right)\left(1+\mathbf{STTHESATW}\frac{W_{EN}}{W_E}\right)\left(1+\mathbf{STTHESATLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E}\right) \quad (3.74)$$

$$\mathbf{THESATG} = \mathbf{THESATGO} \quad (3.75)$$

$$\mathbf{THESATB} = \mathbf{THESATBO} \quad (3.76)$$

3.1.8 Saturation and Channel Length Modulation parameters

$$\mathbf{AX} = \frac{\mathbf{AXO}}{1+\mathbf{AXL}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{AXLEXP}}} \quad (3.77)$$

$$\mathbf{ALP} = \frac{\mathbf{ALPL1}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{ALPLEXP}}}{1+\mathbf{ALPL2}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{ALPLEXP2}}}\left(1+\mathbf{ALPW}\frac{W_{EN}}{W_E}\right) \quad (3.78)$$

$$\mathbf{ALP1} = \frac{\mathbf{ALP1L1}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{ALP1LEXP}}}{1+\mathbf{ALP1L2}\left(\frac{L_{EN}}{L_E}\right)^{\mathbf{ALP1LEXP2}}}\left(1+\mathbf{ALP1W}\frac{W_{EN}}{W_E}\right) \quad (3.79)$$

$$\mathbf{ALPB} = \mathbf{ALPBO} \quad (3.80)$$

$$\mathbf{VP} = \mathbf{VPO} \quad (3.81)$$

$$\mathbf{VPG} = \mathbf{VPGO} \quad (3.82)$$

3.1.9 Gate current parameters

$$\mathbf{GCO} = \mathbf{GCOO} \quad (3.83)$$

$$\mathbf{IGINV} = \mathbf{IGINVLW}\frac{L_E}{L_{EN}}\frac{W_E}{W_{EN}} \quad (3.84)$$

$$\mathbf{IGOVINV} = \mathbf{IGOVINVW}\frac{W_E}{W_{EN}} \quad (3.85)$$

$$\mathbf{IGOVINVD} = \mathbf{IGOVINVDW}\frac{W_E}{W_{EN}} \quad (3.86)$$

$$\mathbf{IGOVACC} = \mathbf{IGOVACCW}\frac{W_E}{W_{EN}} \quad (3.87)$$

$$\mathbf{IGOVACCD} = \mathbf{IGOVACCDW}\frac{W_E}{W_{EN}} \quad (3.88)$$

Notice that, unlike in Leti-UTSOI1, gate currents in overlap regions are not linked with **LOVO** in Leti-UTSOI2.

$$\mathbf{STIG} = \mathbf{STIGO} \quad (3.89)$$

$$\mathbf{GC2CH} = \mathbf{GC2CHO} \quad (3.90)$$

$$\mathbf{GC3CH} = \mathbf{GC3CHO} \quad (3.91)$$

$$\mathbf{GC2OVINV} = \mathbf{GC2OVINVO} \quad (3.92)$$

$$\mathbf{GC3OVINV} = \mathbf{GC3OVINVO} \quad (3.93)$$

$$\mathbf{GC2OVACC} = \mathbf{GC2OVACCO} \quad (3.94)$$

$$\mathbf{GC3OVACC} = \mathbf{GC3OVACCO} \tag{3.95}$$

$$\mathbf{GCDOV} = \mathbf{GCDOVL}\frac{L_E}{L_{EN}} \tag{3.96}$$

$$\mathbf{GCVDOV} = \mathbf{GCVDOVO} \tag{3.97}$$

$$\mathbf{CHIB} = \mathbf{CHIBO} \tag{3.98}$$

$$\mathbf{NIGINV} = \mathbf{NIGINVO} \tag{3.99}$$

3.1.10 Gate Induced Drain/Source Leakage (GIDL/GISL) parameters

$$\mathbf{AGIDL} = \mathbf{AGIDLW}\frac{W_E}{W_{EN}} \tag{3.100}$$

$$\mathbf{AGIDLD} = \mathbf{AGIDLDW}\frac{W_E}{W_{EN}} \tag{3.101}$$

Notice that, as for gate currents, GIDL/GISL currents are not linked with **LOVO** in Leti-UTSOI2.

$$\mathbf{BGIDL} = \mathbf{BGIDLO} \tag{3.102}$$

$$\mathbf{BGIDLD} = \mathbf{BGIDLDO} \tag{3.103}$$

$$\mathbf{STBGIDL} = \mathbf{STBGIDLO} \tag{3.104}$$

$$\mathbf{STBGIDLD} = \mathbf{STBGIDLDO} \tag{3.105}$$

$$\mathbf{CGIDL} = \mathbf{CGIDLO} \tag{3.106}$$

$$\mathbf{CGIDLD} = \mathbf{CGIDLDO} \tag{3.107}$$

$$\mathbf{DGIDL} = \mathbf{DGIDLL}\frac{L_E}{L_{EN}} \tag{3.108}$$

$$\mathbf{DGIDLD} = \mathbf{DGIDLDL}\frac{L_E}{L_{EN}} \tag{3.109}$$

3.1.11 Charge model parameters

$$\mathbf{AREAQ} = L_{E,CV}W_{E,CV} \tag{3.110}$$

$$\mathbf{CGBOV} = \mathbf{CGBOVO} + \mathbf{CGBOVL}\frac{L_{phy}}{L_{EN}} \tag{3.111}$$

$$\mathbf{NSDAC} = \mathbf{NSDACO} \tag{3.112}$$

$$\mathbf{FIF} = \mathbf{FIFW}\frac{W_{E,CV}}{W_{EN}} \tag{3.113}$$

$$\mathbf{FSCEAC} = \mathbf{FSCEACO} \tag{3.114}$$

$$\mathbf{COV} = \varepsilon_{ox}\frac{W_{E,CV}}{\mathbf{TOXE}}\mathbf{LOVO} \tag{3.115}$$

$$\mathbf{COVD} = \varepsilon_{ox}\frac{W_{E,CV}}{\mathbf{TOXE}}\mathbf{LOVDO} \tag{3.116}$$

$$\mathbf{COVDL} = \mathbf{COVDLO}\Big/\max\left(1 + \mathbf{COVDLW}\frac{W_{EN}}{W_{E,CV}}, 10^{-3}\right) \tag{3.117}$$

$$\mathbf{COVDLB} = \mathbf{COVDLBO} \tag{3.118}$$

$$\mathbf{DVFBOV} = \mathbf{DVFBOVO} \tag{3.119}$$

$$\mathbf{CFR} = \mathbf{CFRO} + \mathbf{CFRW}\frac{W_{phy}}{W_{EN}} \qquad (3.120)$$

$$\mathbf{CFRD} = \mathbf{CFRDO} + \mathbf{CFRDW}\frac{W_{phy}}{W_{EN}} \qquad (3.121)$$

$$\mathbf{CSD} = \mathbf{CSDO}\left(\varepsilon_{Si}(1-\mathbf{XGE}) + \varepsilon_{Ge}\mathbf{XGE}\right)\mathbf{TSI}\frac{W_E}{L_E} \qquad (3.122)$$

$$\mathbf{CSDBP} = \mathbf{CSDBPO} \qquad (3.123)$$

3.1.12 Self-heating parameters

$$z_{th} = \exp\left(-\frac{\mathbf{SD}+L}{\mathbf{LAMBTHO}}\right) \qquad (3.124)$$

$$n_{th} = 1 + 2\times\mathbf{FTHO}\times z_{th}\frac{1-z_{th}-\left(1-z_{th}{}^{\mathbf{NF}}\right)/\mathbf{NF}}{\left(1-z_{th}\right)^2} \qquad (3.125)$$

$$\mathbf{RTH} = \frac{\mathbf{RTHO}}{1+\mathbf{RTHL}\frac{L_{G,TH}}{L_{EN}}+\mathbf{RTHW}\frac{W_{G,TH}}{W_{EN}}+\mathbf{RTHLW}\frac{L_{G,TH}}{L_{EN}}\frac{W_{G,TH}}{W_{EN}}}\times n_{th} \qquad (3.126)$$

$$\mathbf{STRTH} = \mathbf{STRTHO} \qquad (3.127)$$

$$\mathbf{CTH} = \mathbf{CTHO}\left(1+\mathbf{RTHL}\frac{L_{G,TH}}{L_{EN}}+\mathbf{RTHW}\frac{W_{G,TH}}{W_{EN}}+\mathbf{RTHLW}\frac{L_{G,TH}}{L_{EN}}\frac{W_{G,TH}}{W_{EN}}\right)\Big/ n_{th} \qquad (3.128)$$

3.1.13 Noise model parameters

$$\mathbf{FNT} = \mathbf{FNTO} \qquad (3.129)$$

$$\mathbf{NFA} = \mathbf{NFALW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E} \qquad (3.130)$$

$$\mathbf{NFB} = \mathbf{NFBLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E} \qquad (3.131)$$

$$\mathbf{NFC} = \mathbf{NFCLW}\frac{L_{EN}}{L_E}\frac{W_{EN}}{W_E} \qquad (3.132)$$

$$\mathbf{EF} = \mathbf{EFO} \qquad (3.133)$$

$$\mathbf{NFE} = \mathbf{NFEO} \qquad (3.134)$$

$$\mathbf{NFEB} = \mathbf{NFEBO} \qquad (3.135)$$

3.2 Stress model for SWSTRESS=1

In this paragraph are reported the modifications brought to mobility, saturation velocity and threshold voltage parameters when the STI-stress model is selected (SWSTRESS=1).

3.2.1 Effective SA/SB related parameters

$$R_A = \frac{1}{\mathbf{NF}}\sum_{i=0}^{\mathbf{NF}-1}\frac{1}{\mathbf{SA}+L/2+i(\mathbf{SD}+L)} \qquad (3.136)$$

$$R_B = \frac{1}{\mathbf{NF}}\sum_{i=0}^{\mathbf{NF}-1}\frac{1}{\mathbf{SB}+L/2+i(\mathbf{SD}+L)} \qquad (3.137)$$

$$R_{A,ref} = \frac{1}{\mathbf{SAREF}+L/2} \qquad (3.138)$$

$$R_{B,ref} = \frac{1}{\mathbf{SBREF} + L/2} \tag{3.139}$$

3.2.2 Modification of mobility related parameters

$$K_{u0} = \left(1 + \frac{\mathbf{LKUO}}{(L+\Delta L_{PS})^{\mathbf{LLODKUO}}} + \frac{\mathbf{WKUO}}{(W_f + \Delta W_{OD} + \mathbf{WLOD})^{\mathbf{WLODKUO}}} + \frac{\mathbf{PKUO}}{(L+\Delta L_{PS})^{\mathbf{LLODKUO}}(W_f + \Delta W_{OD} + \mathbf{WLOD})^{\mathbf{WLODKUO}}}\right)\left(1 + \mathbf{TKUO}\left(\frac{T_{KD}}{T_{KR}} - 1\right)\right) \tag{3.140}$$

$$\rho_\beta = \frac{\mathbf{KUO}}{K_{u0}}(R_A + R_B) \tag{3.141}$$

$$\rho_{\beta,ref} = \frac{\mathbf{KUO}}{K_{u0}}(R_{A,ref} + R_{B,ref}) \tag{3.142}$$

$$\mathbf{BETN} = \frac{1+\rho_\beta}{1+\rho_{\beta,ref}}\mathbf{BETN}_{ref} \tag{3.143}$$

$$\mathbf{THESAT} = \frac{1+\rho_\beta}{1+\rho_{\beta,ref}}\frac{1+\mathbf{KVSAT}\rho_{\beta,ref}}{1+\mathbf{KVSAT}\rho_\beta}\mathbf{THESAT}_{ref} \tag{3.144}$$

3.2.3 Modification of threshold voltage related parameters

$$K_{vth0} = 1 + \frac{\mathbf{LKVTHO}}{(L+\Delta L_{PS})^{\mathbf{LLODVTH}}} + \frac{\mathbf{WKVTHO}}{(W_f + \Delta W_{OD} + \mathbf{WLOD})^{\mathbf{WLODVTH}}} + \frac{\mathbf{PKVTHO}}{(L+\Delta L_{PS})^{\mathbf{LLODVTH}}(W_f + \Delta W_{OD} + \mathbf{WLOD})^{\mathbf{WLODVTH}}} \tag{3.145}$$

$$\Delta R = R_A + R_B - R_{A,ref} - R_{B,ref} \tag{3.146}$$

$$\mathbf{VFB} = \mathbf{VFB}_{ref} + \frac{\mathbf{KVTHO}}{K_{vth0}}\Delta R \tag{3.147}$$

$$\mathbf{VFBB} = \mathbf{VFBB}_{ref} + \frac{\mathbf{KVTHO}}{K_{vth0}}\Delta R \tag{3.148}$$

$$\mathbf{CF} = \mathbf{CF}_{ref} + \frac{\mathbf{STETAO}}{K_{vth0}^{\mathbf{LODETAO}}}\Delta R \tag{3.149}$$

3.3 Stress model for SWSTRESS=2

In this paragraph are reported the modifications brought to mobility, saturation velocity and threshold voltage parameters when the strained-SOI dedicated stress model is selected (SWSTRESS=2).

3.3.1 Effective SA/SB related parameters

$$R_A(i) = \left(1 - \exp\left(-\frac{\mathbf{SA} + L/2 + i(\mathbf{SD} + L)}{\mathbf{STRLAMBDA}}\right)\right)^{-\mathbf{STRALPHA}} \tag{3.150}$$

$$R_B(i) = \left(1 - \exp\left(-\frac{\mathbf{SB} + L/2 + (\mathbf{NF} - 1 - i)(\mathbf{SD} + L)}{\mathbf{STRLAMBDA}}\right)\right)^{-\mathbf{STRALPHA}} \tag{3.151}$$

$$g = 1 - \frac{1}{\mathbf{NF}}\sum_{i=0}^{\mathbf{NF}-1}\left[\frac{2}{R_A(i) + R_B(i)}\right]^{1/\mathbf{STRALPHA}} \tag{3.152}$$

$$R_{A,ref} = \left(1 - \exp\left(-\frac{\mathbf{SAREF} + L/2}{\mathbf{STRLAMBDA}}\right)\right)^{-\mathbf{STRALPHA}} \tag{3.153}$$

$$R_{B,ref} = \left(1 - \exp\left(-\frac{\mathbf{SBREF} + L/2}{\mathbf{STRLAMBDA}}\right)\right)^{-\mathbf{STRALPHA}} \tag{3.154}$$

$$g_{ref} = 1 - \left[\frac{2}{R_{A,ref}(i) + R_{B,ref}(i)}\right]^{1/\mathbf{STRALPHA}} \tag{3.155}$$

3.3.2 Modification of mobility related parameters

$$r_{uo} = \frac{\mathbf{STRRUO}}{1 + \mathbf{STRTRUO}\left(\frac{T_{KD}}{T_{KR}} - 1\right)} \tag{3.156}$$

$$\rho_{\beta} = r_{uo} \times g \tag{3.157}$$

$$\rho_{\beta,ref} = r_{uo} \times g_{ref} \tag{3.158}$$

$$\mathbf{BETN} = \frac{1 + \rho_{\beta}}{1 + \rho_{\beta,ref}} \mathbf{BETN}_{ref} \tag{3.159}$$

$$\mathbf{THESAT} = \frac{1 + \rho_{\beta}}{1 + \rho_{\beta,ref}} \frac{1 + \mathbf{STRRVSAT}\rho_{\beta,ref}}{1 + \mathbf{STRRVSAT}\rho_{\beta}} \mathbf{THESAT}_{ref} \tag{3.160}$$

3.3.3 Modification of threshold voltage related parameters

$$K_{vth0} = 1 + \mathbf{STRWDVFBO} \frac{W_f + \Delta W_{OD} + \mathbf{WLOD}}{W_{EN}} \tag{3.161}$$

$$\mathbf{VFB} = \mathbf{VFB}_{ref} + \frac{\mathbf{STRDVFBO}}{K_{vth0}}\left(g - g_{ref}\right) \tag{3.162}$$

$$\mathbf{VFBB} = \mathbf{VFBB}_{ref} + \frac{\mathbf{STRDVFBO}}{K_{vth0}}\left(g - g_{ref}\right) \tag{3.163}$$

$$\mathbf{CF} = \mathbf{CF}_{ref} + \mathbf{STRDCFL}\left(\frac{\lambda_{2D}}{L_E}\right)^{\mathbf{CFLEXP}}\left(1 + \mathbf{CFW}\frac{W_{EN}}{W_E}\right)\left(g - g_{ref}\right) \tag{3.164}$$

3.4 Asymmetric junctions

After the calculations described in paragraphs 3.1 and 3.2, local parameters are clipped according to the min/max values given in the parameters tables.

Then, if the switch parameter **SWJUNASYM** is equal to 0, drain and source junctions are assumed symmetrical and all parameters related to the drain junction are overwritten by their source side counterparts.

if **SWJUNASYM** = 0:

$$\mathbf{NOVD} = \mathbf{NOV} \tag{3.165}$$

$$\mathbf{IGOVINVD} = \mathbf{IGOVINV} \tag{3.166}$$

$$\mathbf{IGOVACCD} = \mathbf{IGOVACC} \tag{3.167}$$

$$\mathbf{AGIDLD} = \mathbf{AGIDL} \tag{3.168}$$

$$\mathbf{BGIDLD} = \mathbf{BGIDL} \tag{3.169}$$

$$\mathbf{STBGIDLD} = \mathbf{STBGIDL} \tag{3.170}$$

$$\mathbf{CGIDLD} = \mathbf{CGIDL} \tag{3.171}$$

$$\mathbf{DGIDLD} = \mathbf{DGIDL} \tag{3.172}$$

$$\mathbf{COVD} = \mathbf{COV} \tag{3.173}$$

$$\mathbf{CFRD} = \mathbf{CFR} \tag{3.174}$$

If **SWJUNASYM** = 1, the drain side related parameters are kept unchanged. Notice that, if some of the drain side parameters are not specified in the model card, they take their default value and *not* their source side counterpart value.

4 Model equations

In this part are detailed all the equations of the model. The complete calculation of the surface potentials is given in **Error! Reference source not found.** and some useful functions are described in **Error! Reference source not found.**.

4.1 Internal parameters including temperature dependences

In this section are calculated bias independent internal parameters. These calculations include temperature dependences and are carried out from local scale parameters. Local scale parameters are in capital characters and bold font.

4.1.1 Transistor temperature

$$T_{KR} = 273.15 + \mathbf{TR} \tag{4.1}$$

$$T_{KD} = 273.15 + T_{Ambient} \tag{4.2}$$

As in UTSOI1, a temperature node is used to compute the elevation of the channel temperature with respect to the circuit temperature due to self-heating when the **SWSHE** flag is set to 1 (see paragraph 4.9 for details). This temperature elevation is given by ΔT_C. The channel temperature T_{KC} is thus given by:

$$\begin{cases} T_{KC} = T_{KD} + \Delta T_C & \text{if } \mathbf{SWSHE} = 1 \\ T_{KC} = T_{KD} & \text{else} \end{cases} \tag{4.3}$$

$$\Delta T = T_{KC} - T_{KR} \tag{4.4}$$

$$\phi_{T0} = \frac{k_B T_{KC}}{q} \tag{4.5}$$

4.1.2 Local process parameters

$$\varepsilon_{ch} = \varepsilon_{Si}(1 - \mathbf{XGE}) + \varepsilon_{Ge}\mathbf{XGE} \tag{4.6}$$

$$E_{g,Si} = E_{g0,Si} - \frac{\alpha_{Si} {T_{KC}}^2}{\beta_{Si} + T_{KC}} \tag{4.7}$$

$$E_{g,Ge} = E_{g0,Ge} - \frac{\alpha_{Ge} {T_{KC}}^2}{\beta_{Ge} + T_{KC}} \tag{4.8}$$

$$\delta E_g = \left(E_{g,Ge} - E_{g,Si} + C_G(1 - \mathbf{XGE})\right)\mathbf{XGE} \tag{4.9}$$

$$E_g = E_{g,Si} + \delta E_g \tag{4.10}$$

$$n_{eff} = \frac{n_{i,fact,300}}{1 + \sqrt{10\mathbf{XGE}}} \left(\frac{T_{KC}}{300}\right)^{3/2} \exp\left(-\frac{E_g}{2\phi_{T0}}\right) \tag{4.11}$$

$$\delta V_{FB,ch} = 0.05\mathbf{XGE} - \delta E_g / 2 \tag{4.12}$$

$$\delta V_{FB1,NCH} = \frac{q \times \mathbf{NCH} \times 10^6 \times \mathbf{TSI}}{2\varepsilon_{ox}} \left(\mathbf{TOXE} + 4 \times 10^{-10}\mathbf{QMC}\right) \tag{4.13}$$

$$\delta V_{FB2,NCH} = \frac{q \times \mathbf{NCH} \times 10^6 \times \mathbf{TSI}}{2\varepsilon_{ox}} \left(\mathbf{TBOX} + 4 \times 10^{-10}\mathbf{QMC}\right) \tag{4.14}$$

4.1.3 Interface coupling internal parameters

$$\begin{cases} C_{ox1}' = \dfrac{\varepsilon_{ox}}{\mathbf{TOXE}} & \text{if } \mathbf{PNCE} \le 0 \\ C_{ox1}' = \dfrac{\varepsilon_{ox}}{\mathbf{TOXE}}(1+\mathbf{PNCE}) & \text{else} \end{cases} \quad (4.15)$$

$$\begin{cases} C_{ox2}' = \dfrac{\varepsilon_{ox}}{\mathbf{TBOX}}(1-\mathbf{PNCE}) & \text{if } \mathbf{PNCE} \le 0 \\ C_{ox2}' = \dfrac{\varepsilon_{ox}}{\mathbf{TBOX}} & \text{else} \end{cases} \quad (4.16)$$

$$C_{Si0}' = \frac{\varepsilon_{ch}}{\mathbf{TSI}} \quad (4.17)$$

$$\phi_T = \phi_{T0}\left(1+\mathbf{CT}\frac{T_{KR}}{T_{KC}}\right) \quad (4.18)$$

$$k_{1,1D} = \frac{C_{ox1}'}{C_{Si0}'} \quad (4.19)$$

$$k_{2,1D} = \frac{C_{ox2}'}{C_{Si0}'} \quad (4.20)$$

$$k_{eq,1D} = \frac{1}{1+1/k_{1,1D}+1/k_{2,1D}} \quad (4.21)$$

$$C_{eq,1D} = C_{Si0}' k_{eq,1D} \quad (4.22)$$

$$PSCE_1 = \mathbf{PSCE} \quad (4.23)$$

$$PSCE_2 = \mathbf{PSCEB} \times \mathbf{PSCE} \times \mathbf{TBOX}/\mathbf{TOXE} \quad (4.24)$$

$$f_{A0} = \frac{2qn_{eff}\varepsilon_{ch}}{\phi_T} \quad (4.25)$$

$$x_{th,1D} = \ln\left(\frac{C_{Si0}'^2}{2f_{A0}}\right) \quad (4.26)$$

$$x_{SD,dep} = \frac{q \times \mathbf{NSDDC} \times 10^6 \times \mathbf{TSI}}{2(C_{ox1}'+C_{ox2}')\phi_T} \quad (4.27)$$

4.1.4 Drain Induced Barrier Lowering internal parameters

$$CF_1 = \mathbf{CF} + \mathbf{STCF} \times \Delta T \quad (4.28)$$

$$CF_2 = \mathbf{CF} \times \mathbf{CFB} \times \frac{\mathbf{TBOX}}{\mathbf{TOXE}} + \mathbf{STCF} \times \Delta T \quad (4.29)$$

$$x_{d0} = \frac{\mathbf{CFD}}{\phi_T} \quad (4.30)$$

4.1.5 Backplane internal parameters

Since the backplane is located under the buried oxide of the device, it is assumed that its temperature is that of the environment. Thus, the self-heating effect is not included for the corresponding parameters and temperature T_{KD} is considered.

$$n_{eff,sub} = n_{i,fact,300}\left(\frac{T_{KD}}{300}\right)^{3/2}\exp\left(-\frac{E_{g,Si}}{2(k_B T_{KD}/q)}\right) \quad (4.31)$$

$$G_{f,sub} = \frac{\sqrt{2q\varepsilon_{Si}\mathbf{NSUB}\times 10^{6}}}{C_{eq0}\sqrt{k_B T_{KD}/q}} \tag{4.32}$$

$$\xi_{sub} = 1 + \frac{G_{f,sub}}{\sqrt{2}} \tag{4.33}$$

$$\xi_{mrg,sub} = 10^{-5}\xi_{sub} \tag{4.34}$$

$$x_{b,sub} = \ln\left(\frac{\mathbf{NSUB}\times 10^{6}}{n_{eff,sub}}\right) \tag{4.35}$$

$$x_{n,sub} = 2x_{b,sub} \tag{4.36}$$

$$\begin{cases} type_{sub} = 1 & if\ \mathbf{NSUB} \geq 0 \\ type_{sub} = -1 & else \end{cases} \tag{4.37}$$

4.1.6 Quantum mechanical correction internal parameters

$$\begin{cases} \delta V_{FB,qm} = 0 & if\ \mathbf{QMC} = 0 \\ \delta V_{FB,qm} = \dfrac{0.409618895}{10^{18}\mathbf{TSI}^2} & if\ \mathbf{QMC} > 0\ and\ \mathbf{TYPE} = +1\ (NMOS) \\ \delta V_{FB,qm} = \dfrac{0.723134895}{10^{18}\mathbf{TSI}^2} & if\ \mathbf{QMC} > 0\ and\ \mathbf{TYPE} = -1\ (PMOS) \end{cases} \tag{4.38}$$

$$\begin{cases} qq = 0 & if\ \mathbf{QMC} = 0 \\ qq = \dfrac{0.4QM_N\mathbf{QMC}}{\left(10^{18}\mathbf{TSI}^2\phi_T\right)^{1/3}} & if\ \mathbf{QMC} > 0\ and\ \mathbf{TYPE} = +1\ (NMOS) \\ qq = \dfrac{0.4QM_P\mathbf{QMC}}{\left(10^{18}\mathbf{TSI}^2\phi_T\right)^{1/3}} & if\ \mathbf{QMC} > 0\ and\ \mathbf{TYPE} = -1\ (PMOS) \end{cases} \tag{4.39}$$

$$V_{FB1} = \mathbf{TYPE}\left(\mathbf{VFB} + \mathbf{STVFB}\times\Delta T + \delta V_{FB,ch} + \delta V_{FB1,NCH}\right) + \delta V_{FB,qm} + \mathbf{DELVTO} \tag{4.40}$$

$$\begin{cases} V_{FB2} = \mathbf{TYPE}\left(\mathbf{VFBB} + \mathbf{STVFB}\times\Delta T + \delta V_{FB,ch} + \delta V_{FB2,NCH}\right) + \delta V_{FB,qm} & if\ \mathbf{SWSUBDEP} = 0 \\ V_{FB2} = \mathbf{TYPE}\left(\mathbf{VFBB} + \mathbf{STVFB}\times\Delta T + \delta V_{FB,ch} + \delta V_{FB2,NCH} + type_{sub}x_{b,sub}\left(k_B T_{KD}/q\right)\right) + \delta V_{FB,qm} & else \end{cases} \tag{4.41}$$

4.1.7 Mobility internal parameters

$$\beta_{N1} = \mathbf{FACTUO}\times\mathbf{BETN}\times\left(\frac{T_{KR}}{T_{KC}}\right)^{\mathbf{STBET}} \tag{4.42}$$

$$\beta_{N2} = \mathbf{FACTUO}\times\mathbf{BETN}\times\mathbf{BETNB}\times\left(\frac{T_{KR}}{T_{KC}}\right)^{\mathbf{STBET}} \tag{4.43}$$

$$\mu_E = \mathbf{MUE}\times\left(\frac{T_{KR}}{T_{KC}}\right)^{\mathbf{STMUE}} \tag{4.44}$$

$$\theta_\mu = \mathbf{THEMU}\times\left(\frac{T_{KR}}{T_{KC}}\right)^{\mathbf{STTHEMU}} \tag{4.45}$$

$$C_S = \mathbf{CS} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STCS}} \tag{4.46}$$

$$\theta_{CS} = \mathbf{THECS} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STTHECS}} \tag{4.47}$$

$$X_{cor} = \mathbf{XCOR} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STXCOR}} \tag{4.48}$$

$$f_{\mu E} = 10^{-8} \frac{\phi_T}{\mathbf{TSI}} \mu_E \tag{4.49}$$

$$q_{i1th,CS} = 0.5 \times \mathbf{CSTHR} \tag{4.50}$$

$$q_{i2th,CS} = q_{i1th,CS} \times \mathbf{CSTHRB} \tag{4.51}$$

$$\begin{cases} \eta_\mu = 1/2 \times \mathbf{FETA} & if\ \mathbf{TYPE} = +1\ (NMOS) \\ \eta_\mu = 1/3 \times \mathbf{FETA} & if\ \mathbf{TYPE} = -1\ (PMOS) \end{cases} \tag{4.52}$$

4.1.8 Series resistance internal parameters

$$R_S = \mathbf{RS} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STRS}} \tag{4.53}$$

$$f_{RS} = 2\phi_T R_S \tag{4.54}$$

4.1.9 Velocity saturation internal parameters

$$\theta_{sat} = \mathbf{FACTUO} \times \mathbf{THESAT} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STTHESAT} + \mathbf{STBET}} \tag{4.55}$$

Notice the presence of the **FACTUO** pre-factor and of **STBET** in the temperature exponent. This contributes to decouple velocity saturation parameters from low longitudinal field mobility ones, and makes in particular **STTHESAT** the temperature exponent of the saturation velocity itself.

$$f_{vsat} = \phi_T \theta_{sat} \tag{4.56}$$

4.1.10 Channel Length Modulation internal parameters

$$\gamma_{AX} = \left(2^{16/\mathbf{AX}} - 1 \right)^{3/8} - 1 \tag{4.57}$$

$$f_{alp1} = \frac{\mathbf{ALP1}}{\phi_T} \tag{4.58}$$

4.1.11 Gate current internal parameters

$$I_{G,inv} = \mathbf{IGINV} \times \left(\frac{T_{KC}}{T_{KR}} \right)^{\mathbf{STIG}} \tag{4.59}$$

$$I_{G,ovinv} = \mathbf{IGOVINV} \times \left(\frac{T_{KC}}{T_{KR}} \right)^{\mathbf{STIG}} \tag{4.60}$$

$$I_{G,ovinvD} = \mathbf{IGOVINVD} \times \left(\frac{T_{KC}}{T_{KR}} \right)^{\mathbf{STIG}} \tag{4.61}$$

$$I_{G,ovacc} = \mathbf{IGOVACC} \times \left(\frac{T_{KC}}{T_{KR}} \right)^{\mathbf{STIG}} \tag{4.62}$$

$$I_{G,ovaccD} = \mathbf{IGOVACCD} \times \left(\frac{T_{KC}}{T_{KR}} \right)^{\mathbf{STIG}} \tag{4.63}$$

$$B_{ch} = \frac{4}{3} \frac{\sqrt{2qm_0 \mathbf{CHIB}}}{\hbar} \mathbf{TOXP} \tag{4.64}$$

$$B_{ov} = \frac{4}{3} \frac{\sqrt{2qm_0 \mathbf{CHIB}}}{\hbar} \mathbf{TOXP} \tag{4.65}$$

Note that, B_{ch} and B_{ov} are equal in Leti-UTSOI2, since the Leti-UTSOI1 parameter **TOXOV** has been removed.

$$\begin{cases} G_{CQ,ch} = 0 & if\ \ \mathbf{GC3CH} \geq 0 \\ G_{CQ,ch} = -0.495 \mathbf{GC2CH} / \mathbf{GC3CH} & else \end{cases} \tag{4.66}$$

$$\begin{cases} G_{CQ,ovinv} = 0 & if\ \ \mathbf{GC3OVINV} \geq 0 \\ G_{CQ,ovinv} = -0.495 \mathbf{GC2OVINV} / \mathbf{GC3OVINV} & else \end{cases} \tag{4.67}$$

$$\begin{cases} G_{CQ,ovacc} = 0 & if\ \ \mathbf{GC3OVACC} \geq 0 \\ G_{CQ,ovacc} = -0.495 \mathbf{GC2OVACC} / \mathbf{GC3OVACC} & else \end{cases} \tag{4.68}$$

$$\alpha_b = \frac{E_g}{2} \tag{4.69}$$

$$D_{ch} = \phi_T \mathbf{GCO} \tag{4.70}$$

$$D_{ov} = \phi_{T0} \mathbf{GCO} \tag{4.71}$$

$$n_{iginv} = \frac{1}{1 + \mathbf{NIGINV} \times E_g / (2\phi_T)} \tag{4.72}$$

4.1.12 Gate Induced Drain/Source Leakage (GIDL/GISL) internal parameters

$$A_{GIDL} = \frac{4 \times 10^{-18}}{\mathbf{TOXP}^2} \mathbf{AGIDL} \tag{4.73}$$

$$A_{GIDLD} = \frac{4 \times 10^{-18}}{\mathbf{TOXP}^2} \mathbf{AGIDLD} \tag{4.74}$$

$$B_{GIDL} = 5 \times 10^8 \mathbf{TOXP} (1 + \mathbf{STBGIDL} \times \Delta T) \mathbf{BGIDL} \tag{4.75}$$

$$B_{GIDLD} = 5 \times 10^8 \mathbf{TOXP} (1 + \mathbf{STBGIDLD} \times \Delta T) \mathbf{BGIDLD} \tag{4.76}$$

4.1.13 Charge model internal parameters

$$f_{area} = \phi_T \mathbf{AREAQ} \tag{4.77}$$

$$f_{SD,inner} = \frac{q \mathbf{NSDAC} \times 10^6}{4 \varepsilon_{ch} \phi_T} \tag{4.78}$$

$$x_{SD} = \ln \left(\frac{\mathbf{NSDAC} \times 10^6}{n_{eff}} \right) \tag{4.79}$$

$$f_{if} = 1.25 \times 10^{-6} \phi_T \mathbf{FIF} \tag{4.80}$$

4.1.14 Self-heating internal parameters

$$R_{th} = \mathbf{RTH} \times \left(\frac{T_{KR}}{T_{KC}} \right)^{\mathbf{STRTH}} \tag{4.81}$$

4.1.15 Noise model internal parameters

$$n_T = 4k_B T_{KC}\mathbf{FNT} \qquad (4.82)$$

4.2 Terminal voltage conditioning

The input voltages used in the model are V_{GS}, V_{DS} and V_{SB} in nMOSFET and positive V_{DS} configuration (i.e. sign of external voltages is reversed for pMOSFET, and source/drain are interchanged in case of negative V_{DS}), from which V_{SD}, V_{GD}, V_{DB} and V_{GB} are computed. Then, dimensionless quantities are defined from these voltages.

4.2.1 Voltages for channel current and intrinsic charge models

$$x_d = \frac{V_{DS}}{\phi_T} \qquad (4.83)$$

$$x_{dsx} = \frac{\sqrt{V_{DS}^{\ 2} + 0.01} - 0.1}{\phi_T} \qquad (4.84)$$

$$x_{g10} = \frac{V_{GS} - V_{FB1}}{\phi_T} - \frac{x_d - x_{dsx}}{2} \qquad (4.85)$$

$$x_{g20} = \frac{-V_{SB} - V_{FB2}}{\phi_T} - \frac{x_d - x_{dsx}}{2} \qquad (4.86)$$

4.2.2 Voltages for overlap currents and charges

$$x_{gs,ov} = -\frac{V_{GS}}{\phi_{T0}} \qquad (4.87)$$

$$x_{gd,ov} = -\frac{V_{GD}}{\phi_{T0}} \qquad (4.88)$$

$$x_{gs,ovcv} = -\frac{V_{GS} - \mathbf{TYPE} \times \mathbf{DVFBOV} - E_g/2}{\phi_{T0}} \qquad (4.89)$$

$$x_{gd,ovcv} = -\frac{V_{GD} - \mathbf{TYPE} \times \mathbf{DVFBOV} - E_g/2}{\phi_{T0}} \qquad (4.90)$$

4.3 Backplane depletion

Depletion of the backplane is accounted for through the calculation of an effective backplane bias x_{g2eff}.

If backplane depletion is not activated (i.e. **SWSUBDEP**=0), then x_{g2eff} is simply given by:

$$x_{g2eff} = x_{g20} \qquad (4.91)$$

On the contrary, if backplane depletion is activated (i.e. **SWSUBDEP**=1), then the computation of x_{g2eff} uses a PSP-like surface potential calculation sequence. This computation is based on the following analogy: the backplane is considered as the channel of a bulk MOSFET, which gate electrode is the front gate and which gate oxide capacitance is equal to the front gate oxide capacitance in series with the channel film capacitance and the buried oxide capacitance. The detailed calculation of x_{g2eff} is:

$$x_{g1\mathrm{int}} = \mathbf{TYPE} \times type_{sub} \times x_{g10} \qquad (4.92)$$

$$x_{g2\mathrm{int}} = \mathbf{TYPE} \times type_{sub} \times x_{g20} \qquad (4.93)$$

$$x_{gb\mathrm{int}} = x_{g1\mathrm{int}} - x_{g2\mathrm{int}} \qquad (4.94)$$

if $|x_{gbint}| \leq \xi_{mrg,sub}$:

$$\delta x_{g2,sub} = \frac{x_{g\text{bint}}}{\xi_{sub}}\left(1 + \frac{x_{g\text{bint}} G_{f,sub}\left(1 - \exp\left(-x_{n,sub}\right)\right)}{6\sqrt{2}\xi_{sub}^{\ 2}}\right) \tag{4.95}$$

else if $x_{gbint} < -\xi_{mrg,sub}$:

$$y_g = -x_{g\text{bint}} \tag{4.96}$$

$$y_{sub} = 1.25 y_g / \xi_{sub} \tag{4.97}$$

$$\eta = \left(y_{sub} + 10 - \sqrt{\left(y_{sub} - 6\right)^2 + 64}\right) \Big/ 2 \tag{4.98}$$

$$a = \left(y_g - \eta\right)^2 + G_{f,sub}^{\ 2}\left(\eta + 1\right) \tag{4.99}$$

$$c = 2\left(y_g - \eta\right) - G_{f,sub}^{\ 2} \tag{4.100}$$

$$\tau = -\eta + \ln\left(a / G_{f,sub}^{\ 2}\right) \tag{4.101}$$

$$y_0 = \sigma_3\left(a, c, \tau, \eta\right) \tag{4.102}$$

$$\Delta_0 = \exp\left(y_0\right) \tag{4.103}$$

$$\chi_0 = y_0^{\ 2} / \left(2 + y_0^{\ 2}\right) \tag{4.104}$$

$$\chi_1 = 4 y_0 / \left(2 + y_0^{\ 2}\right)^2 \tag{4.105}$$

$$\chi_2 = \left(8 - 12 y_0^{\ 2}\right) / \left(2 + y_0^{\ 2}\right)^3 \tag{4.106}$$

$$p_C = 2\left(y_g - y_0\right) + G_{f,sub}^{\ 2}\left(\Delta_0 - 1 + \exp\left(-x_{n,sub}\right)\left(1 - \chi_1 - 1/\Delta_0\right)\right) \tag{4.107}$$

$$q_C = \left(y_g - y_0\right)^2 + G_{f,sub}^{\ 2}\left(y_0 - \Delta_0 + 1 + \exp\left(-x_{n,sub}\right)\left(1 + \chi_0 - 1/\Delta_0 - y_0\right)\right) \tag{4.108}$$

$$\delta x_{g2,sub} = -y_0 - \frac{2 q_C}{p_C + \sqrt{p_C^{\ 2} - 2 q_C\left(2 - G_{f,sub}^{\ 2}\left(\Delta_0 + \exp\left(-x_{n,sub}\right)\left(1/\Delta_0 - \chi_2\right)\right)\right)}} \tag{4.109}$$

else:

$$x_{g1} = 1.25 + 0.7324648775 G_{f,sub} \tag{4.110}$$

$$\frac{1}{\tilde{x}_{g1}} = \frac{1.25 \xi_{sub} / x_{g1} - 1}{x_{g1}} \tag{4.111}$$

$$\bar{x} = \frac{x_{g\text{bint}}}{\xi_{sub}}\left(1 + \frac{x_{g\text{bint}}}{\tilde{x}_{g1}}\right) \tag{4.112}$$

$$w = 1 - \exp\left(-\bar{x}\right) \tag{4.113}$$

$$x_1 = x_{g\text{bint}} + G_{f,sub}^{\ 2}/2 - G_{f,sub}\sqrt{x_{g\text{bint}} + G_{f,sub}^{\ 2}/4 - w} \tag{4.114}$$

$$b_x = x_{n,sub} + 3 \tag{4.115}$$

$$\eta = \text{MIN\_FUNC}\left(x_1, b_x, 5\right) - \left(b_x - \sqrt{b_x^{\ 2} + 5}\right) \Big/ 2 \tag{4.116}$$

$$\chi_0 = \eta^2 / \left(2 + \eta^2\right) \tag{4.117}$$

$$\chi_1 = 4\eta / \left(2 + \eta^2\right)^2 \tag{4.118}$$

$$\chi_2 = \left(8 - 12\eta^2\right) / \left(2 + \eta^2\right)^3 \tag{4.119}$$

$$a = \left(x_{g\text{bint}} - \eta\right)^2 - G_{f,sub}^{\ 2}\left(\exp\left(-\eta\right) + \eta - 1 - \exp\left(-x_{n,sub}\right)\left(\eta + 1 + \chi_0\right)\right) \tag{4.120}$$

$$b = 1 - G_{f,sub}^{\ 2}\left(\exp\left(-\eta\right) - \chi_2 \exp\left(-x_{n,sub}\right)\right)/2 \tag{4.121}$$

$$c = 2(x_{gbint} - \eta) + G_{f,sub}^2 (1 - \exp(-\eta) - \exp(-x_{n,sub})(1 + \chi_1)) \quad (4.122)$$

$$\tau = x_{n,sub} - \eta + \ln(a / G_{f,sub}^2) \quad (4.123)$$

$$x_0 = \sigma_2(a, b, c, \tau, \eta) \quad (4.124)$$

$$\Delta_0 = \exp(x_0) \quad (4.125)$$

$$\chi_0' = x_0^2 / (2 + x_0^2) \quad (4.126)$$

$$\chi_1' = 4x_0 / (2 + x_0^2)^2 \quad (4.127)$$

$$\chi_2' = (8 - 12x_0^2) / (2 + x_0^2)^3 \quad (4.128)$$

$$p_C = 2(x_{gbint} - x_0) + G_{f,sub}^2 (1 - 1/\Delta_0 + \exp(-x_{n,sub})(\Delta_0 - 1 - \chi_1')) \quad (4.129)$$

$$q_C = (x_{gbint} - x_0)^2 - G_{f,sub}^2 (x_0 - 1 + 1/\Delta_0 + \exp(-x_{n,sub})(\Delta_0 - 1 - \chi_0' - x_0)) \quad (4.130)$$

$$\delta x_{g2,sub} = x_0 + \frac{2q_C}{p_C + \sqrt{p_C^2 - 2q_C (2 - G_{f,sub}^2 (1/\Delta_0 + \exp(-x_{n,sub})(\Delta_0 - \chi_2')))}} \quad (4.131)$$

Finally:

$$x_{g2eff} = \mathbf{TYPE} \times type_{sub} \times (x_{g2int} + \delta x_{g2,sub}) \quad (4.132)$$

4.4 Channel current

This part is dedicated to the calculation of the MOSFET channel current. Since this calculation is completely symmetrical between front and back interfaces, it is valid not only for Ultra-Thin Body and Buried oxide FDSOI transistors, but also for Independent Double Gate MOSFETs.

4.4.1 Quantum mechanical correction in subthreshold regime

To account properly for quantum confinement when the effect is activated (**QMC**>0), the effective geometry of the device is modified. In the first correction detailed here, it is assumed that there's no charge in the channel. Thus, strictly speaking, this correction is valid only in the subthreshold regime. A second correction will be brought afterwards to account properly for quantum confinement also in the strong inversion regime.

if **QMC** > 0:

$$e_1 = \mathrm{MAX\_FUNC}(k_{eq,1D}(x_{g10} - x_{g2eff}), 15, 225) \quad (4.133)$$

$$e_2 = \mathrm{MAX\_FUNC}(-k_{eq,1D}(x_{g10} - x_{g2eff}), 15, 225) \quad (4.134)$$

$$C_{Si}' = \frac{C_{Si0}'}{1 - qq(e_1^{-1/3} + e_2^{-1/3})} \quad (4.135)$$

$$k_{1,1D,QM} = k_{1,1D} \frac{1 - qq(e_1^{-1/3} + e_2^{-1/3})}{1 + k_{1,1D} e_1^{-1/3} qq} \quad (4.136)$$

$$k_{2,1D,QM} = k_{2,1D} \frac{1 - qq(e_1^{-1/3} + e_2^{-1/3})}{1 + k_{2,1D} e_2^{-1/3} qq} \quad (4.137)$$

$$k_{eq,1D,QM} = \frac{1}{1 + 1/k_{1,1D,QM} + 1/k_{2,1D,QM}} \quad (4.138)$$

$$t_{ox1fact} = 1 + k_{1,1D,QM} e_1^{-1/3} qq \quad (4.139)$$

$$t_{ox2fact} = 1 + k_{2,1D,QM} e_2^{-1/3} qq \quad (4.140)$$

else:

$$C_{Si}' = C_{Si0}' \quad (4.141)$$

$$k_{1,1D,QM} = k_{1,1D} \quad (4.142)$$

$$k_{2,1D,QM} = k_{2,1D} \quad (4.143)$$

$$k_{eq,1D,QM} = k_{eq,1D} \quad (4.144)$$

$$t_{ox1fact} = 1 \quad (4.145)$$

$$t_{ox2fact} = 1 \quad (4.146)$$

4.4.2 Short channel effects

$$\delta x_{WI,1D} = k_{eq,1D,QM}\left(x_{g10} - x_{g2eff}\right) \quad (4.147)$$

$$\begin{cases} x_{WI,1D} = x_{g10} - \dfrac{\delta x_{WI,1D}}{k_{1,1D,QM}} + \ln\left(\dfrac{1 + e^{-\delta x_{WI,1D}}}{2}\right) & if\ \delta x_{WI,1D} > 0 \\ x_{WI,1D} = x_{g2eff} + \dfrac{\delta x_{WI,1D}}{k_{2,1D,QM}} + \ln\left(\dfrac{1 + e^{\delta x_{WI,1D}}}{2}\right) & else \end{cases} \quad (4.148)$$

$$x_{1D} = \mathrm{MIN\_FUNC}\left(x_{WI,1D}, x_{th,1D}, 4.0\right) \quad (4.149)$$

$$\delta l_{eff} = \sqrt{1 + 2\frac{x_{th,1D} - x_{1D}}{x_{SD,dep}}} - 1 \quad (4.150)$$

$$x_{edge} = x_{1D} + x_{SD,dep}\delta l_{eff} \quad (4.151)$$

$$c_{sce1} = \frac{1}{1 + PSCE_1 \times \mathrm{MAX\_FUNC}\left(1 + \mathbf{PSCEDLB} \times x_{g20}, 0.5, 0.01\right)} \quad (4.152)$$

$$c_{sce2} = \frac{1}{1 + PSCE_2 \times \mathrm{MAX\_FUNC}\left(1 + \mathbf{PSCEDLB} \times x_{g20}, 0.5, 0.01\right)} \quad (4.153)$$

$$\delta x_{g1,DIBL} = 2CF_1 x_{d0}\left(\sqrt{1 + x_{dsx}/x_{d0}} - 1\right)\left(1 + \mathbf{CFDL} \times \delta l_{eff}\right)\left(1 + \mathbf{CFDLB} \times x_{g20}\right) \quad (4.154)$$

$$\delta x_{g2,DIBL} = 2CF_2 x_{d0}\left(\sqrt{1 + x_{dsx}/x_{d0}} - 1\right)\left(1 + \mathbf{CFDL} \times \delta l_{eff}\right)\left(1 + \mathbf{CFDLB} \times x_{g20}\right) \quad (4.155)$$

$$x_{g1} = \left(x_{g10} - x_{edge} + \delta x_{g1,DIBL}\right)c_{sce1} + x_{edge} + \frac{x_d - x_{dsx}}{2} \quad (4.156)$$

$$x_{g2} = \left(x_{g2eff} - x_{edge} + \delta x_{g2,DIBL}\right)c_{sce2} + x_{edge} + \frac{x_d - x_{dsx}}{2} \quad (4.157)$$

$$x_{g1x} = \mathrm{MIN\_FUNC}\left(x_{g2} + \mathbf{CICF}\left(x_{g1} - x_{g2}\right), 600, 0.01\right) \quad (4.158)$$

$$x_{g2x} = \mathrm{MIN\_FUNC}\left(x_{g1} + \mathbf{CIC}\left(x_{g2} - x_{g1}\right), 600, 0.01\right) \quad (4.159)$$

4.4.3 Interface coupling in subthreshold regime

$$k_1 = \frac{k_{1,1D,QM}}{c_{sce1}} \quad (4.160)$$

$$k_2 = \frac{k_{2,1D,QM}}{c_{sce2}} \quad (4.161)$$

$$k_{eq} = \frac{1}{1 + 1/k_1 + 1/k_2} \quad (4.162)$$

$$A_0 = \frac{f_{A0}}{C_{Si}'^2} \quad (4.163)$$

$$\delta x_{th} = \ln\left(\frac{1+k_1}{1+k_2}\right) \quad (4.164)$$

$$diff_{\min} = 2\delta x_{th}\frac{\exp(\delta x_{th})+1}{\exp(\delta x_{th})-1} \quad (4.165)$$

$$\delta x_{WI} = k_{eq}\left(x_{g1x} - x_{g2x}\right) \quad (4.166)$$

$$x_{1,WI0} = x_{g1x} - \delta x_{WI}/k_1 \quad (4.167)$$

$$x_{2,WI0} = x_{g2x} + \delta x_{WI}/k_2 \quad (4.168)$$

4.4.4 Inversion charge and related quantities at source side

First, the gate charge density at the source side q_{1S}, normalized to $k_1 C_{Si}'\phi_T$, is computed by a call to the "CHARGE_DENSITY" function described in **Error! Reference source not found.**:

$$q_{1S} = \text{CHARGE\_DENSITY}(x_{g1x}, x_{g2x}, 0) \quad (4.169)$$

Then, inversion and back gate charge densities, normalized to $C_{Si}'\phi_T$ and $k_2 C_{Si}'\phi_T$ respectively, are calculated:

$$A_{e1S} = A_0\exp(x_{g1x} - q_{1S}) \quad (4.170)$$

$$f_{qsqS} = k_1^{\,2} q_{1S}^{\,2} - A_{e1S} \quad (4.171)$$

if $f_{qsqS} < -0.005$:

$$f_{qctS} = \sqrt{|f_{qsqS}|}\cot\left(\sqrt{|f_{qsqS}|}/2\right) \quad (4.172)$$

$$f_{shS} = -\frac{f_{qsqS}}{\sin\left(\sqrt{|f_{qsqS}|}/2\right)^2} \quad (4.173)$$

$$f_{\ln S} = \ln(f_{shS}) \quad (4.174)$$

else if $f_{qsqS} > 0.005$:

$$\zeta_S = \exp\left(-\sqrt{|f_{qsqS}|}\right) \quad (4.175)$$

$$f_{qctS} = \sqrt{|f_{qsqS}|}\frac{1+\zeta_S}{1-\zeta_S} \quad (4.176)$$

$$f_{shS} = \frac{4f_{qsqS}}{1-\zeta_S(2-\zeta_S)}\zeta_S \quad (4.177)$$

$$f_{\ln S} = \ln\left(\frac{4f_{qsqS}}{1-\zeta_S(2-\zeta_S)}\right) - \sqrt{|f_{qsqS}|} \quad (4.178)$$

else:

$$f_{qctS} = 2 + \frac{f_{qsqS}}{6}\left(1 - \frac{f_{qsqS}}{60}\left(1 - \frac{f_{qsqS}}{42}\right)\right) \quad (4.179)$$

$$f_{shS} = 4 - \frac{f_{qsqS}}{3}\left(1 - \frac{f_{qsqS}}{20}\left(1 - \frac{5f_{qsqS}}{126}\right)\right) \quad (4.180)$$

$$f_{\ln S} = \ln(f_{shS}) \quad (4.181)$$

if $1.01k_1q_{1S} + f_{qctS} \le 0$:

$$q_{iS} = \frac{k_1q_{1S} - f_{qctS}}{1 - f_{shS}/A_{e1S}} \tag{4.182}$$

$$q_{2S} = \frac{q_{iS} - k_1q_{1S}}{k_2} \tag{4.183}$$

else if $A_{e1S}k_1q_{1S} < 0.9k_1^2q_{1S}^2(k_1q_{1S}+f_{qctS})$:

$$q_{iS} = \frac{A_{e1S}}{k_1q_{1S} + f_{qctS}} \tag{4.184}$$

$$q_{2S} = \frac{q_{iS} - k_1q_{1S}}{k_2} \tag{4.185}$$

else:

$$q_{2S} = x_{g2x} - x_{g1x} + q_{1S} + 2\ln(k_1q_{1S} + f_{qctS}) - f_{\ln S} \tag{4.186}$$

$$q_{iS} = k_1q_{1S} + k_2q_{2S} \tag{4.187}$$

Finally, some required quantities, including the drift electrostatic potential, are computed:

$$A_{e2S} = A_0\exp(x_{g2x} - q_{2S}) \tag{4.188}$$

if $q_{iS} > 10^{-6}$:

$$b_{1S} = A_{e1S}/k_1 \tag{4.189}$$

$$b_{2S} = A_{e2S}/k_2 \tag{4.190}$$

$$a_{1S} = b_{1S} + 2k_1q_{1S} \tag{4.191}$$

$$a_{2S} = b_{2S} + 2k_2q_{2S} \tag{4.192}$$

$$\Sigma_S = 2q_{iS} + b_{1S} + b_{2S} \tag{4.193}$$

$$\begin{cases} Z_S = \dfrac{-4f_{qsqS}\Sigma_S}{q_{iS}(a_{1S}a_{2S} + 2a_{1S}(q_{2S}+2) + 2a_{2S}(q_{1S}+2))} & \text{if } |f_{qsqS}| > 0.005 \\ Z_S = \dfrac{A_{e1S}A_{e2S}\Sigma_S}{q_{iS}\left(a_{1S}A_{e1S} + a_{2S}A_{e2S} + a_{1S}a_{2S}q_{iS}\left(1 + \dfrac{q_{iS}}{6}\left(1 - \dfrac{f_{qsqS}}{30}\left(1 - \dfrac{f_{qsqS}}{28}\left(1 - \dfrac{f_{qsqS}}{30}\right)\right)\right)\right)\right)} & \text{else} \end{cases} \tag{4.194}$$

Finally:

$$x_{driftS} = \ln(q_{iS}) \tag{4.195}$$

4.4.5 Mobility attenuation and series resistance at source side

Front and back transverse effective fields, normalized to $C_{Si}'\phi_T/\varepsilon_{ch}$.

$$e_{surf1S} = 2\ln(1 + \exp(k_1q_{1S}/2)) \tag{4.196}$$

$$e_{surf2S} = 2\ln(1 + \exp(k_2q_{2S}/2)) \tag{4.197}$$

$$e_{cpl1S} = e_{surf2S} - k_2q_{2S} \tag{4.198}$$

$$e_{cpl2S} = e_{surf1S} - k_1q_{1S} \tag{4.199}$$

$$e_{eff1S} = \eta_\mu e_{surf1S} + (1 - \eta_\mu)e_{cpl1S} \tag{4.200}$$

$$e_{eff2S} = \eta_\mu e_{surf2S} + (1 - \eta_\mu)e_{cpl2S} \tag{4.201}$$

Non-universality correction factor:

$$f_{corS} = \frac{\text{MAX\_FUNC}\left(1 + X_{cor}\left(e_{cpl1S} + \mathbf{XCORB} \times e_{cpl2S}\right), 0, 0.01\right)}{\text{MAX\_FUNC}\left(1 + 0.2 \times X_{cor}\left(e_{cpl1S} + \mathbf{XCORB} \times e_{cpl2S}\right), 0, 0.01\right)} \tag{4.202}$$

Coulomb scattering term:

$$q_{i1S} = \frac{e_{surf1S}}{e_{surf1S} + e_{surf2S}} q_{iS} \tag{4.203}$$

$$q_{i2S} = \frac{e_{surf2S}}{e_{surf1S} + e_{surf2S}} q_{iS} \tag{4.204}$$

$$G_{CSS} = C_S\left(1 + \mathbf{CSFI} \times e_{cpl1S} + \mathbf{CSBI} \times e_{cpl2S}\right)\left(1 + q_{i1S}/q_{i1th,CS} + q_{i2S}/q_{i2th,CS}\right)^{-\theta_{CS}} \tag{4.205}$$

Series resistance term:

$$\begin{cases} f_{RSGS} = 1 - \mathbf{RSG} \times q_{iS}{}^{\mathbf{THERSG}} & \text{if } \mathbf{RSG} < 0 \\ f_{RSGS} = 1/\left(1 + \mathbf{RSG} \times q_{iS}{}^{\mathbf{THERSG}}\right) & \text{else} \end{cases} \tag{4.206}$$

$$G_{RSS} = f_{RS} C_{Si}'\left(q_{iS} f_{RSGS} + \mathbf{RSIG}\right) \times \text{MAX\_FUNC}\left(1 - \mathbf{RSB} x_{g20}, 0, 0.01\right) \tag{4.207}$$

Total mobility degradation term, including high field mobility effect:

$$G_{mob1S} = 1 + \left(f_{\mu E} e_{eff\,1S}\right)^{\theta_\mu} + G_{CSS} + \beta_{N1} G_{RSS} \tag{4.208}$$

$$G_{mob2S} = 1 + \left(f_{\mu E} e_{eff\,2S}\right)^{\theta_\mu} + G_{CSS} + \beta_{N2} G_{RSS} \tag{4.209}$$

$$c_{1S} = e_{surf1S} \beta_{N1} \tag{4.210}$$

$$c_{2S} = e_{surf2S} \beta_{N2} \tag{4.211}$$

$$G_{mobS} = f_{corS} \frac{c_{1S} + c_{2S}}{c_{1S}/G_{mob1S} + c_{2S}/G_{mob2S}} \tag{4.212}$$

4.4.6 Drain saturation voltage, including velocity saturation effect

Derivative of inversion charge versus drift potential at the onset of saturation

if $\delta x_{WI} > 0.007$:

$$s_1 = \frac{\delta x_{WI}}{1 - \exp\left(-\delta x_{WI}\right)} \tag{4.213}$$

$$s_2 = \exp\left(-\delta x_{WI}\right) s_1 \tag{4.214}$$

$$\delta x_\infty = \ln\left(\frac{A_0}{2 q_{iS} s_1}\right) + x_{1,WI0} \tag{4.215}$$

$$\hat{q}_{1\infty} = \frac{-\delta x_{WI}}{k_{eq}\left(1 - s_1 - \delta x_{WI}/k_2\right)} \tag{4.216}$$

$$\hat{q}_{2\infty} = \frac{\delta x_{WI}}{k_{eq}\left(1 - s_2 - \delta x_{WI}/k_1\right)} \tag{4.217}$$

$$d_\infty = \frac{\delta x_{WI}}{\left(s_2/k_2 + 1/2\right)/\hat{q}_{2\infty} - \left(s_1/k_1 + 1/2\right)/\hat{q}_{1\infty}} \tag{4.218}$$

else if $\delta x_{WI} < -0.007$:

$$s_2 = \frac{\delta x_{WI}}{\exp(\delta x_{WI}) - 1} \tag{4.219}$$

$$s_1 = \exp(\delta x_{WI}) s_2 \tag{4.220}$$

$$\delta x_\infty = \ln\left(\frac{A_0}{2q_{iS}s_2}\right) + x_{2,WI0} \tag{4.221}$$

$$\hat{q}_{1\infty} = \frac{-\delta x_{WI}}{k_{eq}\left(1 - s_1 - \delta x_{WI}/k_2\right)} \tag{4.222}$$

$$\hat{q}_{2\infty} = \frac{\delta x_{WI}}{k_{eq}\left(1 - s_2 - \delta x_{WI}/k_1\right)} \tag{4.223}$$

$$d_\infty = \frac{\delta x_{WI}}{(s_2/k_2 + 1/2)/\hat{q}_{2\infty} - (s_1/k_1 + 1/2)/\hat{q}_{1\infty}} \tag{4.224}$$

else:

$$s_1 = 1 + \frac{\delta x_{WI}}{2} + \frac{\delta x_{WI}{}^2}{12} \tag{4.225}$$

$$s_2 = 1 - \frac{\delta x_{WI}}{2} + \frac{\delta x_{WI}{}^2}{12} \tag{4.226}$$

$$\hat{q}_{1\infty} = \frac{1}{k_{eq}\left(1/2 + 1/k_2 + \delta x_{WI}/12\right)} \tag{4.227}$$

$$\hat{q}_{2\infty} = \frac{1}{k_{eq}\left(1/2 + 1/k_1 - \delta x_{WI}/12\right)} \tag{4.228}$$

$$\delta x_\infty = \ln\left(\frac{A_0}{2q_{iS}\left(1 - \delta x_{WI}{}^2/24\right)}\right) + \frac{x_{1,WI0} + x_{2,WI0}}{2} \tag{4.229}$$

$$d_\infty = \frac{-12}{4 - 3k_{eq} + 12k_{eq}/(k_1k_2) + (k_{eq}/k_1 - k_{eq}/k_2)\delta x_{WI} + (1/15 - k_{eq}/12)\delta x_{WI}{}^2} \tag{4.230}$$

Calculation of δx_{sat} and q_{iDsat}

if $q_{iS} > 10^{-6}$:

$$w_{sat1S} = \frac{100e_{surf1S}}{100 + e_{surf1S}} \tag{4.231}$$

$$\begin{cases} sat_{fact1S} = 1/\left(1 - w_{sat1S}\mathbf{THESATG}\right) & if\ \mathbf{THESATG} < 0 \\ sat_{fact1S} = 1 + w_{sat1S}\mathbf{THESATG} & else \end{cases} \tag{4.232}$$

$$w_{sat2S} = \frac{100e_{surf2S}}{100 + e_{surf2S}} \tag{4.233}$$

$$\begin{cases} sat_{fact2S} = 1/\left(1 - w_{sat2S}\mathbf{THESATB}\right) & if\ \mathbf{THESATB} < 0 \\ sat_{fact2S} = 1 + w_{sat2S}\mathbf{THESATB} & else \end{cases} \tag{4.234}$$

$$Z_{iS} = \frac{Z_S\Sigma_S}{a_{1S}a_{2S}} - \frac{1}{q_{iS}}\left(\frac{A_{e1S}}{a_{1S}} + \frac{A_{e2S}}{a_{2S}}\right) \tag{4.235}$$

$$d_S = \frac{Z_{iS}q_{iS}}{Z_{iS} + 1} \tag{4.236}$$

$$\delta x_i = \mathrm{MAX\_FUNC}\left(\frac{q_{iS} + d_\infty \delta x_\infty}{d_\infty - d_S}, 0, 10^{-6}\right) \quad (4.237)$$

$$\gamma_{sat} = \frac{f_{vsat}}{G_{mobS}} \frac{sat_{fact1S} + sat_{fact2S}}{2} \quad (4.238)$$

$$v_S = 1 - q_{iS}/d_S \quad (4.239)$$

$$v_D = 1 + \delta x_\infty \quad (4.240)$$

$$w_D = ((2d_S - q_{iS})/d_\infty - 2 - \delta x_\infty)\delta x_i \quad (4.241)$$

$$p_S = 2/\gamma_{sat}^{\ 2} \quad (4.242)$$

$$q_S = p_S v_S \quad (4.243)$$

$$p_D = p_S + w_D \quad (4.244)$$

$$q_D = p_S v_D \quad (4.245)$$

$$r_{cS} = \sqrt{q_S^{\ 2} + 4p_S^{\ 3}/27} \quad (4.246)$$

$$r_{cD} = \sqrt{q_D^{\ 2} + 4p_D^{\ 3}/27} \quad (4.247)$$

$$\delta x_{satS} = \left(\frac{r_{cS} + q_S}{2}\right)^{1/3} - \left(\frac{r_{cS} - q_S}{2}\right)^{1/3} \quad (4.248)$$

$$\delta x_{satD} = \left(\frac{r_{cD} + q_D}{2}\right)^{1/3} - \left(\frac{r_{cD} - q_D}{2}\right)^{1/3} \quad (4.249)$$

$$\delta x_{sat} = 0.94 \times \mathrm{MAX\_FUNC}\left(\delta x_{satS}, \delta x_{satD}, 10(d_S - d_\infty)^2\right) \quad (4.250)$$

$$q_{iDsatS} = q_{iS} + d_S \delta x_{sat} \quad (4.251)$$

$$q_{iDsatD} = d_\infty(\delta x_{sat} - \delta x_\infty) \quad (4.252)$$

$$q_{iDsat} = \mathrm{MAX\_FUNC}\left(q_{iDsatS}, q_{iDsatD}, 36(d_S - d_\infty)^2\right) \quad (4.253)$$

else:

$$d_S = d_\infty \quad (4.254)$$

$$\delta x_{sat} = 0.94 \times (1 + \delta x_\infty) \quad (4.255)$$

$$q_{iDsat} = q_{iS}/2 + d_\infty(\delta x_{sat} - \delta x_\infty/2) \quad (4.256)$$

Normalized saturation and effective drain voltages

$$x_{nDS,0} = \delta x_{sat} + \ln\left(\frac{q_{iS}}{0.5 + \ln(1 + \exp(q_{iDsat} - 0.5))}\right) \quad (4.257)$$

$$x_{nDS,1} = 6 + \ln(1 + \exp(x_{nDS,0} - 6)) \quad (4.258)$$

$$x_{nDS,sat} = 600 - \ln(1 + \exp(600 - x_{nDS,1})) \quad (4.259)$$

$$x_{Deff} = \frac{x_D}{\left(\left(1 + \gamma_{AX}(x_D/x_{nDS,sat})^4\right)^{8/3} + (x_D/x_{nDS,sat})^{16}\right)^{1/16}} \quad (4.260)$$

4.4.7 Inversion charge and related quantities at drain side

Gate charge density at drain side:

$$q_{1D} = \mathrm{CHARGE\_DENSITY}(x_{g1x}, x_{g2x}, x_{Deff}) \quad (4.261)$$

Then, inversion and back gate charge densities, normalized to $C_{Si}'\phi_T$ and $k_2C_{Si}'\phi_T$ respectively, are calculated:

$$A_{e1D} = A_0 \exp\left(x_{g1x} - q_{1D} - x_{Deff}\right) \tag{4.262}$$

$$f_{qsqD} = k_1^{\,2} q_{1D}^{\,2} - A_{e1D} \tag{4.263}$$

if $f_{qsqD} < -0.005$:

$$f_{qctD} = \sqrt{\left|f_{qsqD}\right|}\cot\left(\sqrt{\left|f_{qsqD}\right|}/2\right) \tag{4.264}$$

$$f_{shD} = -\frac{f_{qsqD}}{\sin\left(\sqrt{\left|f_{qsqD}\right|}/2\right)^2} \tag{4.265}$$

$$f_{\ln D} = \ln\left(f_{shD}\right) \tag{4.266}$$

else if $f_{qsqD} > 0.005$:

$$\zeta_D = \exp\left(-\sqrt{\left|f_{qsqD}\right|}\right) \tag{4.267}$$

$$f_{qctD} = \sqrt{\left|f_{qsqD}\right|}\frac{1+\zeta_D}{1-\zeta_D} \tag{4.268}$$

$$f_{shD} = \frac{4 f_{qsqD}}{1-\zeta_D\left(2-\zeta_D\right)}\zeta_D \tag{4.269}$$

$$f_{\ln D} = \ln\left(\frac{4 f_{qsqD}}{1-\zeta_D\left(2-\zeta_D\right)}\right) - \sqrt{\left|f_{qsqD}\right|} \tag{4.270}$$

else:

$$f_{qctD} = 2 + \frac{f_{qsqD}}{6}\left(1 - \frac{f_{qsqD}}{60}\left(1 - \frac{f_{qsqD}}{42}\right)\right) \tag{4.271}$$

$$f_{shD} = 4 - \frac{f_{qsqD}}{3}\left(1 - \frac{f_{qsqD}}{20}\left(1 - \frac{5 f_{qsqD}}{126}\right)\right) \tag{4.272}$$

$$f_{\ln D} = \ln\left(f_{shD}\right) \tag{4.273}$$

if $1.01 k_1 q_{1D} + f_{qctD} \leq 0$:

$$q_{iD} = \frac{k_1 q_{1D} - f_{qctD}}{1 - f_{shD}/A_{e1D}} \tag{4.274}$$

$$q_{2D} = \frac{q_{iD} - k_1 q_{1D}}{k_2} \tag{4.275}$$

else if $A_{e1D} k_1 q_{1D} < 0.9 k_1^2 q_{1D}^2 (k_1 q_{1D} + f_{qctD})$:

$$q_{iD} = \frac{A_{e1D}}{k_1 q_{1D} + f_{qctD}} \tag{4.276}$$

$$q_{2D} = \frac{q_{iD} - k_1 q_{1D}}{k_2} \tag{4.277}$$

else:

$$q_{2D} = x_{g2x} - x_{g1x} + q_{1D} + 2\ln\left(k_1 q_{1D} + f_{qctD}\right) - f_{\ln D} \tag{4.278}$$

$$q_{iD} = k_1 q_{1D} + k_2 q_{2D} \tag{4.279}$$

Finally, some required quantities, including the drift electrostatic potential, are computed:

$$A_{e2D} = A_0 \exp\left(x_{g2x} - q_{2D} - x_{Deff}\right) \quad (4.280)$$

if $q_{iS} > 10^{-6}$:

$$b_{1D} = A_{e1D}/k_1 \quad (4.281)$$

$$b_{2D} = A_{e2D}/k_2 \quad (4.282)$$

$$a_{1D} = b_{1D} + 2k_1 q_{1D} \quad (4.283)$$

$$a_{2D} = b_{2D} + 2k_2 q_{2D} \quad (4.284)$$

$$\Sigma_D = 2q_{iD} + b_{1D} + b_{2D} \quad (4.285)$$

$$\begin{cases} Z_D = \dfrac{-4 f_{qsqD}\Sigma_D}{q_{iD}\left(a_{1D}a_{2D} + 2a_{1D}\left(q_{2D}+2\right) + 2a_{2D}\left(q_{1D}+2\right)\right)} & \text{if } \left|f_{qsqD}\right| > 0.005 \\ Z_D = \dfrac{A_{e1D}A_{e2D}\Sigma_D}{q_{iD}\left(a_{1D}A_{e1D} + a_{2D}A_{e2D} + a_{1D}a_{2D}q_{iD}\left(1+\dfrac{q_{iD}}{6}\left(1-\dfrac{f_{qsqD}}{30}\left(1-\dfrac{f_{qsqD}}{28}\left(1-\dfrac{f_{qsqD}}{30}\right)\right)\right)\right)\right)} & \text{else} \end{cases} \quad (4.286)$$

Finally:

$$x_{driftD} = x_{Deff} + \ln\left(q_{iD}\right) \quad (4.287)$$

4.4.8 Mid-point inversion charge

$$q_{im} = \frac{q_{iS} + q_{iD}}{2} \quad (4.288)$$

$$\delta x_{drift} = x_{driftD} - x_{driftS} \quad (4.289)$$

4.4.9 Mobility attenuation and series resistance

Front and back transverse effective fields at drain side, normalized to $C_{Si}'\phi_T/\varepsilon_{ch}$

$$e_{surf1D} = 2\ln\left(1+\exp\left(k_1 q_{1D}/2\right)\right) \quad (4.290)$$

$$e_{surf2D} = 2\ln\left(1+\exp\left(k_2 q_{2D}/2\right)\right) \quad (4.291)$$

$$e_{cpl1D} = e_{surf2D} - k_2 q_{2D} \quad (4.292)$$

$$e_{cpl2D} = e_{surf1D} - k_1 q_{1D} \quad (4.293)$$

$$e_{eff1D} = \eta_\mu e_{surf1D} + \left(1-\eta_\mu\right)e_{cpl1D} \quad (4.294)$$

$$e_{eff2D} = \eta_\mu e_{surf2D} + \left(1-\eta_\mu\right)e_{cpl2D} \quad (4.295)$$

Mid-values of surface and effective fields

$$e_{surf1} = \frac{e_{surf1S} + e_{surf1D}}{2} \quad (4.296)$$

$$e_{surf2} = \frac{e_{surf2S} + e_{surf2D}}{2} \quad (4.297)$$

$$e_{cpl1} = \frac{e_{cpl1S} + e_{cpl1D}}{2} \quad (4.298)$$

$$e_{cpl2} = \frac{e_{cpl2S} + e_{cpl2D}}{2} \quad (4.299)$$

$$e_{eff\,1} = \frac{e_{eff\,1S} + e_{eff\,1D}}{2} \tag{4.300}$$

$$e_{eff\,2} = \frac{e_{eff\,2S} + e_{eff\,2D}}{2} \tag{4.301}$$

Non-universality correction factor:

$$f_{cor} = \frac{\mathrm{MAX\_FUNC}\left(1 + X_{cor}\left(e_{cpl1} + \mathbf{XCORB} \times e_{cpl2}\right), 0, 0.01\right)}{\mathrm{MAX\_FUNC}\left(1 + 0.2 \times X_{cor}\left(e_{cpl1} + \mathbf{XCORB} \times e_{cpl2}\right), 0, 0.01\right)} \tag{4.302}$$

Coulomb scattering term:

$$q_{i1m} = \frac{e_{surf1}}{e_{surf1} + e_{surf2}} q_{im} \tag{4.303}$$

$$q_{i2m} = \frac{e_{surf2}}{e_{surf1} + e_{surf2}} q_{im} \tag{4.304}$$

$$G_{CS} = C_S\left(1 + \mathbf{CSFI} \times e_{cpl1} + \mathbf{CSBI} \times e_{cpl2}\right)\left(1 + q_{i1m}/q_{i1th,CS} + q_{i2m}/q_{i2th,CS}\right)^{-\theta_{CS}} \tag{4.305}$$

Series resistance term:

$$\begin{cases} f_{RSG} = 1 - \mathbf{RSG} \times q_{im}{}^{\mathbf{THERSG}} & \text{if } \mathbf{RSG} < 0 \\ f_{RSG} = 1/\left(1 + \mathbf{RSG} \times q_{im}{}^{\mathbf{THERSG}}\right) & \text{else} \end{cases} \tag{4.306}$$

$$G_{RS} = f_{RS} C_{Si}'\left(q_{im} f_{RSG} + \mathbf{RSIG}\right) \times \mathrm{MAX\_FUNC}\left(1 - \mathbf{RSB} x_{g20}, 0, 0.01\right) \tag{4.307}$$

Total mobility degradation term, including high field mobility effect:

$$G_{mob1} = 1 + \left(f_{\mu E} e_{eff\,1}\right)^{\theta_\mu} + G_{CS} + \beta_{N1} G_{RS} \tag{4.308}$$

$$G_{mob2} = 1 + \left(f_{\mu E} e_{eff\,2}\right)^{\theta_\mu} + G_{CS} + \beta_{N2} G_{RS} \tag{4.309}$$

$$c_1 = e_{surf1} \beta_{N1} \tag{4.310}$$

$$c_2 = e_{surf2} \beta_{N2} \tag{4.311}$$

$$G_{mob} = f_{cor} \frac{c_1 + c_2}{c_1/G_{mob1} + c_2/G_{mob2}} \tag{4.312}$$

$$\beta_{Neff} = \frac{c_1 + c_2}{e_{surf1} + e_{surf2}} \tag{4.313}$$

4.4.10 Channel length modulation

$$q_{im1}^* = q_{im} + 4 \tag{4.314}$$

$$\begin{cases} r_1 = q_{im}/q_{im1}^* \times 1/\left(1 + \mathbf{ALPB} \times q_{im2}\right) & \text{if } \mathbf{ALPB} > 0 \\ r_1 = q_{im}/q_{im1}^* \times \left(1 - \mathbf{ALPB} \times q_{im2}\right) & \text{else} \end{cases} \tag{4.315}$$

$$\Delta L/L = \mathbf{ALP} \times \ln\left(1 + \frac{x_D - x_{Deff}}{\mathbf{VP}/\phi_t + \mathbf{VPG} \times q_{im}{}^2}\right) \times r_1 \tag{4.316}$$

$$G_{\Delta L} = \frac{1}{1 + \Delta L/L\left(1 + \Delta L/L\right)} \tag{4.317}$$

$$\Delta L_1/L = \left(\mathbf{ALP} + \frac{f_{alp1}}{q_{im1}^*}\right) \times \ln\left(1 + \frac{x_D - x_{Deff}}{\mathbf{VP}/\phi_t + \mathbf{VPG} \times q_{im}{}^2}\right) \times r_1 \tag{4.318}$$

$$F_{\Delta L}=\frac{1+\Delta L_1/L(1+\Delta L_1/L)}{1+\Delta L/L(1+\Delta L/L)} \tag{4.319}$$

4.4.11 Velocity saturation

$$w_{sat1}=\frac{100e_{surf1}}{100+e_{surf1}} \tag{4.320}$$

$$\begin{cases} sat_{fact1}=1/(1-w_{sat1}\textbf{THESATG}) & \textit{if } \textbf{THESATG}<0 \\ sat_{fact1}=1+w_{sat1}\textbf{THESATG} & \textit{else} \end{cases} \tag{4.321}$$

$$w_{sat2}=\frac{100e_{surf2}}{100+e_{surf2}} \tag{4.322}$$

$$\begin{cases} sat_{fact2}=1/(1-w_{sat2}\textbf{THESATB}) & \textit{if } \textbf{THESATB}<0 \\ sat_{fact2}=1+w_{sat2}\textbf{THESATB} & \textit{else} \end{cases} \tag{4.323}$$

$$G_\gamma=f_{vsat}\delta x_{drift}\frac{sat_{fact1}+sat_{fact2}}{2} \tag{4.324}$$

$$z_{sat}=\left(\frac{G_\gamma}{G_{mob}G_{\Delta L}}\right)^2 \tag{4.325}$$

$$G_{vsat}=G_{mob}G_{\Delta L}\sqrt{1+z_{sat}} \tag{4.326}$$

4.4.12 Quantum confinement

Here is detailed the second quantum confinement correction that complements the correction described in paragraph 4.4.1.

if **QMC** > 0:

$$qm_{fact1}=\frac{1+k_1qq0.6/\left(e_{surf1}{}^2+60\right)^{1/6}}{t_{ox1fact}} \tag{4.327}$$

$$qm_{fact2}=\frac{1+k_2qq0.6/\left(e_{surf2}{}^2+60\right)^{1/6}}{t_{ox2fact}} \tag{4.328}$$

$$qm_{fact}=\frac{e_{surf1}+e_{surf2}}{e_{surf1}/qm_{fact1}+e_{surf2}/qm_{fact2}} \tag{4.329}$$

else:

$$qm_{fact1}=1 \tag{4.330}$$

$$qm_{fact2}=1 \tag{4.331}$$

$$qm_{fact}=1 \tag{4.332}$$

4.4.13 Channel current

if $q_{iS} > 10^{-6}$:

$$Z_{iD} = \frac{Z_D \Sigma_D}{a_{1D} a_{2D}} - \frac{1}{q_{iD}} \left(\frac{A_{e1D}}{a_{1D}} + \frac{A_{e2D}}{a_{2D}} \right) \tag{4.333}$$

$$\begin{cases} d_D = \dfrac{Z_{iD} q_{iD}}{Z_{iD} + 1} & if \;\; q_{iD} > 10^{-6} \\ d_D = d_\infty & else \end{cases} \tag{4.334}$$

if $|d_D - d_S| > 10^{-3}$:

$$\begin{aligned} L_S &= q_{iD} - q_{iS} - d_D \delta x_{drift} \\ L_D &= q_{iD} - q_{iS} - d_S \delta x_{drift} \\ U_S &= \sqrt{L_S^{\,2} + 1 + 36 (d_D - d_S)^2} \\ U_D &= \sqrt{L_D^{\,2} + 1 + 36 (d_D - d_S)^2} \\ \delta i_{drift} &= \frac{L_S U_D - L_D U_S + \left(1 + 36 (d_D - d_S)^2\right) \ln\left((L_D + U_D)/(L_S + U_S)\right)}{4 (d_D - d_S)} \end{aligned} \tag{4.335}$$

else:

$$\delta i_{drift} = -\frac{\delta x_{drift}^{\;3} (d_D - d_S)^2}{24 \sqrt{1 + 36 (d_D - d_S)^2}} \tag{4.336}$$

else:

$$d_D = d_\infty \tag{4.337}$$

$$\delta i_{drift} = 0 \tag{4.338}$$

$$i_{DS,norm} = q_{im} \delta x_{drift} + \delta i_{drift} + q_{iS} - q_{iD} \tag{4.339}$$

$$I_{DS} = \frac{F_{\Delta L}}{G_{vsat} q m_{fact}} \beta_{Neff} \phi_T^{\,2} C_{Si}' i_{DS,norm} \tag{4.340}$$

4.5 Gate current, intrinsic charges and overlap related variables

In this paragraph are defined some variables that will be used for gate current, GIDL/GISL current and intrinsic charge models.

4.5.1 Effective gate charge at front and back interfaces

if $q_{iS} > 10^{-6}$:

$$\hat{q}_{1S} = \frac{a_{1S}}{A_{e1S} / q_{iS} - Z_S} \tag{4.341}$$

$$\hat{q}_{1D} = \frac{a_{1D}}{A_{e1D} / q_{iD} - Z_D} \tag{4.342}$$

$$k_1 h_{10} = \frac{i_{DS,norm}}{\hat{q}_{1S} - \hat{q}_{1D}} \quad (4.343)$$

$$\hat{q}_{2S} = \frac{a_{2S}}{A_{e2S}/q_{iS} - Z_S} \quad (4.344)$$

$$\hat{q}_{2D} = \frac{a_{2D}}{A_{e2D}/q_{iD} - Z_D} \quad (4.345)$$

$$k_2 h_{20} = \frac{i_{DS,norm}}{\hat{q}_{2S} - \hat{q}_{2D}} \quad (4.346)$$

else:

$$\zeta_1 = -2s_1\left(\frac{1}{k_1\hat{q}_{1\infty}} + \frac{1}{d_\infty}\right) \quad (4.347)$$

$$\zeta_2 = -2s_2\left(\frac{1}{k_2\hat{q}_{2\infty}} + \frac{1}{d_\infty}\right) \quad (4.348)$$

$$\xi_1 = \frac{\zeta_2/k_2 + (\zeta_2 - \zeta_1)/d_\infty - (\zeta_1/k_1 + \zeta_2/k_2)/\hat{q}_{1\infty}}{3 + 2(s_1/k_1 + s_2/k_2)} \quad (4.349)$$

$$\xi_2 = \frac{\zeta_1/k_1 + (\zeta_1 - \zeta_2)/d_\infty - (\zeta_2/k_2 + \zeta_1/k_1)/\hat{q}_{2\infty}}{3 + 2(s_2/k_2 + s_1/k_1)} \quad (4.350)$$

$$k_1 h_{10} = -\frac{1}{\hat{q}_{1\infty}(\xi_1\hat{q}_{1\infty} + 1/d_\infty)} \quad (4.351)$$

$$k_2 h_{20} = -\frac{1}{\hat{q}_{2\infty}(\xi_2\hat{q}_{2\infty} + 1/d_\infty)} \quad (4.352)$$

$$k_1 h_1 = k_1 h_{10}\frac{\sqrt{1+z_{sat}}}{1+3z_{sat}/2} \quad (4.353)$$

$$k_2 h_2 = k_2 h_{20}\frac{\sqrt{1+z_{sat}}}{1+3z_{sat}/2} \quad (4.354)$$

$$\Delta_{k1q1} = \frac{k_1 q_{1D} - k_1 q_{1S}}{2} \quad (4.355)$$

$$\Delta_{k2q2} = \frac{k_2 q_{2D} - k_2 q_{2S}}{2} \quad (4.356)$$

$$P_1 = \frac{\Delta_{k1q1}}{k_1 h_1} \quad (4.357)$$

$$P_2 = \frac{\Delta_{k2q2}}{k_2 h_2} \quad (4.358)$$

4.5.2 Surface potential and gate dielectric voltage drop in gate-source overlap region

$$G_{ov} = \frac{\sqrt{2q\varepsilon_{ch}\mathbf{NOV}\times 10^6}}{C_{ox1}'\sqrt{\phi_{T0}}} \quad (4.359)$$

$$\xi_{ov} = 1 + \frac{G_{ov}}{\sqrt{2}} \quad (4.360)$$

$$\xi_{mrg,ov} = 10^{-5}\,\xi_{ov} \quad (4.361)$$

$$x_{g1,ov} = 1.25 + 0.7324648775\,G_{ov} \quad (4.362)$$

$$x_{S,ov} = \mathrm{SP\_FDSOI\_OV}(x_{gs,ov}) \tag{4.363}$$

$$x_{S,ovcv} = \mathrm{SP\_FDSOI\_OV}(x_{gs,ovcv}) \tag{4.364}$$

$$V_{ovS} = -\phi_{T0}(x_{gs,ov} + x_{S,ov}) \tag{4.365}$$

$$V_{ovS,cv} = -\phi_{T0}(x_{gs,ovcv} + x_{S,ovcv}) \tag{4.366}$$

4.5.3 Surface potential and gate dielectric voltage drop in gate-drain overlap region

$$G_{ov} = \frac{\sqrt{2q\varepsilon_{ch}\mathbf{NOVD} \times 10^{6}}}{C_{ox1}'\sqrt{\phi_{T0}}} \tag{4.367}$$

$$\xi_{ov} = 1 + \frac{G_{ov}}{\sqrt{2}} \tag{4.368}$$

$$\xi_{mrg,ov} = 10^{-5}\xi_{ov} \tag{4.369}$$

$$x_{g1,ov} = 1.25 + 0.7324648775 G_{ov} \tag{4.370}$$

$$x_{D,ov} = \mathrm{SP\_FDSOI\_OV}(x_{gd,ov}) \tag{4.371}$$

$$x_{D,ovcv} = \mathrm{SP\_FDSOI\_OV}(x_{gd,ovcv}) \tag{4.372}$$

$$V_{ovD} = -\phi_{T0}(x_{gd,ov} + x_{D,ov}) \tag{4.373}$$

$$V_{ovD,cv} = -\phi_{T0}(x_{gd,ovcv} + x_{D,ovcv}) \tag{4.374}$$

4.6 Gate current

In this section is detailed the calculation of gate current components. This calculation is not carried out when the flag **SWIGATE** is set to 0.

4.6.1 Gate to source overlap component

$$\psi_t = \mathrm{MIN\_FUNC}(V_{ovS} + D_{ov}, 0, 0.01) \tag{4.375}$$

$$G_{C2,oveff} = \frac{\mathbf{GC2OVACC} + \mathbf{GC2OVINV}\exp(x_{gs,ov}/2)}{1 + \exp(x_{gs,ov}/2)} \tag{4.376}$$

$$G_{C3,oveff} = \frac{\mathbf{GC3OVACC} + \mathbf{GC3OVINV}\exp(x_{gs,ov}/2)}{1 + \exp(x_{gs,ov}/2)} \tag{4.377}$$

$$G_{CQ,oveff} = \frac{G_{CQ,ovacc} + G_{CQ,ovinv}\exp(x_{gs,ov}/2)}{1 + \exp(x_{gs,ov}/2)} \tag{4.378}$$

$$I_{G,oveff} = \frac{I_{G,ovacc} + I_{G,ovinv}\exp(x_{gs,ov}/2)}{1 + \exp(x_{gs,ov}/2)} \tag{4.379}$$

$$\begin{cases} z_g = \mathrm{MIN\_FUNC}\left(\dfrac{\sqrt{V_{ovS}{}^{2} + 10^{-4}}}{\mathbf{CHIB}}, G_{CQ,oveff}, 10^{-6}\right) & \text{if } G_{C3,oveff} < 0 \\ z_g = \dfrac{\sqrt{V_{ovS}{}^{2} + 10^{-4}}}{\mathbf{CHIB}} & \text{else} \end{cases} \tag{4.380}$$

$$\Delta_{Si} = \exp(3 + x_{S,ov} + \psi_t/\phi_{T0}) \tag{4.381}$$

$$\Delta_{gate} = \exp(3 + x_{S,ov} + (\psi_t - V_{GS})/\phi_{T0}) \tag{4.382}$$

$$f_{GS,ov} = \frac{1 + \exp(\mathbf{GCDOV}(V_{GD} - \mathbf{GCVDOV}))}{1 + \exp(\mathbf{GCDOV}(V_{GD} - \mathbf{GCVDOV}))\exp(\mathbf{GCDOV} \times V_{SD})} \tag{4.383}$$

$$I_{GS,ov} = I_{G,oveff} \ln\left(\frac{1+\Delta_{Si}}{1+\Delta_{gate}}\right)\exp\left(B_{ov}\left(z_g\left(G_{C2,oveff} + z_g G_{C3,oveff}\right)-3/2\right)\right)\times f_{GS,ov} \tag{4.384}$$

4.6.2 Gate to drain overlap component

$$\psi_t = \text{MIN\_FUNC}\left(V_{ovD} + D_{ov}, 0, 0.01\right) \tag{4.385}$$

$$G_{C2,oveff} = \frac{\textbf{GC2OVACC} + \textbf{GC2OVINV}\exp\left(x_{gd,ov}/2\right)}{1+\exp\left(x_{gd,ov}/2\right)} \tag{4.386}$$

$$G_{C3,oveff} = \frac{\textbf{GC3OVACC} + \textbf{GC3OVINV}\exp\left(x_{gd,ov}/2\right)}{1+\exp\left(x_{gd,ov}/2\right)} \tag{4.387}$$

$$G_{CQ,oveff} = \frac{G_{CQ,ovacc} + G_{CQ,ovinv}\exp\left(x_{gd,ov}/2\right)}{1+\exp\left(x_{gd,ov}/2\right)} \tag{4.388}$$

$$I_{G,oveff} = \frac{I_{G,ovaccD} + I_{G,ovinvD}\exp\left(x_{gd,ov}/2\right)}{1+\exp\left(x_{gd,ov}/2\right)} \tag{4.389}$$

$$\begin{cases} z_g = \text{MIN\_FUNC}\left(\dfrac{\sqrt{V_{ovD}^{\ 2}+10^{-4}}}{\textbf{CHIB}}, G_{CQ,oveff}, 10^{-6}\right) & if\ \ G_{C3,oveff} < 0 \\ z_g = \dfrac{\sqrt{V_{ovD}^{\ 2}+10^{-4}}}{\textbf{CHIB}} & else \end{cases} \tag{4.390}$$

$$\Delta_{Si} = \exp\left(3 + x_{D,ov} + \psi_t/\phi_{T0}\right) \tag{4.391}$$

$$\Delta_{gate} = \exp\left(3 + x_{D,ov} + \left(\psi_t - V_{GD}\right)/\phi_{T0}\right) \tag{4.392}$$

$$f_{GD,ov} = \frac{1+\exp\left(\textbf{GCDOV}\left(V_{GS} - \textbf{GCVDOV}\right)\right)}{1+\exp\left(\textbf{GCDOV}\left(V_{GS} - \textbf{GCVDOV}\right)\right)\exp\left(\textbf{GCDOV}\times V_{DS}\right)} \tag{4.393}$$

$$I_{GD,ov} = I_{G,oveff} \ln\left(\frac{1+\Delta_{Si}}{1+\Delta_{gate}}\right)\exp\left(B_{ov}\left(z_g\left(G_{C2,oveff} + z_g G_{C3,oveff}\right)-3/2\right)\right)\times f_{GD,ov} \tag{4.394}$$

4.6.3 Gate to channel component

$$x_{DS} = -2\Delta_{k1q1}/k_1 \tag{4.395}$$

$$V_m = \phi_T\left(\frac{x_{DS}}{2} - \ln\left(\frac{1+\exp\left(x_{DS} - x_{Deff}\right)}{2}\right)\right) \tag{4.396}$$

$$q_{1m} = \frac{q_{1S} + q_{1D}}{2} \tag{4.397}$$

$$V_{oxm} = \phi_T q_{1m} \tag{4.398}$$

$$\psi_t = \text{MIN\_FUNC}\left(V_{oxm} + D_{ch}, 0, 0.01\right) \tag{4.399}$$

$$\begin{cases} z_g = \text{MIN\_FUNC}\left(\dfrac{\sqrt{V_{oxm}^{\ 2}+10^{-4}}}{\textbf{CHIB}}, G_{CQ,ch}, 10^{-6}\right) & if\ \ \textbf{GC3CH} < 0 \\ z_g = \dfrac{\sqrt{V_{oxm}^{\ 2}+10^{-4}}}{\textbf{CHIB}} & else \end{cases} \tag{4.400}$$

$$\Delta_{Si} = \exp\left(\left(x_{g1x} - q_{1m} + \left(\psi_t - \alpha_b - V_m\right)/\phi_T\right)\times n_{iginv}\right) \tag{4.401}$$

$$\Delta_{gate} = \Delta_{Si}\exp\left(-\left(V_{GS} - V_m\right)/\phi_T \times n_{iginv}\right) \tag{4.402}$$

$$I_{GC0} = I_{G,inv}\ln\left(\frac{1+\Delta_{Si}}{1+\Delta_{gate}}\right)\exp\left(B_{ch}\left(z_g\left(\textbf{GC2CH} + z_g\textbf{GC3CH}\right)-3/2\right)\right) \tag{4.403}$$

4.6.4 Source/drain partitioning of gate to channel current

if $x_{g1x} > 0$:

$$u_0 = \frac{\mathbf{CHIB}/\phi_T}{B_{ch}(\mathbf{GC2CH} + 2z_g\mathbf{GC3CH})} \quad (4.404)$$

$$x = \frac{x_{DS}}{2u_0} \quad (4.405)$$

$$b = \frac{u_0}{k_1 h_1 / k_1} \quad (4.406)$$

$$B_g = b(1-b)/2 \quad (4.407)$$

$$A_g = 1/2 - 3B_g \quad (4.408)$$

$$p_{GC} = (1-b)\frac{\sinh(x)}{x} + b\cosh(x) \quad (4.409)$$

$$p_{GD} = \frac{p_{GC}}{2} - B_g \sinh(x) - \frac{A_g}{x}\left(\cosh(x) - \frac{\sinh(x)}{x}\right) \quad (4.410)$$

else:

$$p_{GC} = 1 \quad (4.411)$$

$$p_{GD} = 1/2 \quad (4.412)$$

$$I_{GC} = I_{GC0}\,p_{GC} \quad (4.413)$$

$$I_{GCD} = I_{GC0}\,p_{GD} \quad (4.414)$$

$$I_{GCS} = I_{GC} - I_{GCD} \quad (4.415)$$

4.6.5 Gate to source and gate to drain total currents

$$I_{GS} = I_{GCS} + I_{GS,ov} \quad (4.416)$$

$$I_{GD} = I_{GCD} + I_{GD,ov} \quad (4.417)$$

4.7 Gate Induced Drain/Source Leakage (GIDL/GISL)

This paragraph details the calculation of GIDL and GISL currents. Notice that the model, coming from UTSOI1, has been simplified. In particular, GIDL/GISL currents are no longer proportional to **LOV**.

4.7.1 Gate induced source leakage

$$V_{tovS} = \sqrt{V_{ovS}^{\;2} + \mathbf{CGIDL}^2 V_{SB}^{\;2} + 10^{-6}} \quad (4.418)$$

$$I_{GISL} = -A_{GIDL} V_{SD} V_{ovS} V_{tovS} \exp\left(-\frac{B_{GIDL}}{V_{tovS}}\right)\frac{1 + \exp(\mathbf{DGIDL} \times V_{SD})}{2} \quad (4.419)$$

4.7.2 Gate induced drain leakage

$$V_{tovD} = \sqrt{V_{ovD}^{\;2} + \mathbf{CGIDLD}^2 V_{DB}^{\;2} + 10^{-6}} \quad (4.420)$$

$$I_{GIDL} = -A_{GIDLD} V_{DS} V_{ovD} V_{tovD} \exp\left(-\frac{B_{GIDLD}}{V_{tovD}}\right)\frac{1 + \exp(\mathbf{DGIDLD} \times V_{DS})}{2} \quad (4.421)$$

4.8 Charge model

This part is dedicated to the calculations of intrinsic and parasitic charges in the different electrodes. The intrinsic charge model is derived from [9].

4.8.1 Quantum mechanical corrections

$$k_1q_{1m} = \frac{k_1q_{1S} + k_1q_{1D}}{2} + \mathbf{FSCEAC}\frac{\delta x_{WI,1D} - \delta x_{WI}}{1 + q_{im}/4} \tag{4.422}$$

$$k_2q_{2m} = \frac{k_2q_{2S} + k_2q_{2D}}{2} - \mathbf{FSCEAC}\frac{\delta x_{WI,1D} - \delta x_{WI}}{1 + q_{im}/4} \tag{4.423}$$

$$\begin{cases} k_1q_{1eff} = k_1q_{1m} - \dfrac{qm_{fact1} - 1}{qm_{fact1}} q_{i1m} & \text{if } \mathbf{QMC} > 0 \\ k_1q_{1eff} = k_1q_{1m} & \text{else} \end{cases} \tag{4.424}$$

$$\begin{cases} k_2q_{2eff} = k_2q_{2m} - \dfrac{qm_{fact2} - 1}{qm_{fact2}} q_{i2m} & \text{if } \mathbf{QMC} > 0 \\ k_2q_{2eff} = k_2q_{2m} & \text{else} \end{cases} \tag{4.425}$$

4.8.2 Intrinsic charge model

$$Q_G = C_{Si}' f_{area}\left(k_1q_{1eff} + \frac{\Delta_{k1q1}}{3}P_1\right) \tag{4.426}$$

$$Q_B = C_{Si}' f_{area}\left(k_2q_{2eff} + \frac{\Delta_{k2q2}}{3}P_2\right) \tag{4.427}$$

$$Q_D = -\frac{C_{Si}' f_{area}}{2}\left[k_1q_{1eff} + \frac{\Delta_{k1q1}}{3}\left(1 + P_1 - \frac{P_1^2}{5}\right) + k_2q_{2eff} + \frac{\Delta_{k2q2}}{3}\left(1 + P_2 - \frac{P_2^2}{5}\right)\right] \tag{4.428}$$

4.8.3 Parasitic charges

Inner fringe charges, computed if $\mathbf{FIF} > 0$

$$x_{effS} = x_{driftS} + x_{th,1D} + 2\ln(2) \tag{4.429}$$

$$x_{effD} = x_{driftD} + x_{th,1D} + 2\ln(2) \tag{4.430}$$

$$x_S^* = \text{MIN\_FUNC}\left(x_{effS}, x_{th,1D}, 9.0\right) \tag{4.431}$$

$$x_D^* = \text{MIN\_FUNC}\left(x_{effD}, x_{th,1D} + x_D, 9.0\right) \tag{4.432}$$

$$\lambda_f = \lambda_{2D}\sqrt{k_{eq}\left(1/2 + 1/k_2\right)} \tag{4.433}$$

$$\lambda_b = \lambda_{2D}\sqrt{k_{eq}\left(k_1/k_2\right)\left(1/2 + 1/k_1\right)} \tag{4.434}$$

$$x_{\alpha f} = \lambda_f^2 f_{SD,inner} \tag{4.435}$$

$$x_{\alpha b} = \lambda_b^2 f_{SD,inner} \tag{4.436}$$

$$x_{edge,fS} = x_S^* + 2x_{\alpha f}\left(\sqrt{1 + \left(x_{SD} - x_S^*\right)/x_{\alpha f}} - 1\right) \tag{4.437}$$

$$x_{edge,fD} = x_D^* + 2x_{\alpha f}\left(\sqrt{1 + \left(x_{SD} + x_D - x_D^*\right)/x_{\alpha f}} - 1\right) \tag{4.438}$$

$$x_{edge,bS} = x_S^* + 2x_{\alpha b}\left(\sqrt{1 + \left(x_{SD} - x_S^*\right)/x_{\alpha b}} - 1\right) \tag{4.439}$$

$$x_{edge,bD} = x_D^* + 2x_{\alpha b}\left(\sqrt{1+\left(x_{SD}+x_D-x_D^*\right)/x_{\alpha b}}-1\right) \tag{4.440}$$

$$Q_{GS,if} = -f_{if}C_{Si}'\lambda_f k_1 c_{sce1}\frac{\text{MAX\_FUNC}\left(x_{edge,fS}-x_{effS},0.0,1.0\right)^2}{x_{edge,fS}-x_S^*} \tag{4.441}$$

$$Q_{GD,if} = -f_{if}C_{Si}'\lambda_f k_1 c_{sce1}\frac{\text{MAX\_FUNC}\left(x_{edge,fD}-x_{effD},0.0,1.0\right)^2}{x_{edge,fD}-x_D^*} \tag{4.442}$$

$$Q_{BS,if} = -f_{if}C_{Si}'\lambda_b k_2 c_{sce2}\frac{\text{MAX\_FUNC}\left(x_{edge,bS}-x_{effS},0.0,1.0\right)^2}{x_{edge,bS}-x_S^*} \tag{4.443}$$

$$Q_{BD,if} = -f_{if}C_{Si}'\lambda_b k_2 c_{sce2}\frac{\text{MAX\_FUNC}\left(x_{edge,bD}-x_{effD},0.0,1.0\right)^2}{x_{edge,bD}-x_D^*} \tag{4.444}$$

Outer fringe and overlap charges

$$Q_{GS} = \mathbf{CFR}\times V_{GS} \tag{4.445}$$

$$Q_{GD} = \mathbf{CFRD}\times V_{GD} \tag{4.446}$$

$$Q_{ovS} = \mathbf{COV}\times V_{ovS,cv}\times\text{MAX\_FUNC}\left(1-\mathbf{COVDL}\times\delta l_{eff}\left(1-\mathbf{COVDLB}\times x_{g20}\right),0.0,0.01\right) \tag{4.447}$$

$$Q_{ovD} = \mathbf{COVD}\times V_{ovD,cv}\times\text{MAX\_FUNC}\left(1-\mathbf{COVDL}\times\delta l_{eff}\left(1-\mathbf{COVDLB}\times x_{g20}\right),0.0,0.01\right) \tag{4.448}$$

$$Q_{GB} = \mathbf{CGBOV}\times V_{GB} \tag{4.449}$$

Drain to source direct coupling

$$Q_{DS} = \mathbf{CSD}\times V_{DS} \tag{4.450}$$

Substrate extrinsic charge model

$$Q_{BS} = -\left(C_{ox2}'\times A_{source,f}+\mathbf{CSDBP}\times P_{source,f}\right)V_{SB} \tag{4.451}$$

$$Q_{BD} = -\left(C_{ox2}'\times A_{drain,f}+\mathbf{CSDBP}\times P_{drain,f}\right)V_{DB} \tag{4.452}$$

4.9 Self-heating

As in Leti-UTSOI1, a temperature node named “Tnode” is used to compute the channel temperature elevation induced by the self-heating effect.

Note that, from version Leti-UTSOI 2.1.0, this node is accessible.

While this node voltage represented one hundredth of the temperature elevation in Leti-UTSOI 2.0.0, it corresponds, from Leti-UTSOI 2.1.0, to the actual temperature elevation (i.e. there is no more 1/100 factor).

This node is linked to the ground node through a simple parallel RC circuit, as illustrated in Figure 4.1.

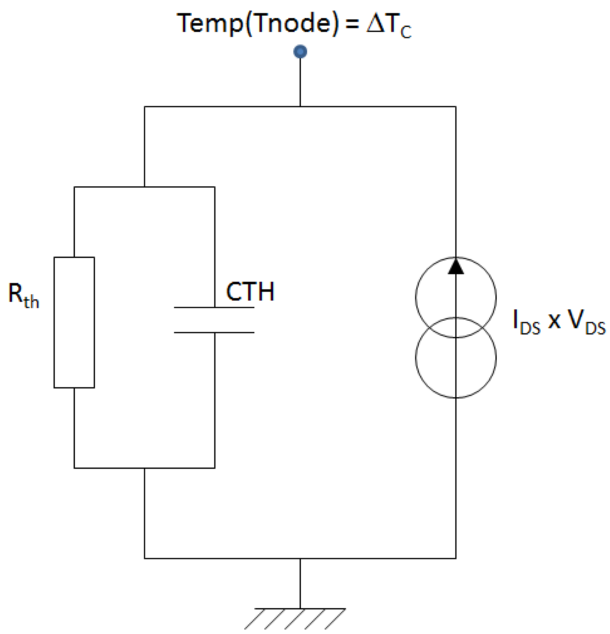

Figure 4.1- Description of the self-heating equivalent circuit used to compute channel temperature elevation.

$$\Delta T_C = Temp(Tnode) \quad (4.453)$$

$$I_{th} = \frac{\Delta T_C}{R_{th}} - I_{DS} V_{DS} \quad (4.454)$$

$$Q_{th} = \mathbf{CTH} \times \Delta T_C \quad (4.455)$$

4.10 Noise model

In this section are described the noise sources and the calculation of their power spectral densities. The way thermal induced gate noise is implemented in the VerilogA code is also indicated.

4.10.1 Channel thermal noise

$$d_m = -\frac{d_S + d_D}{2} \quad (4.456)$$

$$q_{im}^* = q_{im} + d_m \quad (4.457)$$

$$t_1 = \frac{q_{im}}{q_{im}^*} \quad (4.458)$$

$$t_2 = \left(-\frac{\Delta_{k1q1}}{6k_1 h_{10}}\right)^2 \quad (4.459)$$

$$R = \frac{1 + 3z_{sat}/2}{\sqrt{1 + z_{sat}}} - 1 \quad (4.460)$$

$$l_C = 1 - 12t_2 R \quad (4.461)$$

$$g_{ideal} = \beta_{Neff} C_{Si}' \phi_T q_{im}^* \frac{F_{\Delta L}}{G_{vsat} q m_{fact}} \quad (4.462)$$

$$g_{Sid} = \frac{g_{ideal}}{l_C^2}\left(t_1 + 12t_2 - 24(1 + t_1)t_2 R\right) \quad (4.463)$$

$$S_{ids,th} = n_T g_{Sid} \quad (4.464)$$

4.10.2 Induced gate noise

Induced gate noise and its correlation with drain thermal noise are computed only when **SWIGN** flag is set to 1.

$$C_{Geff} = (1 + z_{sat}) \frac{k_1 C_{Si}'}{qm_{fact1}} \mathbf{AREAQ} \tag{4.465}$$

$$g_{Sig} = \frac{g_{ideal} I_C^{\,2}}{t_1/12 - (1/5 + t_1 - 12t_2)t_2 - 8/5(1 + t_1 - 12t_2)t_2 R} \tag{4.466}$$

$$S_{ig,th} = n_T g_{Sig} \frac{(2\pi f_{op} C_{Geff}/g_{Sig})^2}{1 + (2\pi f_{op} C_{Geff}/g_{Sig})^2} \tag{4.467}$$

The gate induced noise current is finally partitioned between the gate-source and the gate-drain branches, with a V_{DS} dependent fraction equal to $1/2 + \sqrt{t_2}/4$ and $1/2 - \sqrt{t_2}/4$, respectively. The noise currents in these two branches are thus perfectly correlated and correspond to the following spectral densities:

$$S_{igs,th} = \left(\frac{1}{2} + \frac{\sqrt{t_2}}{4}\right)^2 S_{ig,th} \tag{4.468}$$

$$S_{igd,th} = \left(\frac{1}{2} - \frac{\sqrt{t_2}}{4}\right)^2 S_{ig,th} \tag{4.469}$$

4.10.3 Drain and gate thermal noise correlation

$$m_{igid} = \frac{\sqrt{t_2}}{I_C^{\,2}} (1 - 12t_2 - (t_1 + 96t_2/5 - 12t_1 t_2)t_2 R) \tag{4.470}$$

$$S_{igid,th} = n_T \frac{2j\pi f_{op} C_{Geff} m_{igid}}{1 + 2j\pi f_{op} C_{Geff}/g_{Sig}} \tag{4.471}$$

4.10.4 VerilogA implementation of induced gate noise and correlation

Since there is no noise function with frequency dependence suitable for the induced gate noise in VerilogA, an internal node NSIG linked to the ground through a parallel RC circuit is used. The equivalent circuit is described in Figure 4.2 and the currents in the different branches are given by:

$$I(NOIR) = g_{Sig} V(NSIG) \tag{4.472}$$

$$I(NOIC) = \frac{d}{dt}(C_{Geff} V(NSIG)) \tag{4.473}$$

$$I(NOII) = \text{white\_noise}(Mult_f n_T g_{Sig}) \tag{4.474}$$

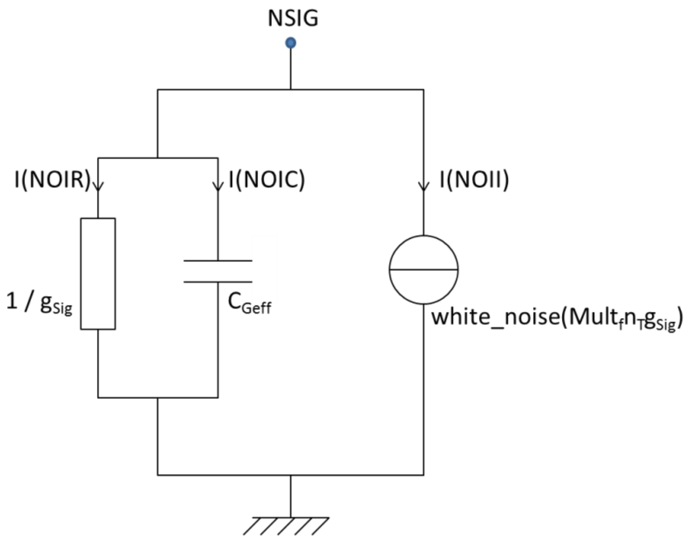

Figure 4.2- Description of the equivalent circuit used to define induced gate noise.

The noise current in the gate-source and gate-drain branches is obtained by:

$$I_{gs,th} = \frac{d}{dt}\left(-\left(\frac{1}{2}+\frac{\sqrt{t_2}}{4}\right)C_{Geff}V(NSIG)\right) \tag{4.475}$$

$$I_{gd,th} = \frac{d}{dt}\left(-\left(\frac{1}{2}-\frac{\sqrt{t_2}}{4}\right)C_{Geff}V(NSIG)\right) \tag{4.476}$$

A variable c_{igid} is then defined to obtain the correct correlation between the drain thermal noise current and the gate induced one:

$$c_{igid} = m_{igid}\sqrt{\frac{g_{Sig}}{g_{Sid}}} \tag{4.477}$$

The channel thermal noise current is finally given as the sum of an uncorrelated part and a correlated one:

$$I_{ds,th} = \text{white\_noise}\left(Mult_f S_{ids,th}\left(1-c_{igid}{}^2\right)\right)+m_{igid}I(NOII) \tag{4.478}$$

4.10.5 Channel flicker noise

$$N_{unit} = \frac{C_{Si}'\phi_T}{q} \tag{4.479}$$

$$N^* = N_{unit}d_m \tag{4.480}$$

$$N_m^* = N_{unit}(q_{im}+1) \tag{4.481}$$

$$\Delta N = N_{unit}(q_{iS}-q_{iD}) \tag{4.482}$$

$$f_{NFE} = \text{MAX\_FUNC}\left(1+\frac{e_{surf1}\mathbf{NFE}+e_{surf2}\mathbf{NFEB}}{q_{im}+1},0.01,0.0001\right) \tag{4.483}$$

$$S_{ids,fl} = \frac{q\beta_{Neff}\phi_T{}^2 I_{DS}}{f_{op}{}^{\mathbf{EF}} G_{vsat} N^*}\left[\left(\mathbf{NFA}-N^*\mathbf{NFB}+N^{*2}\mathbf{NFC}\right)\ln\left(\frac{N_m^*+\Delta N/2}{N_m^*-\Delta N/2}\right)+\left(\mathbf{NFB}+\mathbf{NFC}\left(N_m^*-2N^*\right)\right)\Delta N\right]f_{NFE} \tag{4.484}$$

4.10.6 Shot noises

Gate current shot noise

$$S_{igs,sh} = 2q|I_{GS}| \tag{4.485}$$

$$S_{igd,sh} = 2q|I_{GD}| \tag{4.486}$$

GIDL/GISL current shot noise

$$S_{ids,sh} = 2q|I_{GIDL} - I_{GISL}| \tag{4.487}$$

4.11 Total currents and charges

According to Figure 1.3, the total currents in the branches and the total node charges are obtained as follows.

4.11.1 Static currents

$$I_{DS,dc} = Mult_f \times \mathbf{TYPE} \times (I_{DS} + I_{GIDL} - I_{GISL}) \tag{4.488}$$

$$I_{GS,dc} = Mult_f \times \mathbf{TYPE} \times I_{GS} \tag{4.489}$$

$$I_{GD,dc} = Mult_f \times \mathbf{TYPE} \times I_{GD} \tag{4.490}$$

$$I_{BS,dc} = 0 \tag{4.491}$$

$$I_{BD,dc} = 0 \tag{4.492}$$

$$I_{GB,dc} = 0 \tag{4.493}$$

4.11.2 Total charges

$$Q_{G,tot} = Mult_f \times \mathbf{TYPE} \times (Q_G + Q_{GS,if} + Q_{GD,if} + Q_{GS} + Q_{GD} + Q_{ovS} + Q_{ovD} + Q_{GB}) \tag{4.494}$$

$$Q_{D,tot} = Mult_f \times \mathbf{TYPE} \times (Q_D + Q_{DS} - Q_{GD,if} - Q_{GD} - Q_{ovD} - Q_{BD,if} - Q_{BD}) \tag{4.495}$$

$$Q_{B,tot} = Mult_f \times \mathbf{TYPE} \times (Q_B + Q_{BS,if} + Q_{BD,if} + Q_{BS} + Q_{BD} - Q_{GB}) \tag{4.496}$$

$$Q_{S,tot} = -Q_{G,tot} - Q_{D,tot} - Q_{B,tot} \tag{4.497}$$

4.11.3 Dynamic currents

$$I_{DS,ac} = Mult_f \times \mathbf{TYPE} \times d(Q_D + Q_{DS})/dt \tag{4.498}$$

$$I_{GS,ac} = Mult_f \times \mathbf{TYPE} \times d(Q_G + Q_{GS,if} + Q_{GS} + Q_{ovS})/dt \tag{4.499}$$

$$I_{GD,ac} = Mult_f \times \mathbf{TYPE} \times d(Q_{GD,if} + Q_{GD} + Q_{ovD})/dt \tag{4.500}$$

$$I_{BS,ac} = Mult_f \times \mathbf{TYPE} \times d(Q_B + Q_{BS,if} + Q_{BS})/dt \tag{4.501}$$

$$I_{BD,ac} = Mult_f \times \mathbf{TYPE} \times d(Q_{BD,if} + Q_{BD})/dt \tag{4.502}$$

$$I_{GB,ac} = Mult_f \times \mathbf{TYPE} \times dQ_{GB}/dt \tag{4.503}$$

5 Operating Point output

In this section are described the quantities of DC operating point output, defined with **nMOSFET sign and positive V_{DS} convention**. These values give information on the device state at its current operation point.

5.1 Voltages

First, device threshold voltage is calculated. This requires re-computing of several quantities in order to get device state (temperature, effective channel length, effective back gate depletion effect, quantum confinement correction) at gate to source voltage equal to threshold voltage. Therefore, an initial value of threshold voltage is computed from (5.1) to (5.8). Then, required expressions of sections 4.1 to 4.4.2 are computed with TKD instead of TKC, and with $V_{GS} = v_{th}$ as given by (5.8) as input gate to source voltage, to get updated values of k_1, k_2, $diff_{min}$,… Finally, equation sequence (5.1) to (5.8) is re-computed to obtain final threshold voltage value.

$$r_{1,op} = \frac{k_2}{k_1(1+k_2)} \tag{5.1}$$

$$r_{2,op} = \frac{k_1}{k_2(1+k_1)} \tag{5.2}$$

$$x_{1sat,op} = \ln\left(k_1(1+r_{1,op})\frac{diff_{\min}}{A_0}\right)+2 \tag{5.3}$$

$$x_{2sat,op} = \ln\left(k_2(1+r_{2,op})\frac{diff_{\min}}{A_0}\right)+2 \tag{5.4}$$

$$x_{th1,op} = x_{1sat,op}(1+r_{1,op}) - x_{g2x}r_{1,op} \tag{5.5}$$

$$x_{th2,op} = x_{2sat,op}(1+1/r_{2,op}) - x_{g2x}/r_{2,op} \tag{5.6}$$

$$x_{g1th,op} = \frac{\mathrm{MIN\_FUNC}(x_{th1,op}, x_{th2,op}, 38) - x_{g2}}{\mathbf{CICF}} + x_{g2} \tag{5.7}$$

$$v_{th} = \phi_T\left(\frac{x_{g1th,op} - x_{edge}}{c_{sce1}} - \delta x_{g1,DIBL} + x_{edge}\right) + V_{FB1} \tag{5.8}$$

We compute also the drain saturation voltage:

$$v_{Dsat} = \phi_T x_{nDS,sat} \tag{5.9}$$

Name	Unit	Definition	Value
Vds	V	Internal drain-source DC voltage	V_{DS}
Vsb	V	Internal source-bulk DC voltage	V_{SB}
Vgs	V	Internal gate-source DC voltage	V_{GS}
Vth	V	Threshold voltage	v_{th}
Vth_drive	V	Effective gate drive voltage	$V_{GS} - v_{th}$
Vdsat	V	Drain saturation voltage at the given bias	v_{Dsat}
Vdsat_marg	V	V_{DS} voltage margin	$V_{DS} - v_{Dsat}$

5.2 Current components

Name	Unit	Definition	Value
Id	A	Total DC drain current flowing into drain terminal	**TYPE** x $(I_{DS,dc} - I_{GD,dc})$
Ig	A	Total DC gate current flowing into gate terminal	**TYPE** x $(I_{GS,dc} + I_{GD,dc})$
Is	A	Total DC source current flowing into source terminal	**TYPE** x $(-I_{DS,dc} - I_{GS,dc})$
Ib	A	Total DC bulk current flowing into bulk terminal	0
Ids	A	DC channel current excl. tunnel, GISL and GIDL currents	$Mult_f$ x I_{DS}

Igidl	A	DC Gate Induced Drain Leakage current	$Mult_f$ x I_{GIDL}
Igisl	A	DC Gate Induced Source Leakage current	$Mult_f$ x I_{GISL}
Igs	A	DC gate-source leakage current	$Mult_f$ x I_{GS}
Igd	A	DC gate-drain leakage current	$Mult_f$ x I_{GD}
Isb	A	DC source-bulk current	*0*
Idb	A	DC drain-bulk current	*0*

5.3 Conductances and transconductances

Here, V_G, V_B and V_D refer to the electrode potentials with the nMOSFET sign convention already applied.

Name	Unit	Definition	Value
Gm	S	Internal DC transconductance	∂**Id**$/\partial V_G$
Gmb	S	Internal DC bulk transconductance	∂**Id**$/\partial V_B$
Gds	S	Internal DC output conductance	∂**Id**$/\partial V_D$

5.4 Capacitances and transcapacitances

Here, V_G, V_B and V_D refer to the electrode potentials with the nMOSFET sign convention already applied.

Name	Unit	Definition	Value
Cgg	F	Internal AC gate capacitance	**TYPE** x $\partial Q_{G,tot}/\partial V_G$
Cgd	F	Internal AC gate-drain transcapacitance	-**TYPE** x $\partial Q_{G,tot}/\partial V_D$
Cgb	F	Internal AC gate-bulk transcapacitance	-**TYPE** x $\partial Q_{G,tot}/\partial V_B$
Cgs	F	Internal AC gate-source transcapacitance	**Cgg - Cgd - Cgb**
Cdd	F	Internal AC drain capacitance	**TYPE** x $\partial Q_{D,tot}/\partial V_D$
Cdg	F	Internal AC drain-gate transcapacitance	-**TYPE** x $\partial Q_{D,tot}/\partial V_G$
Cdb	F	Internal AC drain-bulk transcapacitance	-**TYPE** x $\partial Q_{D,tot}/\partial V_B$
Cds	F	Internal AC drain-source transcapacitance	**Cdd - Cdg - Cdb**
Cbb	F	Internal AC bulk capacitance	**TYPE** x $\partial Q_{B,tot}/\partial V_B$
Cbg	F	Internal AC bulk-gate transcapacitance	-**TYPE** x $\partial Q_{B,tot}/\partial V_G$
Cbd	F	Internal AC bulk-drain transcapacitance	-**TYPE** x $\partial Q_{B,tot}/\partial V_D$
Cbs	F	Internal AC bulk-source transcapacitance	**Cbb - Cbg - Cbd**
Csg	F	Internal AC source-gate transcapacitance	**Cgg - Cdg - Cbg**
Csb	F	Internal AC source-bulk transcapacitance	**Cbb - Cgb - Cdb**
Csd	F	Internal AC source-drain transcapacitance	**Cdd - Cgd - Cbd**
Css	F	Internal AC source capacitance	**Csg + Csd + Csb**

5.5 Miscellaneous

Name	Unit	Definition	Value
TYPE	---	MOSFET type	**TYPE**
Tk	K	MOSFET device temperature	T_{KC}
Dtsh	K	MOSFET device temperature increase due to self-heating	ΔT_C
Self_gain	---	Internal UTSOI model self-gain	**Gm / Gds**
Rout	Ω	AC output resistance	*1* / **Gds**
Beff	A/V^2	Gain factor in saturation	*2***Id / Vgt**^{2}
Ft	Hz	Unity gain frequency	**Gm** / (2π**Cgg**)
Rgate	Ω	MOS gate resistance (not included in this version)	*0*
Gmoverid	1/V	Transconductance over drain current ratio	**Gm / Id**
Vearly	V	Equivalent Early voltage	**Id / Gds**

6 Parameters extraction

The following tables summarize the main steps of a local parameter extraction sequence, first for a long channel transistor, and then for short channel devices. Note that accounting for self heating requires temperature dependence extraction at each step of the flow.

6.1 Long channel device

Step	Physical effect	Curves	Parameters
1	Self heating	DC self heating measurement	**RTH**
2	Process	Cgc(Vg) at various Vb	**TOXE, VFB, (TSI)**
3	Process	Cgb(Vg) in subthreshold regime	**TBOX, NSUB, (CGBOV)**
4	Process	Log(Id)(Vg) at low Vd and various Vb	**VFB, CT, (NSUB)**
5	Process	Log(Id)(Vg) at low Vd and various temperatures	**STVFB**
6	Mobility	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and Vb=0V	**BETN, CS, THECS, MUE, THEMU**
7	Mobility	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and various Vb	**BETN, CS, THECS, MUE, THEMU, XCOR, BETNB**
8	Mobility	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and various temp.	**STBET, STCS, STTHECS, STMUE, STTHEMU, STXCOR**
9	Saturation velocity	Id(Vd), Log(Gd)(Vd) at high Vg	**AX, THESAT**
10	Gate current	Ig(Vg)	**IGINV, IGOVINV, IGOVACC, GC2CH, GC3CH, GC2OV, GC3OV, CHIB**
11	Gate current	Ig(Vg) at various temperatures	**STIG**
12	GIDL	Log(Id)(Vg) at high Vd and various Vb	**AGIDL, BGIDL, CGIDL**
13	GIDL	Log(Id)(Vg) at high Vd and various temperatures	**STBGIDL**

6.2 Short channel devices

Step	Physical effect	Curves	Parameters
1	Self heating	DC self heating measurement	**RTH**
4	Process	Log(Id)(Vg) at low Vd and various Vb	**VFB, VFBB, PSCE, PSCEB**
5	Process	Log(Id)(Vg) at low Vd and various temperatures	**STVFB**
6	Mobility, Rseries	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and Vb=0V	**BETN, CS, RS, RSG, THERSG**
7	Mobility, Rseries	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and various Vb	**BETN, CS, RS, RSG, THERSG, XCOR**
8	Mobility, Rseries	Id(Vg), Gm(Vg), Gm2(Vg) at low Vd and various temp.	**STBET, STRS, STXCOR**
9	DIBL	Log(Id)(Vg) at high Vd and various Vb	**CF, CFB**
10	DIBL	Log(Id)(Vg) at high Vd and various temperatures	**STCF**
11	DIBL	Log(Id)(Vd), Log(Gd)(Vd) at low Vg	**CF, CFD**
12	Sat. velocity, CLM	Id(Vd), Log(Gd)(Vd) at various Vg Gm(Vg) at various Vd	**AX, ALP, ALP1, VP, THESAT, THESATG**
13	Sat. velocity, CLM	Id(Vd) at high Vg and various Vb	**THESAT, THESATB**
14	Sat. velocity, CLM	Id(Vd), Log(Gd)(Vd) at high Vg and various temp.	**STTHESAT**
15	Capacitance	Cgb(Vg)	**CGBOV**
16	Capacitance	Cgc(Vg)	**AREAQ, COV, NOV, CFR**
17	Gate current	Ig(Vg)	**IGINV, IGOVINV, IGOVACC**
18	GIDL	Log(Id)(Vg) at high Vd	**AGIDL**

7 Acknowledgments

Authors would like to warmly thank Patrick Scheer, André Juge, Gilles Gouget, Salim El-Ghouli, from STMicroelectronics, as well as STMicroelectronics compact modelling teams for support, helpful discussions and advices.

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9 Model history

This section details all modifications brought to the code from Leti-UTSOI2.0.0.

9.1 Leti-UTSOI2.0.0 to Leti-UTSOI2.1.0

Important change: Channel temperature elevation node is now accessible from the circuit netlist and can be declared in transistor instantiation. Thus, with Leti-UTSOI2.1.0, transistor instantiation accepts 5 nodes (D, G, S, B, Tnode), while 4 nodes were available with previous versions.

9.1.1 Bug fixes

- ***BF1***: Modification of **CSD** default value for consistency with default global parameter values.
- ***BF2***: Correction of a bug concerning temperature dependence of DIBL. **CF** scaling law is now applied to **STCF**, which suppresses apparition of undesirable DIBL on long channel devices at low and/or high temperature when **STCF** is non-null. Hard clamp previously applied to **CF** has been removed to avoid discontinuities on derivatives that could appear with some parameter configurations and activated self-heating.
- ***BF3***: Correction of a bug concerning the conditionnal clipping of **SWSHE** flag. In previous version, condition was defined for local scale mode only.
- ***BF4***: Correction of **CFB** clipping. In previous version, clipping was done on **CF*****CFB**, which could lead to uncorrect clipping in some cases (**CF** < 0 and **CFB** < 0).
- ***BF5***: Correction of a bug concerning the recalculation of DIBL related variable “xd0” when self-heating is activated. Line was missing.
- ***BF6***: Modification of **CIC** and **CICF** implementation to avoid negative transcapacitances that could be observed for **CIC** and/or **CICF** different from 1.
- ***BF7***: Improvement of numerical robustness in the subthreshold regime: corrects a bug in thermal noise calculation and avoids divisions by zero that could occur in some extreme bias/temperature conditions.
- ***BF8***: Adding of a protection in the calculation of effective V_{DS}.
- ***BF9***: Correction of GIDL/GISL component output.
- ***BF10***: Modification of the operating point section to account properly for source/drain interchange.

9.1.2 Accuracy and predictability improvements

- ***AP1***: The effect of effective channel length dependence on front and back gate biases has been introduced in the 2D electrostatic part of the model (subthreshold slope, DIBL) through local parameters **PSCEDL** and **CFDL**, and in overlap capacitance model through parameter **COVDL**.
- ***AP2***: The impact of narrow channel effect on front/back gate to interface couplings has been introduced through parameter **PNCE**.
- ***AP3***: To improve the description of gate to source/drain overlap tunnelling currents, **GC2OV** and **GC3OV** parameters have been split into **GC2OVINV**, **GC3OVINV**, **GC2OVACC** and **GC3OVACC**.
- ***AP4***: Gate to channel tunnelling current model has been improved for a better description in the subthreshold regime, with introduction of local parameter **NIGINV**.
- ***AP5***: Predictability of the 2D electrostatic part of the model has been improved, by linking subthreshold slope and DIBL related parameters (**PSCE**, **CF**) to process parameters (**TSI**, **TOXE**, **TBOX**) in scaling laws. In addition, introduction of subthreshold slope degradation parameter in model equations has been modified, so that threshold voltage roll-off predictability is also improved.
- ***AP6***: Scaling law of **BETN** has been changed for better accuracy. PSP-like scaling law has been adopted.
- ***AP7***: Introduction of narrow-short channel effect in **VFB** scaling law has been modified for better description.

- ***AP8***: The impact of 2D electrostatic effect on back gate depletion has been introduced through calculation of an effective back gate doping level.
- ***AP9***: Adding of a flat-band voltage adjustment parameter for overlap capacitances (**DVFBOV**).

9.1.3 Changes in model inputs and outputs

- ***IO1***: Warnings about clipping of instance, global and local parameters, as well as channel temperature elevation, have been added. Display is controlled through **SWCLIPCHK** flag.
- ***IO2***: Device temperature node (Tnode) was internal in previous version, and was corresponding to 1/100th of channel temperature elevation due to self-heating. This node is now accessible (declared as "inout") and represents the actual channel temperature elevation. Device instantiation requires now 5 nodes.
- ***IO3***: Modification of some parameter clipping: **MULT** min value from 1 to 0, **PSCE** min value from -0.5 to 0 and **AX** max value from 12 to 16. Change of **RTHL**, **RTHW** and **RTHLW** default values.
- ***IO4***: Update of description and notation of operating point outputs. Adding of MOSFET type and device temperature as new outputs.

9.2 Leti-UTSOI2.1.0 to Leti-UTSOI2.1.1

9.2.1 Bug fixes

- ***BF1***: Modification of smoothing in drain saturation voltage calculation to improve smoothness of third order derivatives.
- ***BF2***: Modification of smoothing in gate current model to improve smoothness of third order derivatives.

9.2.2 Accuracy and predictability improvements

- ***AP1***: Improvement of threshold voltage calculation in Operating Point section.

9.3 Leti-UTSOI2.1.1 to Leti-UTSOI2.2.0

9.3.1 Bug fixes

- ***BF1***: Parameters **DLQ** and **DWQ** were involved in device effective length and width, respectively, for computation of external parasitic capacitances, such as external fringe capacitance or gate to substrate one. This is no longer the case, and these capacitances are now calculated with the physical length and width of the device.
- ***BF2***: In the scaling law of velocity saturation parameter **THESAT**, **THESATO** and **THESATL** were not treated similarly. This has been modified for more consistent description of this scaling law.

9.3.2 Accuracy and predictability improvements

- ***AP1***: Additional flexibility has been introduced in channel length modulation model for more accurate description of current and conductances over applied biases.
- ***AP2***: Model has been extended to the case of doped thin film transistors, with introduction of channel doping level local parameter **NCH**.
- ***AP3***: Channel length dependence over front and back bias in subthreshold and moderate inversion regimes has been introduced in Leti-UTSOI 2.1. This part of the model has been improved for better accuracy, with a physical description of source/drain depletion effect.

- ***AP4***: Mobility model accuracy has been improved, in particular with the introduction of transverse field dependence of Coulomb scattering component.
- ***AP5***: Series resistance model flexibility has been increased, with introduction of source/drain extension component and explicit back bias dependence.
- ***AP6***: Gate-overlap tunnelling current description at high drain voltage has been improved.
- ***AP7***: Introduction high longitudinal field dependence of GISL/GIDL currents.
- ***AP8***: Introduction of a physical inner fringe capacitance model, including source/drain depletion effect (see AP3), for better description of short channel capacitances.
- ***AP9***: Overlap capacitance model flexibility has been increased to account for source/drain depletion effect introduced in DC model (see AP3).
- ***AP10:*** Global scale parameters **VFBL2** and **VFBLEXP2** have been added for more flexibility in **VFB** scaling description.
- ***AP11:*** Global scale parameters **ALPLEXP2** and **ALP1LEXP2** have been added for more flexibility in **ALP** and **ALP1** scaling description, respectively.
- ***AP12:*** Description of edge effect in gate to substrate parasitic capacitance has been introduced through global scale parameter **CGBOVO**.
- ***AP13***: Geometrical dependences of thermal resistance and thermal capacitance have been extended to multifinger transistors, by accounting for thermal coupling between fingers.
- ***AP14***: A new strain relaxation model, dedicated to strained-SOI technologies, has been introduced besides existing STI-based stress model.
- ***AP15***: High order derivability of the model around null source-drain voltage has been improved.

9.3.3 Changes in model inputs and outputs

- ***IO1***: Warnings about clipping of instance, global and local parameters, as well as channel temperature elevation, have been updated. Display is still controlled through **SWCLIPCHK** flag.