APPENDIX A: Parameter List

A.1 Model Control Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
None	level	The model selector	8	none	
None	version	Model version selector	3.2	none	
None	binUnit	Bining unit selector	1	none	
None	param-Chk	Parameter value check	False	none	
mobMod	mobMod	Mobility model selector	1	none	
capMod	capMod	Flag for capacitance models	3	none	
nqsMod[a]	nqsMod	Flag for NQS model	0	none	
noiMod	noiMod	Flag for noise models	1	none	

a. nqsMod is now an element (instance) parameter, no longer a model parameter.

A.2 DC Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Vth0	vth0	Threshold voltage @Vbs=0 for Large L.	0.7 (NMOS) -0.7 (PMOS)	V	nI-1
VFB	vfb	Flat-band voltage	Calculated	V	nI-1
K1	k1	First order body effect coefficient	0.5	$V^{1/2}$	nI-2
K2	k2	Second order body effect coefficient	0.0	none	nI-2
K3	k3	Narrow width coefficient	80.0	none	
K3b	k3b	Body effect coefficient of k3	0.0	1/V	
W0	w0	Narrow width parameter	2.5e-6	m	
Nlx	nlx	Lateral non-uniform doping parameter	1.74e-7	m	
Vbm	vbm	Maximum applied body bias in Vth calculation	-3.0	V	
Dvt0	dvt0	first coefficient of short-channel effect on Vth	2.2	none	
Dvt1	dvt1	Second coefficient of short-channel effect on Vth	0.53	none	
Dvt2	dvt2	Body-bias coefficient of short-channel effect on Vth	-0.032	1/V	
Dvt0w	dvt0w	First coefficient of narrow width effect on Vth for small channel length	0	1/m	
Dvt1w	dvtw1	Second coefficient of narrow width effect on Vth for small channel length	5.3e6	1/m	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Dvt2w	dvt2w	Body-bias coefficient of narrow width effect for small channel length	-0.032	1/V	
$\mu 0$	u0	Mobility at Temp = Tnom NMOSFET PMOSFET	 670.0 250.0	cm^2/Vs	
Ua	ua	First-order mobility degradation coefficient	2.25E-9	m/V	
Ub	ub	Second-order mobility degradation coefficient	5.87E-19	$(m/V)^2$	
Uc	uc	Body-effect of mobility degradation coefficient	mobMod =1, 2: -4.65e-11 mobMod =3: -0.046	m/V^2 1/V	
νsat	vsat	Saturation velocity at Temp = Tnom	8.0E4	m/sec	
A0	a0	Bulk charge effect coefficient for channel length	1.0	none	
Ags	ags	gate bias coefficient of Abulk	0.0	1/V	
B0	b0	Bulk charge effect coefficient for channel width	0.0	m	
B1	b1	Bulk charge effect width offset	0.0	m	
Keta	keta	Body-bias coefficient of bulk charge effect	-0.047	1/V	
A1	a1	First non-saturation effect parameter	0.0	1/V	
A2	a2	Second non-saturation factor	1.0	none	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Rdsw	rdsw	Parasitic resistance per unit width	0.0	$\Omega\text{-}\mu m^{Wr}$	
Prwb	prwb	Body effect coefficient of Rdsw	0	$V^{-1/2}$	
Prwg	prwg	Gate bias effect coefficient of Rdsw	0	1/V	
Wr	wr	Width Offset from Weff for Rds calculation	1.0	none	
Wint	wint	Width offset fitting parameter from I-V without bias	0.0	m	
Lint	lint	Length offset fitting parameter from I-V without bias	0.0	m	
dWg	dwg	Coefficient of Weff's gate dependence	0.0	m/V	
dWb	dwb	Coefficient of Weff's substrate body bias dependence	0.0	$m/V^{1/2}$	
Voff	voff	Offset voltage in the subthreshold region at large W and L	-0.08	V	
Nfactor	nfactor	Subthreshold swing factor	1.0	none	
Eta0	eta0	DIBL coefficient in subthreshold region	0.08	none	
Etab	etab	Body-bias coefficient for the subthreshold DIBL effect	-0.07	1/V	
Dsub	dsub	DIBL coefficient exponent in subthreshold region	drout	none	
Cit	cit	Interface trap capacitance	0.0	F/m^2	
Cdsc	cdsc	Drain/Source to channel coupling capacitance	2.4E-4	F/m^2	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Cdscb	cdscb	Body-bias sensitivity of Cdsc	0.0	F/Vm^2	
Cdscd	cdscd	Drain-bias sensitivity of Cdsc	0.0	F/Vm^2	
Pclm	pclm	Channel length modulation parameter	1.3	none	
Pdiblc1	pdiblc1	First output resistance DIBL effect correction parameter	0.39	none	
Pdiblc2	pdiblc2	Second output resistance DIBL effect correction parameter	0.0086	none	
Pdiblcb	pdiblcb	Body effect coefficient of DIBL correction parameters	0	1/V	
Drout	drout	L dependence coefficient of the DIBL correction parameter in Rout	0.56	none	
Pscbe1	pscbe1	First substrate current body-effect parameter	4.24E8	V/m	
Pscbe2	pscbe2	Second substrate current body-effect parameter	1.0E-5	m/V	nI-3
Pvag	pvag	Gate dependence of Early voltage	0.0	none	
δ	delta	Effective Vds parameter	0.01	V	
Ngate	ngate	poly gate doping concentration	0	cm^{-3}	
$\alpha0$	alpha0	The first parameter of impact ionization current	0	m/V	
$\alpha1$	alpha1	Isub parameter for length scaling	0.0	1/V	
$\beta0$	beta0	The second parameter of impact ionization current	30	V	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Rsh	rsh	Source drain sheet resistance in ohm per square	0.0	Ω/ square	
Js0sw	jssw	Side wall saturation current density	0.0	A/m	
Js0	js	Source drain junction saturation current per unit area	1.0E-4	A/m^2	
ijth	ijth	Diode limiting current	0.1	A	nI-3

A.3 C-V Model Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Xpart	xpart	Charge partitioning flag	0.0	none	
CGS0	cgso	Non LDD region source-gate overlap capacitance per channel length	calculated	F/m	nC-1
CGD0	cgdo	Non LDD region drain-gate overlap capacitance per channel length	calculated	F/m	nC-2
CGB0	cgbo	Gate bulk overlap capacitance per unit channel length	0.0	F/m	
Cj	cj	Bottom junction capacitance per unit area at zero bias	5.0e-4	F/m^2	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Mj	mj	Bottom junction capacitance grating coefficient	0.5		
Mjsw	mjsw	Source/Drain side wall junction capacitance grading coefficient	0.33	none	
Cjsw	cjsw	Source/Drain side wall junction capacitance per unit area	5.E-10	F/m	
Cjswg	cjswg	Source/drain gate side wall junction capacitance grading coefficient	Cjsw	F/m	
Mjswg	mjswg	Source/drain gate side wall junction capacitance grading coefficient	Mjsw	none	
Pbsw	pbsw	Source/drain side wall junction built-in potential	1.0	V	
Pb	pb	Bottom built-in potential	1.0	V	
Pbswg	pbswg	Source/Drain gate side wall junction built-in potential	Pbsw	V	
CGS1	cgs1	Light doped source-gate region overlap capacitance	0.0	F/m	
CGD1	cgd1	Light doped drain-gate region overlap capacitance	0.0	F/m	
CKAPPA	ckappa	Coefficient for lightly doped region overlap capacitance Fringing field capacitance	0.6	V	
Cf	cf	fringing field capacitance	calculated	F/m	nC-3
CLC	clc	Constant term for the short channel model	0.1E-6	m	
CLE	cle	Exponential term for the short channel model	0.6	none	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
DLC	dlc	Length offset fitting parameter from C-V	lint	m	
DWC	dwc	Width offset fitting parameter from C-V	wint	m	
Vfbcv	vfbcv	Flat-band voltage parameter (for capMod=0 only)	-1	V	
noff	noff	CV parameter in Vgsteff,CV for weak to strong inversion	1.0	none	nC-4
voffcv	voffcv	CV parameter in Vgsteff,CV for week to strong inversion	0.0	V	nC-4
acde	acde	Exponential coefficient for charge thickness in capMod=3 for accumulation and depletion regions	1.0	m/V	nC-4
moin	moin	Coefficient for the gate-bias dependent surface potential	15.0	none	nC-4

A.4 NQS Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Elm	elm	Elmore constant of the channel	5	none	

A.5 dW and dL Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Wl	wl	Coefficient of length dependence for width offset	0.0	m^{Wln}	
Wln	wln	Power of length dependence of width offset	1.0	none	
Ww	ww	Coefficient of width dependence for width offset	0.0	m^{Wwn}	
Wwn	wwn	Power of width dependence of width offset	1.0	none	
Wwl	wwl	Coefficient of length and width cross term for width offset	0.0	$m^{Wwn+Wln}$	
Ll	ll	Coefficient of length dependence for length offset	0.0	m^{Lln}	
Lln	lln	Power of length dependence for length offset	1.0	none	
Lw	lw	Coefficient of width dependence for length offset	0.0	m^{Lwn}	
Lwn	lwn	Power of width dependence for length offset	1.0	none	
Lwl	lwl	Coefficient of length and width cross term for length offset	0.0	$m^{Lwn+Lln}$	
Llc	Llc	Coefficient of length dependence for CV channel length offset	Ll	m^{Lln}	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Lwc	Lwc	Coefficient of width dependence for CV channel length offset	Lw	m^{Lwn}	
Lwlc	Lwlc	Coefficient of length and width-dependence for CV channel length offset	Lwl	$m^{Lwn+Lln}$	
Wlc	Wlc	Coefficient of length dependence for CV channel width offset	Wl	m^{Wln}	
Wwc	Wwc	Coefficient of widthdependence for CV channel width offset	Ww	m^{Wwn}	
Wwlc	Wwlc	Coefficient of length and width-dependence for CV channel width offset	Wwl	$m^{Wln+Wwn}$	

A.6 Temperature Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Tnom	tnom	Temperature at which parameters are extracted	27	^{o}C	
μte	ute	Mobility temperature exponent	-1.5	none	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Kt1	kt1	Temperature coefficient for threshold voltage	-0.11	V	
Kt1l	kt1l	Channel length dependence of the temperature coefficient for threshold voltage	0.0	Vm	
Kt2	kt2	Body-bias coefficient of Vth temperature effect	0.022	none	
Ua1	ua1	Temperature coefficient for Ua	4.31E-9	m/V	
Ub1	ub1	Temperature coefficient for Ub	-7.61E-18	$(m/V)^2$	
Uc1	uc1	Temperature coefficient for Uc	mobMod=1, 2: -5.6E-11 mobMod=3: -0.056	m/V^2 1/V	
At	at	Temperature coefficient for saturation velocity	3.3E4	m/sec	
Prt	prt	Temperature coefficient for Rdsw	0.0	Ω-µm	
At	at	Temperature coefficient for saturation velocity	3.3E4	m/sec	
nj	nj	Emission coefficient of junction	1.0	none	
XTI	xti	Junction current temperature exponent coefficient	3.0	none	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
tpb	tpb	Temperature coefficient of Pb	0.0	V/K	
tpbsw	tpbsw	Temperature coefficient of Pbsw	0.0	V/K	
tpbswg	tpbswg	Temperature coefficient of Pbswg	0.0	V/K	
tcj	tcj	Temperature coefficient of Cj	0.0	1/K	
tcjsw	tcjsw	Temperature coefficient of Cjsw	0.0	1/K	
tcjswg	tcjswg	Temperature coefficient of Cjswg	0.0	1/K	

A.7 Flicker Noise Model Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Noia	noia	Noise parameter A	(NMOS) 1e20 (PMOS) 9.9e18	none	
Noib	noib	Noise parameter B	(NMOS) 5e4 (PMOS) 2.4e3	none	
Noic	noic	Noise parameter C	(NMOS) -1.4e-12 (PMOS) 1.4e-12	none	
Em	em	Saturation field	4.1e7	V/m	

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Af	af	Flicker noise exponent	1	none	
Ef	ef	Flicker noise frequency exponent	1	none	
Kf	kf	Flicker noise coefficient	0	none	

A.8 Process Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Tox	tox	Gate oxide thickness	1.5e-8	m	
Toxm	toxm	Tox at which parameters are extracted	Tox	m	nI-3
Xj	xj	Junction Depth	1.5e-7	m	
$\gamma 1$	gamma1	Body-effect coefficient near the surface	calcu-lated	$V^{1/2}$	nI-5
$\gamma 2$	gamma2	Body-effect coefficient in the bulk	calcu-lated	$V^{1/2}$	nI-6
Nch	nch	Channel doping concentration	1.7e17	$1/cm^3$	nI-4
Nsub	nsub	Substrate doping concentration	6e16	$1/cm^3$	
Vbx	vbx	Vbs at which the depletion region width equals xt	calcu-lated	V	nI-7
Xt	xt	Doping depth	1.55e-7	m	

A.9 Geometry Range Parameters

Symbols used in equation	Symbols used in SPICE	Description	Default	Unit	Note
Lmin	lmin	Minimum channel length	0.0	m	
Lmax	lmax	Maximum channel length	1.0	m	
Wmin	wmin	Minimum channel width	0.0	m	
Wmax	wmax	Maximum channel width	1.0	m	
binUnit	binunit	Bin unit scale selector	1.0	none	

A.10 Model Parameter Notes

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

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

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

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

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

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

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

where Φ_s is calculated by

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

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

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

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

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

nI-3.

If *pscbe*2 <= 0.0, a warning message will be given.
If *ijth* < 0.0, a fatal error message will occur.
If *Toxm* < = 0.0, a fatal error message will occur.

nI-4. If N_{ch} is not given and γ_1 is given, N_{ch} is calculated from

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

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

nI-5. If γ_1 is not given, it is calculated by

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

nI-6. If γ_2 is not given, it is calculated by

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

nI-7. If V_{bx} is not given, it is calculated by

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

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

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

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

if (*dlc* is given and is greater than 0),

$Cgdo = dlc * Cox - Cgd1$
if ($Cgdo < 0$)
$Cgdo = 0$
else $Cgdo = 0.6\, Xj * Cox$

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

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

nC-4.

If ($acde < 0.4$) or ($acde > 1.6$), a warning message will be given.
If ($moin < 5.0$) or ($moin > 25.0$), a warning message will be given.
If ($noff < 0.1$) or ($noff > 4.0$), a warning message will be given.
If ($voffcv < -0.5$) or ($voffcv > 0.5$), a warning message will be given.

APPENDIX B: Equation List

B.1 I-V Model

B.1.1 Threshold Voltage

$$
\begin{aligned}
V_{th} &= V_{th0ox} + K_{1ox} \cdot \sqrt{\Phi_s - V_{bseff}} - K_{2ox} V_{bseff} \\
&+ K_{1ox}\left(\sqrt{1+\frac{Nlx}{L_{eff}}} - 1\right)\sqrt{\Phi_s} + \left(K_3 + K_{3b} V_{bseff}\right)\frac{T_{ox}}{W_{eff}' + W_0}\Phi_s \\
&- D_{VT0w}\left(\exp\left(-D_{VT1w}\frac{W_{eff}' L_{eff}}{2l_{tw}}\right) + 2\exp\left(-D_{VT1w}\frac{W_{eff}' L_{eff}}{l_{tw}}\right)\right)\left(V_{bi} - \Phi_s\right) \\
&- D_{VT0}\left(\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right)\left(V_{bi} - \Phi_s\right) \\
&- \left(\exp\left(-D_{sub}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{sub}\frac{L_{eff}}{l_{to}}\right)\right)\left(E_{tao} + E_{tab} V_{bseff}\right) V_{ds}
\end{aligned}
$$

$$V_{th0ox} = V_{th0} - K_1 \cdot \sqrt{\Phi_s}$$

$$K_{1ox} = K_1 \cdot \frac{T_{ox}}{T_{oxm}}$$

$$K_{2ox} = K_2 \cdot \frac{T_{ox}}{T_{oxm}}$$

$$l_t = \sqrt{\varepsilon_{si} X_{dep} / C_{ox}}(1 + D_{VT2} V_{bseff})$$

$$l_{tw} = \sqrt{\varepsilon_{si} X_{dep} / C_{ox}}(1 + D_{VT2w} V_{bseff})$$

$$l_{to} = \sqrt{\varepsilon_{si} X_{dep0} / C_{ox}}$$

$$X_{dep} = \sqrt{\frac{2\varepsilon_{si}(\Phi_s - V_{bseff})}{qN_{ch}}}$$

$$X_{dep0} = \sqrt{\frac{2\varepsilon_{si}\Phi_s}{qN_{ch}}}$$

$$V_{bseff} = V_{bc} + 0.5[V_{bs} - V_{bc} - \delta_1 + \sqrt{(V_{bs} - V_{bc} - \delta_1)^2 - 4\delta_1 V_{bc}}\ ] \qquad (\delta 1 = 0.001)$$

$$V_{bc} = 0.9\left(\Phi_s - \frac{K_1^{\ 2}}{4K_2^{\ 2}}\right)$$

$$V_{bi} = v_t \ln\left(\frac{N_{ch} N_{DS}}{n_i^{\ 2}}\right)$$

B.1.2 Effective (V_{gs}-V_{th})

$$V_{gsteff} = \frac{2\,n\,v_t \ln\left[1 + \exp\left(\frac{V_{gs} - V_{th}}{2\,n\,v_t}\right)\right]}{1 + 2\,n\,C_{OX}\sqrt{\frac{2\Phi_s}{q\varepsilon_{si}N_{ch}}}\exp\left(-\frac{V_{gs} - V_{th} - 2V_{off}}{2\,n\,v_t}\right)}$$

$$n = 1 + N_{factor}\frac{C_d}{C_{ox}} + \frac{(C_{dsc} + C_{dscd}V_{ds} + C_{dscb}V_{bseff})\left(\exp(-D_{VT1}\frac{L_{eff}}{2l_t}) + 2\exp(-D_{VT1}\frac{L_{eff}}{l_t})\right)}{C_{ox}} + \frac{C_{it}}{C_{ox}}$$

$$C_d = \frac{\varepsilon_{si}}{X_{dep}}$$

B.1.3 Mobility

For mobMod=1

$$\mu_{eff} = \frac{\mu_o}{1 + (U_a + U_c V_{bseff})(\frac{V_{gsteff} + 2V_{th}}{T_{OX}}) + U_b(\frac{V_{gsteff} + 2V_{th}}{T_{OX}})^2}$$

For mobMod=2

$$\mu_{eff} = \frac{\mu_o}{1 + (U_a + U_c V_{bseff})(\frac{V_{gsteff}}{T_{OX}}) + U_b(\frac{V_{gsteff}}{T_{OX}})^2}$$

For mobMod=3

$$\mu_{eff} = \frac{\mu_o}{1 + [U_a(\frac{V_{gsteff} + 2V_{th}}{T_{OX}}) + U_b(\frac{V_{gsteff} + 2V_{th}}{T_{OX}})^2](1 + U_c V_{bseff})}$$

B.1.4 Drain Saturation Voltage

For $R_{ds} > 0$ or $\lambda \neq 1$:

$$V_{dsat} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

$$a = A_{bulk}{}^2 W_{eff} \nu_{sat} C_{ox} R_{DS} + \left(\frac{1}{\lambda} - 1\right) A_{bulk}$$

$$b = -\left((V_{gsteff} + 2v_t)\left(\frac{2}{\lambda} - 1\right) + A_{bulk} E_{sat} L_{eff} + 3A_{bulk}(V_{gsteff} + 2v_t) W_{eff} \nu_{sat} C_{ox} R_{DS} \right)$$

$$c = (V_{gsteff} + 2v_t) E_{sat} L_{eff} + 2(V_{gsteff} + 2v_t)^2 W_{eff} \nu_{sat} C_{ox} R_{DS}$$

$$\lambda = A_1 V_{gsteff} + A_2$$

For $R_{ds} = 0$ and $\lambda = 1$:

$$V_{dsat} = \frac{E_{sat} \; L_{eff} (V_{gsteff} + 2v_t)}{A_{bulk} \; E_{sat} \; L_{eff} + (V_{gsteff} + 2v_t)}$$

$$A_{bulk} = \left(1 + \frac{K_{1ox}}{2\sqrt{\Phi_s - V_{bseff}}} \left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}} \left(1 - A_{gs} V_{gsteff} \left(\frac{L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}} \right)^2 \right) + \frac{B_0}{W_{eff}' + B_1} \right) \right) \cdot \frac{1}{1 + Keta V_{bseff}}$$

$$E_{sat} = \frac{2 v_{sat}}{\mu_{eff}}$$

B.1.5 Effective V_{ds}

$$V_{dseff} = V_{dsat} - \frac{1}{2}\left(V_{dsat} - V_{ds} - \delta + \sqrt{(V_{dsat} - V_{ds} - \delta)^2 + 4\delta V_{dsat}}\right)$$

B.1.6 Drain Current Expression

$$I_{ds} = \frac{I_{dso(Vdseff)}}{1 + \frac{R_{ds} I_{dso(Vdseff)}}{V_{dseff}}}\left(1 + \frac{V_{ds} - V_{dseff}}{V_A}\right)\left(1 + \frac{V_{ds} - V_{dseff}}{V_{ASCBE}}\right)$$

$$I_{dso} = \frac{W_{eff}\mu_{eff}C_{ox}V_{gsteff}\,(1 - A_{bulk}\,\frac{V_{dseff}}{2(V_{gsteff} + 2v_t)})V_{dseff}}{L_{eff}\,[1 + V_{dseff}\ /\ (E_{sat}L_{eff})]}$$

$$V_A = V_{Asat} + (1 + \frac{P_{vag}V_{gsteff}}{E_{sat}L_{eff}})(\frac{1}{V_{ACLM}} + \frac{1}{V_{ADIBLC}})^{-1}$$

$$V_{ACLM} = \frac{A_{bulk}E_{sat}L_{eff} + V_{gsteff}}{P_{CLM}A_{bulk}E_{sat}\ litl}(V_{ds} - V_{dseff})$$

$$V_{ADIBLC} = \frac{(V_{gsteff} + 2v_t)}{\theta_{rout}(1 + P_{DIBLCB}V_{bseff})}\left(1 - \frac{A_{bulk}V_{dsat}}{A_{bulk}V_{dsat} + V_{gsteff} + 2v_t}\right)$$

$$\theta_{rout} = P_{DIBLC1}\left[\exp(-D_{ROUT}\frac{L_{eff}}{2l_{t0}}) + 2\exp(-D_{ROUT}\frac{L_{eff}}{l_{t0}})\right] + P_{DIBLC2}$$

$$\frac{1}{V_{ASCBE}} = \frac{P_{scbe2}}{L_{eff}}\exp\left(\frac{-P_{scbe1}\,litl}{V_{ds} - V_{dseff}}\right)$$

$$V_{Asat} = \frac{E_{sat}L_{eff} + V_{dsat} + 2R_{DS}v_{sat}C_{ox}W_{eff}V_{gsteff}[1 - \frac{A_{bulk}V_{dsat}}{2(V_{gsteff} + 2v_t)}]}{2/\lambda - 1 + R_{DS}v_{sat}C_{ox}W_{eff}A_{bulk}}$$

$$litl = \sqrt{\frac{\varepsilon_{si}T_{ox}X_j}{\varepsilon_{ox}}}$$

B.1.7 Substrate Current

$$I_{sub} = \frac{\alpha_0 + \alpha_1 \cdot L_{eff}}{L_{eff}}(V_{ds} - V_{dseff})\exp\left(-\frac{\beta_0}{V_{ds} - V_{dseff}}\right)\frac{I_{ds0}}{1 + \frac{R_{ds}I_{ds0}}{V_{dseff}}}\left(1 + \frac{V_{ds} - V_{dseff}}{V_A}\right)$$

B.1.8 Polysilicon Depletion Effect

$$V_{poly} = \frac{1}{2} X_{poly} E_{poly} = \frac{qN_{gate} X_{poly}^2}{2\varepsilon_{si}}$$

$$\varepsilon_{ox} E_{ox} = \varepsilon_{si} E_{poly} = \sqrt{2q\varepsilon_{si} N_{gate} V_{poly}}$$

$$V_{gs} - V_{FB} - \Phi_s = V_{poly} + V_{ox}$$

$$a\left(V_{gs} - V_{FB} - \Phi_s - V_{poly}\right)^2 - V_{poly} = 0$$

$$a = \frac{\varepsilon_{ox}^{\;2}}{2q\varepsilon_{si} N_{gate} T_{ox}^{\;2}}$$

$$V_{gs\_eff} = V_{FB} + \Phi_s + \frac{q\varepsilon_{si} N_{gate} T_{ox}^{\;2}}{\varepsilon_{ox}^{\;2}} \left(\sqrt{1 + \frac{2\varepsilon_{ox}^{\;2}\left(V_{gs} - V_{FB} - \Phi_s\right)}{q\varepsilon_{si} N_{gate} T_{ox}^{\;2}}} - 1 \right)$$

B.1.9 Effective Channel Length and Width

$$L_{eff} = L_{drawn} - 2dL$$

$$W_{eff} = W_{drawn} - 2dW$$

$$W_{eff}' = W_{drawn} - 2dW'$$

$$dW = dW' + dW_g V_{gsteff} + dW_b\left(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s}\right)$$
$$dW' = W_{int} + \frac{W_l}{L^{W\ln}} + \frac{W_w}{W^{Wwn}} + \frac{W_{wl}}{L^{W\ln}W^{Wwn}}$$

$$dL = L_{int} + \frac{L_l}{L^{L\ln}} + \frac{L_w}{W^{Lwn}} + \frac{L_{wl}}{L^{L\ln}W^{Lwn}}$$

B.1.10Source/Drain Resistance

$$R_{ds} = \frac{R_{dsw}\left(1 + P_{rwg}V_{gsteff} + P_{rwb}\left(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s}\right)\right)}{\left(10^6 W_{eff}'\right)^{W_r}}$$

B.1.11Temperature Effects

$$V_{th(T)} = V_{th(Tnorm)} + (K_{T1} + K_{t1l} / L_{eff} + K_{T2}V_{bseff})(T / T_{norm} - 1)$$

$$\mu_{o(T)} = \mu_{o(Tnorm)}\left(\frac{T}{T_{norm}}\right)^{\mu_{te}}$$

$$v_{sat(T)} = v_{sat(Tnorm)} - A_T(T / T_{norm} - 1)$$

$$R_{dsw(T)} = R_{dsw(T_{norm})} + \mathrm{P}_{rt}\left(\frac{T}{T_{norm}} - 1\right)$$

$$U_{a(T)} = U_{a(Tnorm)} + U_{a1}(T / T_{norm} - 1)$$

$$U_{b(T)} = U_{b(Tnorm)} + U_{b1}(T / T_{norm} - 1)$$

$$U_{c(T)} = U_{c(Tnorm)} + U_{c1}(T / T_{norm} - 1)$$

B.2 Capacitance Model Equations

B.2.1 Dimension Dependence

$$\mathrm{L}_{\mathrm{active}} = \mathrm{L}_{\mathrm{drawn}} - 2\delta\mathrm{L}_{\mathrm{eff}}$$

$$\mathrm{W}_{\mathrm{active}} = \mathrm{W}_{\mathrm{drawn}} - 2\delta\mathrm{W}_{\mathrm{eff}}$$

$$\delta L_{eff} = DLC + \frac{Llc}{L^{L\ln}} + \frac{Lwc}{W^{Lwn}} + \frac{Lwlc}{L^{L\ln} W^{Lwn}}$$

$$\delta W_{eff} = DWC + \frac{Wlc}{L^{W\ln}} + \frac{Wwc}{W^{Wwn}} + \frac{Wwlc}{L^{W\ln} W^{Wwn}}$$

B.2.2 Overlap Capacitance

B.2.2.1 Source Overlap Capacitance

(1) for capMod = 0

$$\frac{Q_{overlap,s}}{W_{active}} = \mathrm{CGS0}V_{gs}$$

(2) for capMod = 1

If $V_{gs} < 0$

$$\frac{Q_{overlap,s}}{W_{active}} = CGS0 \cdot V_{gs} + \frac{CKAPPA \cdot CGS1}{2}\left(-1 + \sqrt{1 - \frac{4V_{gs}}{CKAPPA}}\right)$$

Else

$$\frac{Q_{overlap,s}}{W_{active}} = \left(CGS0 + CKAPPA \cdot CGS1\right) \cdot V_{gs}$$

(3) for capMod = 2

$$\frac{Q_{overlaps}}{W_{active}} = CGS0 \cdot V_{gs} + CGS1\left(V_{gs} - V_{gs,overlap} - \frac{CKAPPA}{2}\left(-1 + \sqrt{1 - \frac{4V_{gs,overlap}}{CKAPPA}}\right)\right)$$

$$V_{gs,overlap} = \frac{1}{2}\left(V_{gs} + \delta_1 - \sqrt{\left(V_{gs} + \delta_1\right)^2 + 4\delta_1}\right), \quad \delta_1 = 0.02$$

B.2.2.2 Drain Overlap Capacitance

(1) for capMod = 0

$$\frac{Q_{overlap,d}}{W_{active}} = \mathrm{CGD0}V_{gd}$$

(2) for capMod = 1

If $V_{gd} < 0$

$$\frac{Q_{overlap,d}}{W_{active}} = CGD0 \cdot V_{gs} + \frac{CKAPPA \cdot CGD1}{2}\left(-1 + \sqrt{1 - \frac{4V_{gd}}{CKAPPA}}\right)$$

Else

$$\frac{Q_{overlap,d}}{W_{active}} = (CGD0 + CKAPPA \cdot CGD1) \cdot V_{gd}$$

(3) for capMod = 2

$$\frac{Q_{overlap,d}}{W_{active}} = CGD0 \cdot V_{gd} + CGD1\left(V_{gd} - V_{gd,overlap} - \frac{CKAPPA}{2}\left(-1 + \sqrt{1 - \frac{4V_{gd,overlap}}{CKAPPA}}\right)\right)$$

$$V_{gd,overlap} = \frac{1}{2}\left(V_{gd} + \delta_1 - \sqrt{(V_{gd} + \delta_1)^2 + 4\delta_1}\right), \quad \delta_1 = 0.02$$

B.2.2.3 Gate Overlap Charge

$$\mathrm{Q_{overlap,g}} = -\left(\mathrm{Q_{overlap,s}} + \mathrm{Q_{overlap,d}}\right)$$

B.2.3 Instrinsic Charges

(1) **capMod = 0**

a. Accumulation region ($V_{gs} < V_{fbcv} + V_{bs}$)

$$Q_g = W_{active} L_{active} C_{ox} \left(V_{gs} - V_{bs} - V_{fbcv}\right)$$

$$Q_{sub} = -Q_g$$

$$Q_{inv} = 0$$

b. Subthreshold region ($V_{gs} < V_{th}$)

$$Q_{sub0} = -W_{active} L_{active} C_{ox} \cdot \frac{K_{1ox}{}^2}{2} \left(-1 + \sqrt{1 + \frac{4\left(V_{gs} - V_{fbcv} - V_{bs}\right)}{K_{1ox}{}^2}} \right)$$

$$Q_g = -Q_b$$

$$Q_{inv} = 0$$

c. Strong inversion ($V_{gs} > V_{th}$)

$$V_{dsat,cv} = \frac{V_{gs} - V_{th}}{A_{bulk}'}$$

$$A_{bulk}' = A_{bulk0}\left(1 + \left(\frac{CLC}{Leff}\right)^{CLE}\right)$$

$$A_{bulk0} = \left(1 + \frac{K_{1ox}}{2\sqrt{\Phi_s - V_{bseff}}}\left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}} + \frac{B_0}{W_{eff}' + B_1}\right)\right)\cdot\frac{1}{1 + KetaV_{bseff}}$$

$$V_{th} = V_{fbcv} + \Phi_s + K_{1ox}\sqrt{\Phi_s - V_{bseff}}$$

(i) 50/50 Charge partition

If $V_{ds} < V_{dsat}$

$$Q_g = C_{ox} W_{active} L_{active}\left(V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}' V_{ds}^{\,2}}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2}\right)}\right)$$

$$Q_{inv} = -W_{active} L_{active} C_{ox} [V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2} + \frac{A_{bulk}'^2 V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_b = W_{active} L_{active} C_{ox} [V_{fb} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1 - A_{bulk}')A_{bulk}' V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_s = Q_d = 0.5 Q_{inv} = -W_{active} L_{active} C_{ox} [V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2} + \frac{A_{bulk}'^2 V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

otherwise

$$Q_g = W_{active} L_{active} C_{ox} (V_{gs} - V_{fb} - \Phi_s - \frac{V_{dsat}}{3})$$

$$Q_s = Q_d = -\frac{1}{3} W_{active} L_{active} C_{ox} (V_{gs} - V_{th})$$

$$Q_b = -W_{active} L_{active} C_{ox} (V_{fb} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3})$$

(ii) 40/60 channel-charge Partition

if ($V_{ds} < V_{dsat}$)

$$Q_g = C_{ox} W_{active} L_{active} [V_{gs} - V_{fb} - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}' V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2})}]$$

$$Q_{inv} = -W_{active} L_{active} C_{ox} [V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2} + \frac{A_{bulk}'^2 V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_b = W_{active} L_{active} C_{ox} [V_{fb} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1 - A_{bulk}')A_{bulk}' V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_d = -W_{active} L_{active} C_{ox}$$

$$\left[\frac{V_{gs} - V_{th}}{2} - \frac{A_{bulk}'}{2} V_{ds} + \frac{A_{bulk}' V_{ds} [\frac{(V_{gs} - V_{th})^2}{6} - \frac{A_{bulk}' V_{ds}(V_{gs} - V_{th})}{8} + \frac{(A_{bulk}' V_{ds})^2}{40}}{(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})^2} \right]$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

otherwise

$$Q_g = W_{active} L_{active} C_{ox} (V_{gs} - V_{fb} - \Phi_s - \frac{V_{dsat}}{3})$$

$$Q_d = -\frac{4}{15} W_{active} L_{active} C_{ox} (V_{gs} - V_{th})$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

$$Q_b = -W_{active} L_{active} C_{ox} (V_{fb} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3})$$

(iii) 0/100 Channel-charge Partition

if $V_{ds} < V_{dsat}$

$$Q_g = C_{ox} W_{active} L_{active} [V_{gs} - V_{fb} - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}' V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2})}]$$

$$Q_{inv} = -W_{active} L_{active} C_{ox} [V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2} + \frac{A_{bulk}'^2 V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_b = W_{active} L_{active} C_{ox} [V_{fb} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1 - A_{bulk}')A_{bulk}' V_{ds}^2}{12(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})}]$$

$$Q_d = -W_{active} L_{active} C_{ox} \left[\frac{V_{gs} - V_{th}}{2} + \frac{A_{bulk}'}{4} V_{ds} - \frac{(A_{bulk}' V_{ds})^2}{24(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds})} \right]$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

otherwise

$$Q_g = W_{active} L_{active} C_{ox}(V_{gs} - V_{fb} - \Phi_s - \frac{V_{dsat}}{3})$$

$$Q_b = -W_{active} L_{active} C_{ox}(V_{fb} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3})$$

$$Q_d = 0$$

$$Qs = -(Q_g + Q_b)$$

(2) **capMod = 1**

The flat-band voltage V_{fb} is calculated from

$$V_{fb} = V_{th} - \Phi_s - K_{1ox}\sqrt{\Phi_s - V_{bseff}}$$

where the bias dependences of V_{th} given in Section B.1.1 are not considered in calculating V_{fb} for capMod = 1.

if ($V_{gs} < V_{fb} + V_{bs} + V_{gsteffcv}$)

$$Q_{g1} = -W_{active} L_{active} C_{ox} \left(V_{gs} - Vfb - V_{bs} - V_{gsteffcv} \right)$$

else

$$Q_{g1} = W_{active} L_{active} C_{ox} \cdot \frac{K_{1ox}{}^2}{2} \left(-1 + \sqrt{1 + \frac{4\left(V_{gs} - V_{fb} - V_{gsteff,CV} - V_{bseff}\right)}{K_{1ox}{}^2}} \right)$$

$$Q_{b1} = -Q_{g1}$$

$$V_{dsat,cv} = \frac{V_{gsteffcv}}{A_{bulk}'}$$

$$\mathrm{A}_{\mathrm{bulk}}' = \mathrm{A}_{\mathrm{bulk0}} \left(1 + \left(\frac{CLC}{\mathrm{L}_{\mathrm{eff}}} \right)^{CLE} \right)$$

$$A_{bulk0} = \left(1 + \frac{K_{1ox}}{2\sqrt{\Phi_s - V_{bseff}}} \left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}} + \frac{B_0}{W_{eff}' + B_1} \right) \right) \cdot \frac{1}{1 + KetaV_{bseff}}$$

$$V_{gsteff,cv} = noff \cdot nv_t \ln\left(1 + \exp\left(\frac{V_{gs} - V_{th} - voffcv}{noff \cdot nv_t}\right)\right)$$

if (V_{ds} <=V_{dsat})

$$Q_g = Q_{g1} + W_{active} L_{active} C_{ox}\left(V_{gsteff\,cv} - \frac{V_{ds}}{2} + \frac{A_{bulk}' V_{ds}^2}{12\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{ds}\right)}\right)$$

$$Q_b = Q_{b1} + W_{active} L_{active} C_{ox}\left(\frac{1 - A_{bulk}'}{2} V_{ds} - \frac{(1 - A_{bulk}') A_{bulk}' V_{ds}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{ds}\right)}\right)$$

(i) 50/50 Channel-charge Partition

$$Q_s = Q_d = -\frac{W_{active} L_{active} C_{ox}}{2}\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{ds} + \frac{A_{bulk}'^2 V_{ds}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{ds}\right)}\right)$$

(ii) 40/60 Channel-charge partition

$$Q_s = -\frac{W_{active}L_{active}C_{ox}}{2\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2}V_{ds}\right)^2}$$

$$\left(V_{gsteffcv}{}^3 - \frac{4}{3}V_{gstefcvf}{}^2\left(A_{bulk}'V_{ds}\right) + \frac{2}{3}V_{gsteffcv}\left(A_{bulk}'V_{ds}\right)^2 - \frac{2}{15}\left(A_{bulk}'V_{ds}\right)^3\right)$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

(iii) 0/100 Channel-charge Partition

$$Q_s = -W_{active}L_{active}C_{ox}\left(\frac{V_{gstefcv}}{2} + \frac{A_{bulk}'V_{ds}}{4} - \frac{\left(A_{bulk}'V_{ds}\right)^2}{24\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right)$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

if ($V_{ds} > V_{dsat}$)

$$Q_g = Q_{g1} + W_{active}L_{active}C_{ox}\left(V_{gsteff\,cv} - \frac{V_{dsat}}{3}\right)$$

$$Q_b = Q_{b1} - W_{active}L_{active}C_{ox}\frac{\left(V_{gsteffcv} - V_{dsat}\right)}{3}$$

(i) 50/50 Channel-charge Partition

$$Q_s = Q_d = -\frac{W_{active} L_{active} C_{ox}}{3} V_{gsteff\,cv}$$

(ii) 40/60 Channel-charge Partition

$$Q_s = -\frac{2W_{active} L_{active} C_{ox}}{5} V_{gsteffcv}$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

(iii) 0/100 Channel-charge Partition

$$Q_s = -W_{active} L_{active} C_{ox} \frac{2V_{gstefcv}}{3}$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

(3) **capMod = 2**

The flat-band voltage V_{fb} is calculated from

$$vfb = V_{th} - \Phi_s - K_{1ox} \sqrt{\Phi_s - V_{bseff}}$$

where the bias dependences of V_{th} given in Section B.1.1 are not considered in calculating V_{fb} for capMod = 2.

$$\mathrm{Q_g} = -\left(\mathrm{Q_{inv}} + \mathrm{Q_{acc}} + \mathrm{Q_{sub0}} + \delta\mathrm{Q_{sub}}\right)$$

$$\mathrm{Q_b} = \mathrm{Q_{acc}} + \mathrm{Q_{sub0}} + \delta\mathrm{Q_{sub}}$$

$$\mathrm{Q_{inv}} = \mathrm{Q_s} + \mathrm{Q_d}$$

$$V_{FBeff} = vfb - 0.5\left\{V_3 + \sqrt{V_3^{\,2} + 4\delta_3 vfb}\right\} \quad where \quad V_3 = vfb - V_{gb} - \delta_3; \quad \delta_3 = 0.02$$

$$Q_{acc} = -W_{active} L_{active} C_{ox}\left(V_{FBeff} - vfb\right)$$

$$Q_{sub0} = -W_{active} L_{active} C_{ox} \cdot \frac{K_{1ox}{}^2}{2}\left(-1 + \sqrt{1 + \frac{4\left(V_{gs} - V_{FBeff} - V_{gsteff,CV} - V_{bseff}\right)}{K_{1ox}{}^2}}\right)$$

$$V_{dsat,cv} = \frac{V_{gsteff,cv}}{A_{bulk}'}$$

$$A_{bulk}' = A_{bulk0}\left(1 + \left(\frac{\mathrm{CLC}}{L_{active}}\right)^{\mathrm{CLE}}\right)$$

$$A_{bulk0} = \left(1 + \frac{K_{1ox}}{2\sqrt{\Phi_s - V_{bseff}}}\left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_J X_{dep}}} + \frac{B_0}{W_{eff}' + B_1}\right)\right) \cdot \frac{1}{1 + KetaV_{bseff}}$$

$$V_{gsteff,cv} = noff \cdot nv_t \ln\left(1 + \exp\left(\frac{V_{gs} - V_{th} - voffcv}{noff \cdot nv_t}\right)\right)$$

$$V_{cveff} = V_{dsat,cv} - 0.5\left\{V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,cv}}\right\} \quad where \quad V_4 = V_{dsat,cv} - V_{ds} - \delta_4; \quad \delta_4 = 0.02$$

$$Q_{inv} = -W_{active} L_{active} C_{ox}\left(\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{cveff}\right) + \frac{A_{bulk}'^2 V_{cveff}^2}{12\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{cveff}\right)}\right)$$

$$\delta Q_{sub} = W_{active} L_{active} C_{ox}\left(\frac{1 - A_{bulk}'}{2} V_{cveff} - \frac{(1 - A_{bulk}')A_{bulk}' V_{cveff}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{cveff}\right)}\right)$$

B.2.3.1 50/50 Charge partition

$$Q_s = Q_d = 0.5 Q_{inv} = -\frac{W_{active} L_{active} C_{ox}}{2} \left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}}{2} V_{cveff} \right)} \right)$$

B.2.3.2 40/60 Channel-charge Partition

$$Q_s = -\frac{W_{active} L_{active} C_{ox}}{2\left(V_{gsteff\,cv} - \frac{A_{bulk}'}{2} V_{cveff} \right)^2} \left(V_{gsteffcv}^{\ 3} - \frac{4}{3} V_{gsteffc}^{\ 2} \left(A_{bulk}' V_{cveff} \right) + \frac{2}{3} V_{gsteff} \left(A_{bulk}' V_{cveff} \right)^2 - \frac{2}{15} \left(A_{bulk}' V_{cveff} \right)^3 \right)$$

$$Q_d = -\frac{W_{active} L_{active} C_{ox}}{2\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{cveff} \right)^2} \left(V_{gsteffcv}^{\ 3} - \frac{5}{3} V_{gsteffc}^{\ 2} \left(A_{bulk}' V_{cveff} \right) + V_{gsteff\,cv} \left(A_{bulk}' V_{cveff} \right)^2 - \frac{1}{5} \left(A_{bulk}' V_{cveff} \right)^3 \right)$$

B.2.3.3 0/100 Charge Partition

$$Q_s = -W_{active} L_{active} C_{ox} \left(\frac{V_{gsteffcv}}{2} + \frac{A_{bulk}' V_{cveff}}{4} - \frac{\left(A_{bulk}' V_{cveff} \right)^2}{24\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{cveff} \right)} \right)$$

$$Q_d = -W_{active} L_{active} C_{ox} \left(\frac{V_{gsteffcv}}{2} - \frac{3A_{bulk}' V_{cveff}}{4} + \frac{\left(A_{bulk}' V_{cveff} \right)^2}{8\left(V_{gsteffcv} - \frac{A_{bulk}'}{2} V_{cveff} \right)} \right)$$

(3) **capMod = 3 (Charge-Thickness Model)**

capMod = 3 also uses the bias-independent V_{th} to calculate V_{fb} as in capMod = 1 and 2.

$$vfb = V_{th} - \Phi_s - K_{1ox}\sqrt{\Phi_s - V_{bseff}}$$

For the finite charge thickness (X_{DC}) formulations, refer to Chapter 4.

$$Q_{acc} = WLC_{oxeff} \cdot V_{gbacc}$$

$$V_{gbacc} = \frac{1}{2} \cdot \left[V_0 + \sqrt{V_0^2 + 4\delta_3 V_{fb}}\right]$$

$$V_0 = V_{fb} + V_{bseff} - V_{gs} - \delta_3$$

$$V_{FBeff} = vfb - 0.5\left\{V_3 + \sqrt{V_3^2 + 4\delta_3 vfb}\right\} \quad where \quad V_3 = vfb - V_{gb} - \delta_3; \quad \delta_3 = 0.02$$

$$C_{oxeff} = \frac{C_{ox} C_{cen}}{C_{ox} + C_{cen}}$$

$$C_{cen} = \varepsilon_{si} / X_{DC}$$

$$\Phi_\delta = \Phi_s - 2\Phi_B = v_t \ln\left(\frac{V_{gsteffCV} \cdot (V_{gsteffCV} + 2K_{1ox}\sqrt{2\Phi_B}}{moin \cdot K_{1ox}{}^2 v_t}\right)$$

$$Q_{sub0} = -WLC_{oxeff} \cdot \frac{K_{1ox}{}^2}{2} \cdot \left[-1 + \sqrt{1 + \frac{4\left(V_{gs} - V_{FBeff} - V_{bseffs} - V_{gsteff,cv}\right)}{K_{1ox}{}^2}}\right]$$

$$V_{cveff} = V_{dsat} - \frac{1}{2} \cdot \left(V_1 + \sqrt{V_1{}^2 + 4\delta_3 V_{dsat}}\right)$$

$$V_1 = V_{dsat} - V_{ds} - \delta_3$$

$$V_{dsat} = \frac{V_{gsteff,cv} - \varphi_\delta}{A_{bulk}'}$$

$$Q_{inv} = -WLC_{oxeff} \cdot \left[V_{gsteff,cv} - \varphi_\delta - \frac{1}{2} A_{bulk}' V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{12 \cdot \left(V_{gsteff,cv} - \varphi_\delta - A_{bulk}' V_{cveff}/2\right)}\right]$$

$$\delta Q_{sub} = WLC_{oxeff} \cdot \left[\frac{1 - A_{bulk}'}{2} V_{cveff} - \frac{(1 - A_{bulk}') \cdot A_{bulk}' V_{cveff}^2}{12 \cdot \left(V_{gsteff,cv} - \varphi_\delta - A_{bulk}' V_{cveff} / 2 \right)} \right]$$

(i) 50/50 Charge Partition

$$Q_S = Q_D = \frac{1}{2} Q_{inv} = -\frac{WLC_{oxeff}}{2} \left[V_{gsteffcv} - \varphi_\delta - \frac{1}{2} A_{bulk}' V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{12 \cdot \left(V_{gsteffcv} - \varphi_\delta - A_{bulk}' V_{cveff} / 2 \right)} \right]$$

(ii) 40/60 Charge Partition

$$Q_S = -\frac{WLC_{oxeff}}{2 \left(V_{gsteffcv} - \varphi_\delta - A_{bulk}' V_{cveff} / 2 \right)^2} \left[(V_{gsteffcv} - \varphi_\delta)^3 - \frac{4}{3} (V_{gsteffcv} - \varphi_\delta)^2 A_{bulk}' V_{cveff} + \frac{2}{3} (V_{gsteffcv} - \varphi_\delta)(A_{bulk}' V_{cveff})^2 - \frac{2}{15} (A_{bulk}' V_{cveff})^3 \right]$$

$$Q_D = -\frac{WLC_{oxeff}}{2 \left(V_{gsteffcv} - \varphi_\delta - A_{bulk}' V_{cveff} / 2 \right)^2} \left[(V_{gsteffcv} - \varphi_\delta)^3 - \frac{5}{3} (V_{gsteffcv} - \varphi_\delta)^2 A_{bulk}' V_{cveff} + (V_{gsteffcv} - \varphi_\delta)(A_{bulk}' V_{cveff})^2 - \frac{1}{5} (A_{bulk}' V_{cveff})^3 \right]$$

(iii) 0/100 Charge Partition

$$Q_S = -\frac{WLC_{oxeff}}{2} \cdot \left[V_{gsteff,cv} - \varphi_\delta + \frac{1}{2} A_{bulk}' V_{cveff} - \frac{A_{bulk}'^2 V_{cveff}^2}{12 \cdot \left(V_{gsteff,cv} - \varphi_\delta - A_{bulk}' V_{cveff} / 2 \right)} \right]$$

$$Q_D = -\frac{WLC_{oxeff}}{2} \cdot \left[V_{gsteff,cv} - \varphi_\delta - \frac{3}{2} A_{bulk}' V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{4 \cdot \left(V_{gsteff,cv} - \varphi_\delta - A_{bulk}' V_{dveff} / 2 \right)} \right]$$