Agilent Technologies

Advanced Design System 2011.01

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Nonlinear Devices

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Devices and Models, BJT

- *AgilentHBT_NPN_Th (Agilent Heterojunction Bipolar Transistor with Thermal Node, NPN)* (ccnld)
- *AgilentHBT Model (Agilent Heterojunction Bipolar Transistor Model)* (ccnld)
- *BJT4_NPN, BJT4_PNP (Bipolar Junction Transistors with Substrate Terminal, NPN, PNP)* (ccnld)
- *BJT Model (Bipolar Transistor Model)* (ccnld)
- *BJT NPN, BJT PNP (Bipolar Junction Transistors NPN, PNP)* (ccnld)
- *EE BJT2 Model (EEsof Bipolar Transistor Model)* (ccnld)
- *HICUM0 1 12* (ccnld)
- *HICUM0 1 12 model* (ccnld)
- *HICUM0_1_2 (HICUM Level 0, Version 1.2)* (ccnld)
- *HICUM0_1_2 model (HICUM Level 0, Version 1.2)* (ccnld)
- *HICUM0 (HICUM Level 0 Model Instance)* (ccnld)
- *HICUM0 model (HICUM Level 0 Model)* (ccnld)
- *HICUM2 21 (HICUM Bipolar Junction Transistor Version 2.21)* (ccnld)
- *HICUM2 21 model (HICUM Bipolar Junction Transistor Version 2.21 Model)* (ccnld)
- *HICUM2 22 (HICUM Bipolar Junction Transistor Version 2.22)* (ccnld)
- *HICUM2 22 model (HICUM Bipolar Junction Transistor Version 2.22 Model)* (ccnld)
- *HICUM2_23 (HICUM Bipolar Junction Transistor Version 2.23)* (ccnld)
- *HICUM2_23 model (HICUM Bipolar Junction Transistor Version 2.23)* (ccnld)
- *HICUM Model (Bipolar Transistor Model)* (ccnld)
- *HICUM NPN, HICUM PNP (HICUM Bipolar Transistors, NPN, PNP)* (ccnld)
- *M504 BJT4 NPN, M504 BJT4 PNP (Mextram 504 Nonlinear Bipolar Transistors with Substrate Terminal, NPN, PNP)* (ccnld)
- *M504 BJT5 NPN, M504 BJT5 PNP (Mextram 504 Nonlinear Bipolar Transistors with Substrate and Thermal Terminals, NPN, PNP)* (ccnld)
- *M504 BJT NPN, M504 BJT PNP (Mextram 504 Nonlinear Bipolar Transistors)* (ccnld)
- *MEXTRAM 504 Model (MEXTRAM 504 Model)* (ccnld)
- *MEXTRAM Model (MEXTRAM Model)* (ccnld)
- *STBJT Model (ST Bipolar Transistor Model)* (ccnld)
- *VBIC5 NPN, VBIC5 PNP (VBIC Nonlinear Bipolar Transistors with Thermal Terminal, NPN, PNP)* (ccnld)
- *VBIC Model (VBIC Model)* (ccnld)
- *VBIC NPN, VBIC PNP (VBIC Nonlinear Bipolar Transistors, NPN, PNP)* (ccnld)

Bin Model

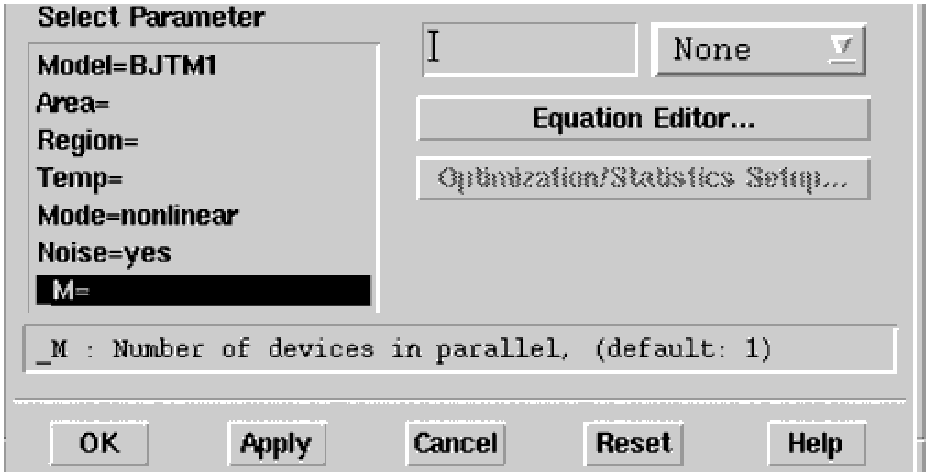
The BinModel in the BJT library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to *BinModel (Bin Model for Automatic Model Selection)* (ccsim).

Multiplicity Parameter _M

The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M*, the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)

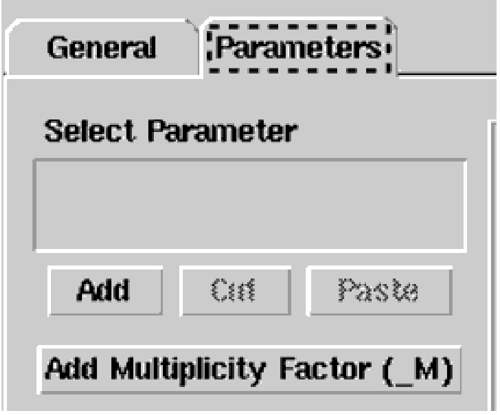


Select Parameter

Model=BJTM1
Area=
Region=
Temp=
Mode=nonlinear
Noise=yes
_M=

_M : Number of devices in parallel, (default: 1)

For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor_M**.



Netlist Syntax

Models for the ADS circuit simulator have the following syntax:

```
model modelname modeltype [param=value]*
```

where `model` is a keyword, `modelname` is the user-defined name for the model and `modeltype` is one of the predefined model types (e.g., Diode, BJT, MOSFET). After these three required fields comes zero or more `param=value` pairs. `param` is a model keyword and value is its user-assigned value. There is no required order for the `param=value` pairs. Model keywords that are not specified take on their default values. Refer to documentation for each model type to see the list of model parameters, their meanings and default values.

The model statement must be on a single line. Use the backslash "\"as a line continuation character. The instance and model parameter names are case sensitive; most, (not all) model parameters have their first character capitalized and the rest are lower case. Scale factors (e.g., p=10^{-12}, n=10^{-9}, u=10^{-6}, m=10^{-3}, k=10^{+3}, M=10^{+6}) can be used with numbers for numeric values. For more information about the circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

A netlist translator is available for translating models and subcircuits from Pspice, Hspice, and Spectre syntax to the form used by the ADS Circuit Simulator. Refer to *Netlist Translator for SPICE and Spectre* (netlist) for more information.

Parameter Aliases

For compatibility with other simulators, some models accept two or more different keywords for the same parameter. For example, the Diode model accepts both model keywords Is and Js for the saturation current. In the documentation, the parameter Name column lists the aliases in parentheses after the main parameter name. The main parameter name is the one that appears in the ADS dialog box for the model.

Tnom

All nonlinear device models have a parameter that specifies the temperature at which the model parameters were extracted. Normally called Tnom, some models may use Tref, Tr, or Tmeas. The default value for Tnom is specified on the Options item in the Tnom field. If Options.Tnom is not specified it defaults to 25°C. This is true for all nonlinear devices.

It is strongly suggested that the user explicitly set Tnom in each model and not depend on its default value. First, this provides a self-documenting model; other users of the device will not have to guess at what Tnom should be. Second, different users of the same model would get different results for the same circuit if they simulate with different values of Options.Tnom.

Temp and Trise

The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp, which defaults to 25°C.

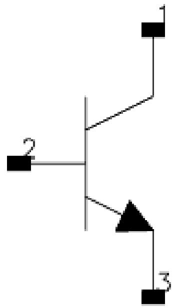
For compatibility with other simulators, many of the nonlinear devices allow the user to specify Trise for each device instance, which specifies actual device temperature as an increase from ambient. It defaults to zero. The Trise instance value is used only if the Temp instance value is not specified. If the user does not specify Trise on the instance, a default value for Trise can also be specified in the model. It defaults to zero. The following shows the logic of how the instance temperature is calculated if it is not explicitly specified.

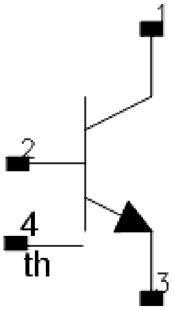
```
if Instance.Temp is not specified
 if instance.Trise is not specified
   Instance.Temp = Options.Temp + Model.Trise
 else
   Instance.Temp = Options.Temp + Instance.Trise
```

AgilentHBT_NPN (Agilent Heterojunction Bipolar Transistor, NPN)

AgilentHBT_NPN_Th (Agilent Heterojunction Bipolar Transistor with Thermal Node, NPN)

Symbols





Parameters

Name	Description	Units	Default
Model	Model instance name	None	HBTM1
Area	Scaling factor for resistances, currents, and capacitances	None	1.0
Temp	Device operating temperature	°C	25
Trise	Temperature rise over ambient	°C	0
Mode	Simulation mode: nonlinear or linear (refer to note 3)	None	Nonlinear
Noise	Noise generation option: yes, no	None	yes
SelfTmod	Self-Heating Model, 0=Off, 1=On	None	0
_M	Number of devices in parallel	None	1

Notes/Equations

1. The Area factor scales the device capacitances, currents, and resistances. The parasitic capacitances (*Cpbe*, *Cpbc*, *Cpce*) and inductances, (*Lpb*, *Lpc*, *Lpe*) are not scaled by this factor. In addition, Rth1, Cth1, Rth2, and Cth2 are not scaled with the Area factor. For more information on area scaling dependence, refer to the section *Area Scaling Equations* (ccnld) of the AgilentHBT_Model component documentation.
2. The Temp parameter specifies the physical (operating) temperature of the device; if

different from the temperature at which the model parameters are extracted (specified by Tnom in the model), certain model parameters are scaled such that the device is simulated at its operating temperature. For more information on the temperature scaling relationships, refer to the section *Temperature Scaling Equations* (ccnld) of the AgilentHBT_Model component documentation.

3. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with *Mode=linear* are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
4. DC operating point parameters that can be sent to the dataset are listed in the following table.

DC Operating Point Parameters

Name	**Description**	**Units**
Ic †	Total current flowing into the collector terminal	amperes
Ib †	Total current flowing into the base terminal	amperes
Ie †	Total current flowing into the emitter terminal	amperes
Power †	Total power dissipation	watts
Temp †	Intrinsic device /(junction/) temperature	celsius
Vbe †	Voltage across the base and emitter terminals	volts
Vbc †	Voltage across the base and collector terminals	volts
Vce †	Voltage across the collector and emitter terminals	volts
BetaDC †	$\frac{\mathrm{Ic}}{\mathrm{Ib}}$: DC current gain	
Gm_ext †	$\frac{\mathrm{Gm\_int}}{1+\mathrm{Gm\_int}\times\left(\mathrm{Re}+\frac{\mathrm{Re+Rbi+Rbx}}{\mathrm{BetaDC}}\right)}$:Estimated extrinsic transconductance in CE-configuration	siemens
Gm_int †	$\left.\frac{\partial I_{CE}}{\partial I_{BEi}}\right\vert_{V_{cei}}$: Intrinsic transconductance	siemens
Ft_ext †	$\frac{1}{2\pi\times(\mathrm{Tau\_ext})}$: Estimated extrinsic fT	hertz
Fmax †	$\sqrt{\frac{f_{t\_ext}}{8\pi\vert R\,Ceff\vert}}$ where !ccnld-3-03-006.gif!This estimate of Fmax /(from unilateral gain/) based on Vaidyanathan and Pulfrey	hertz
Tau_ss †	$\frac{\mathrm{Cm}}{\mathrm{Gm\_int}}$: Small-signal delay. This modifies the overall intrinsic transconductance to gm = Gm_int × exp/(- <i>j</i> ω × Tau_ss/)	seconds
Rpi †	$\frac{1}{\mathrm{Gbei}+\mathrm{Gbex}}$: Total base-emitter resistance for hybrid-п model	ohms
Rmu †	$\frac{1}{\mathrm{Gbci}+\mathrm{Gbcx}}$: Total base-collector resistance for hybrid-п model	ohms
Ro †		

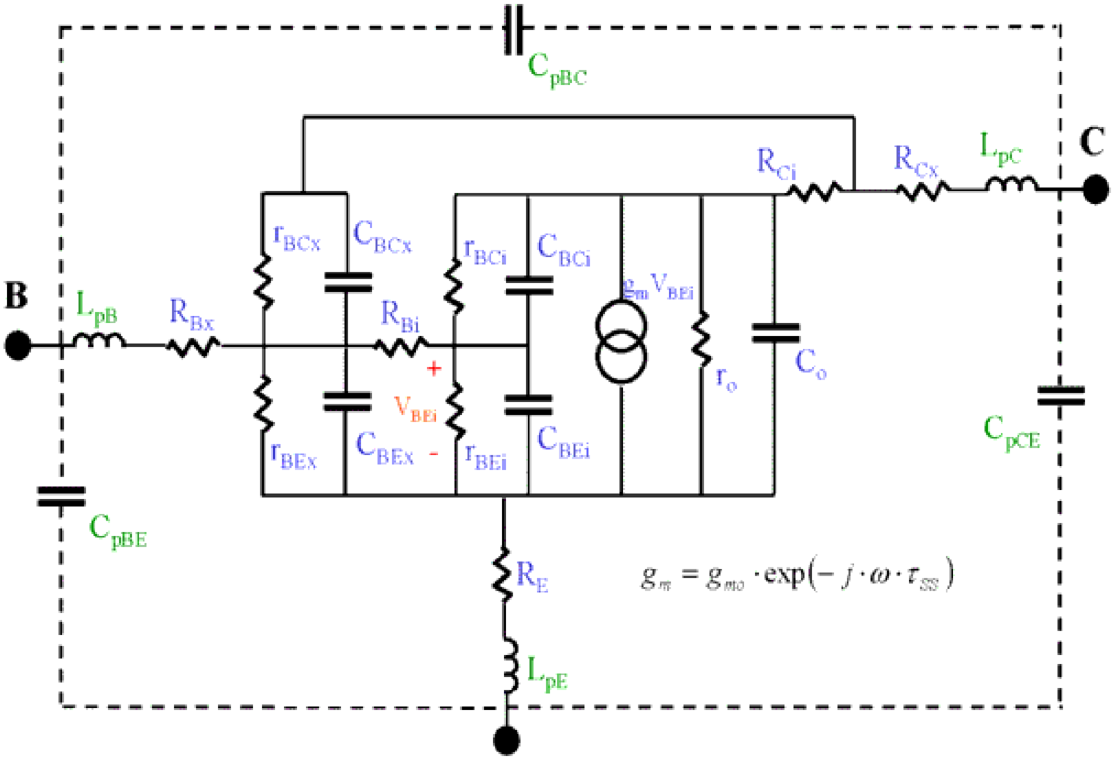
Ro †	$\frac{1}{\left.\frac{\partial I_{CE}}{\partial V_{CEi}}\right\vert_{V_{BEi}}}$: Output resistance	ohms
Re †	Area and temperature scaled emitter resistance	ohms
Rbi †	Area and temperature scaled intrinsic base resistance	ohms
Rbx †	Area and temperature scaled extrinsic base resistance	ohms
Rci †	Area and temperature scaled intrinsic collector resistance	ohms
Rcx †	Area and temperature scaled extrinsic collector resistance	ohms
Cpi †	Cbei + Cbex: Total base-emitter capacitance for hybrid-π model	farads
Cmu †	Cbci + Cbcx: Total base-collector capacitance for hybrid-π model	farads
Co †	$\left.\frac{\partial Q_{CC}}{\partial V_{CEi}}\right\vert_{V_{BEi}} + \left(\left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right\vert_{V_{BEi}}\right)$: Collector-emitter \/(output/) capacitance	farads
Gbei	$\frac{dI_{BEi}}{dV_{BEi}}$: Intrinsic base-emitter conductance	siemens
Gbci	$\frac{dI_{BCi}}{dV_{BCi}}$: Intrinsic base-collector conductance	siemens
Gbex	$\frac{dI_{BEx}}{dV_{BEx}}$: Extrinsic base-emitter conductance	siemens
Gbcx	$\frac{dI_{BCx}}{dV_{BCx}}$: Extrinsic base-collector conductance	siemens
Cbei	$\left.\frac{\partial Q_{BB}}{\partial V_{BEi}}\right\vert_{V_{CEi}} + \left(\left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right\vert_{V_{BEi}}\right)$: Total intrinsic base-emitter capacitance /(diffusion _ depletion/)	farads
Cbci	$-\left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right\vert_{V_{BEi}}$: Total intrinsic base-collector capacitance /(diffusion _ depletion/)	farads
Cbex	$\frac{dQ_{BEx}}{dV_{BEx}}$: Extrinsic base-emitter depletion capacitance	farads
Cbcx	$\frac{dQ_{BCx}}{dV_{BCx}}$: Extrinsic base-collector depletion capacitance	farads
Cbei_depl	$\frac{dQ_{BEid}}{dV_{BEi}}$: Intrinsic base-emitter depletion capacitance	farads
Cbci_depl	$\frac{dQ_{BCid}}{dV_{BCi}}$: Intrinsic base-collector depletion capacitance	farads
Cm	$-\left.\frac{\partial Q_{CC}}{\partial V_{BEi}}\right\vert_{V_{CEi}} + \left(\left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right\vert_{V_{BEi}}\right)$: Transcapacitance which is used to calculate the small-signal delay Tau_ss	farads
Vbei	Voltage across the intrinsic base and intrinsic emitter	volts
Vbci	Voltage across the intrinsic base and intrinsic collector	volts
Vcei	Voltage across the intrinsic collector and intrinsic emitter	volts
BetaAC	Gm_int × Rpi: gm_int/gBE	

Tau_int	!ccnld-3-03-023.gif!Intrinsic delay in forward active mode	seconds
Tau_ext	/(/(Tau_int + /(Re + Rci + Rcx/) × /(Cbci_depl + Cbcx_depl/) + /(Cbci_depl + Cbcx + Cbei_depl + Cbex/) /) / Gm_int. Estimated extrinsic /(total/) emitter-collector delay in forward-active mode.	seconds
Ft_int	$\frac{1}{2\pi \times (\text{Tau\_int})}$: Estimated intrinsic fT	hertz
Teff	Effective \/(limited/) device temperature used in model equations. Approximately within [-200,500].	celsius
Rth1	Temperature scaled thermal resistance #1	Kelvin/watt
Cth1	Thermal capacitance #1	sec watt/Kelvin
Rth2	Temperature scaled thermal resistance #2	Kelvin/watt
Cth2	Thermal capacitance #2	sec watt/Kelvin
Gmdc_int	$\frac{DI_{CE}}{DV_{BEi}}$ Intrinsic DC transconductance. Includes modulation of temperature with bias. Gmdc_int=Gm_int+Gth Dthi	siemens
Gmdc_ext	$\frac{DI_{CE}}{DV_{BEx}}$ Extrinsic DC transconductance. Includes modulation of temperature with bias. Gmdc_ext=Gm_ext+Gth Dthx	siemens
Godc_int	$\frac{DI_{CE}}{DV_{CEx}}$ Intrinsic DC output conductance. Includes modulation of temperature with bias.	siemens
Gth	$\left.\frac{\partial I_{CE}}{\partial T}\right\vert_{V_{BE}, V_{CE}}$ Rate of change in intrinsic collector current with temperature	amp/Kelvin
Dthi	$\left.\frac{\partial T}{\partial V_{BEi}}\right\vert_{V_{CEi}}$ Rate of change in temperature with intrinsic base-emitter voltage	Kelvin/volt
Dthx	$\left.\frac{\partial T}{\partial V_{BEx}}\right\vert_{V_{CEx}}$ Rate of change in temperature with extrinsic base-emitter voltage	Kelvin/volt
Ibb	Total intrinsic base current.[‡]	ampere
Icc	Total intrinsic collector current.[‡]	ampere
Qbb	Total intrinsic base charge.[‡]	coulombs
Qcc	Total intrinsic collector charge.[‡]	coulombs

[†] Parameters are displayed under "Brief Device Operating Point".

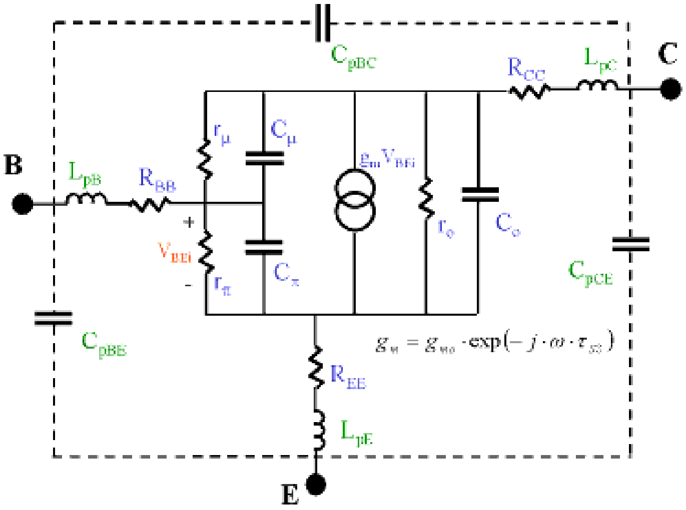
[‡] From *2-Port Network of the Large-Signal Intrinsic Model in AgilentHBT Model (Agilent Heterojunction Bipolar Transistor Model)* (ccnld).

5. The operating point parameter calculations do not account for the parasitic capacitances (*Cpbe*, *Cpbc*, *Cpce*) and inductances (*Lpb*, *Lpc*, *Lpe*).
   The DC operating point results can be used to construct an accurate small-signal representation of the large-signal topology.



6. The circuit elements of the small-signal model correspond to the DC operating point parameters as follows:
   R_E = Re
   R_{Bi} = Rbi
   R_{Bx} = Rbx
   R_{Ci} = Rci
   R_{Cx} = Rcx
   r_{BEx} = 1/Gbex
   r_{BCx} = 1/Gbcx
   C_{BEx} = Cbex
   C_{BCx} = Cbcx
   r_{BEi} = 1/Gbei
   r_{BCi} = 1/Gbci
   C_{BEi} = Cbei
   C_{BCi} = Cbci
   g_{mo} = Gm_int
   τ_{SS} = Tau_ss
   r_o = Ro
   C_o = Co
7. The DC operating point parameters can be also used to construct a standard hybrid-п

model.



R_{EE} = Re

R_{BB} = Rbi + Rbx

R_{CC} = Rci + Rcx

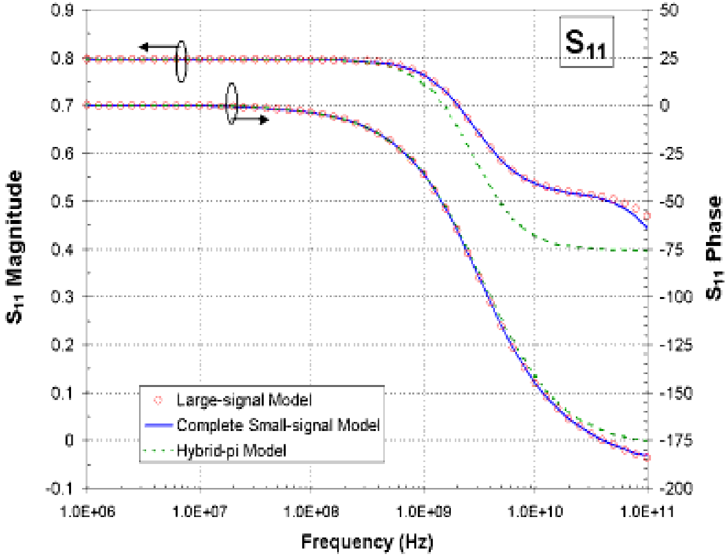
$r\pi$ = Rpi
$r\mu$ = Rmu
$C\pi$ = Cpi
$C\mu$ = Cmu
g_{mo} = Gm_int

τ_{SS} = Tau_ss

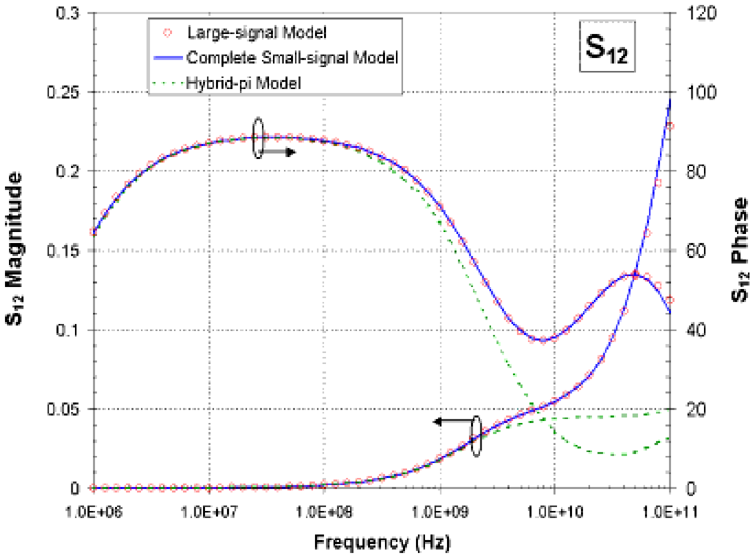
r_o = Ro

C_o = Co

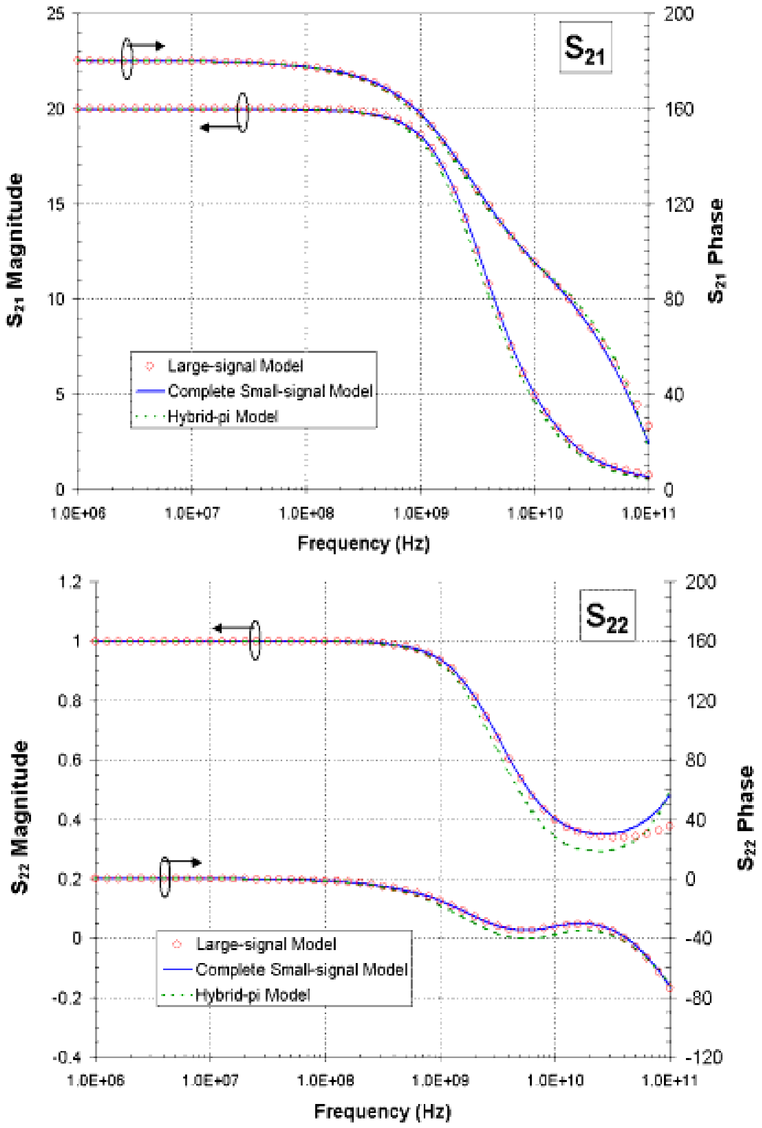
8. The following 2 illustrations show the accuracy of the two small-signal models. Note the limited accuracy of the hybrid-π model topology at high frequencies.



8.



(Default parameters of AgilentHBT_Model: VBE=1.39V and VCE=3V)

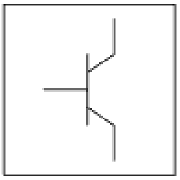


(Default parameters of AgilentHBT_Model: VBE=1.39V and VCE=3V)

9. This device has no default artwork associated with it.

AgilentHBT_Model (Agilent Heterojunction Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units

Name	Description and Comments	Units	Default
Tnom	Nominal temperature (temperature at which the room temperature parameters are extracted)	°C	25
Re	Emitter resistance	Ohm	2.0
Rci	Intrinsic collector resistance	Ohm	1.0
Rcx	Extrinsic collector resistance	Ohm	5.0
Rbi	Intrinsic base resistance	Ohm	15.0
Rbx	Extrinsic base resistance	Ohm	5.0
Is	Collector-Emitter current: Forward collector saturation current	A	1.0e-25
Nf	Collector-Emitter current: Forward collector current ideality factor	None	1.0
Isr	Collector-Emitter current: Reverse emitter saturation current	A	1.00e-15
Nr	Collector-Emitter current: Reverse emitter current ideality factor	None	2.0
Ish	Base-Emitter current: Ideal base-emitter current	A	1.0e-27
Nh	Base-Emitter current: Ideal base-emitter current ideality factor	None	1.0
Ise	Base-Emitter current: Non-ideal base-emitter current	A	1.0e-18
Ne	Base-Emitter current: Non-ideal base-emitter current ideality factor	None	2.0
Isrh	Base-Collector current: Ideal base-collector saturation current	A	1.0e-15
Nrh	Base-Collector current: Ideal base-collector current ideality factor	None	2.0
Isc	Base-Collector current: Non-ideal base-collector saturation current	A	1.0e-13
Nc	Base-Collector current: Non-ideal base-collector current ideality factor	None	2.0
Abel	Base-Emitter current: Portion of base-emitter current allocated to extrinsic region	None	0.0
Vaf	Forward Early voltage	V	500
Var	Reverse Early voltage	V	1000
Isa	Base-emitter heterojunction saturation current (BE barrier effects)	A	1.0e+10

Na	Base-emitter heterojunction ideality factor	None	1.0
Isb	Base-collector heterojunction saturation current (BC barrier effects)	A	1.0e+10
Nb	Base-collector heterojunction ideality factor	None	1.0
Ikdc1	I-V knee effect: Slope of q3 function	A	1.0
Ikdc2Inv †	I-V knee effect: Transition width of Ic	A^{-1}	infinity †
Ikdc3	I-V knee effect: I-V knee effect critical current	A	1.0
VkdcInv	I-V knee effect: Transition width of Vcb	V^{-1}	0.1
Nkdc	I-V knee effect: Maximum value of q3	None	3.0
Gkdc	I-V knee effect: Exponent of q3 factor in base current	None	0.0
Ik	High injection roll-off current	A	1.0
Cje	Base-emitter capacitance: zero-bias capacitance	F	4.0e-14
Vje	Base-emitter capacitance: built-in voltage	V	1.3
Mje	Base-emitter capacitance: grading factor	None	0.3
Cemax	Base-emitter capacitance: maximum value in forward bias	F	1.0e-13
Vpte	Base-emitter capacitance: punch-through voltage	V	1.0
Mjer	Base-emitter capacitance: grading factor beyond punchthrough	None	0.05
Abex	Base-emitter capacitance: ratio between extrinsic and total base-emitter regions	None	0.0
Cjc	Base-collector capacitance: zero-bias capacitance	F	5.0e-14
Vjc	Base-collector capacitance: built-in voltage	V	1.1
Mjc	Base-collector capacitance: grading factor	None	0.3
Ccmax	Base-collector capacitance: maximum value in forward bias	F	9.0e-14
Vptc	Base-collector capacitance: punch-through voltage	V	3.0
Mjcr	Base-collector capacitance: grading factor beyond punch-through	None	0.03
Abcx	Base-collector capacitance: Ratio between extrinsic and total base-collector regions	None	0.75
Tfb	Base delay: Intrinsic base transit time	sec	1.0e-12
Fextb	Base delay: Fraction of base delay charge allocated to B-C junction	None	0.2
Tfc0	Collector delay: Low current transit time	sec	2.0e-12
Tcmin	Collector delay: High current transit time	sec	5.0e-13
Itc	Collector delay: Midpoint in Ice between Tfc0 and Tcmin	A	0.006
Itc2	Collector delay: Width in Ic between Tfc0 and Tcmin	A	0.008
Vtc0Inv	Collector delay: Rate of change of Tfc0 with Vcb	V^{-1}	0.3
Vtr0	Collector delay: Transition width in Vcb to Vmx0	V	2.0
Vmx0	Collector delay: Maximum Vcb for Tfc0	V	2.0
VtcminInv	Collector delay: Rate of change of Tcmin with Vcb	V^{-1}	0.5
Vtrmin	Collector delay: Transition width in Vcb to Vmxmin	V	1.0
Vmxmin	Collector delay: Maximum Vbc for Tcmin	V	1.0
VtcInv	Collector delay: Rate of change of Itc with Vcb	V^{-1}	0.1
Vtc2Inv	Collector delay: Rate of change of Itc2 with Vcb	V^{-1}	0.1
Fextc	Collector delay: Fraction of collector delay charge allocated to B-C junction	None	0.8
Tkrk	Kirk effect delay: Kirk effect delay time	sec	1.00e-12
Ikrk	Kirk effect delay: Critical current for Kirk effect	A	0.025

Ikrktr	Kirk effect delay: Transition width to Ikirk=0	A	1.00e-06
Vkrk	Kirk effect delay: Rate of change of Ikrk with Vcb	V	3.0
Vkrk2Inv	Kirk effect delay: Rate of change of Tkrk with Vcb	V^{-1}	0.2
Gkrk	Kirk effect delay: Exponent of Kirk effect delay	None	4.0
Vktr	Kirk effect delay: Transition width in Vcb to Vkmx	V	1.0
Vkmx	Kirk effect delay: Maximum Vcb	V	1.0
Fexke	Fraction of Kirk effect charge allocated to the B-C junction	None	0.2
Tr	Reverse transit time	sec	1.0e-09
Cpce	Parasitic / fringing collector-emitter capacitance	F	1.0e-15
Cpbe	Parasitic / fringing base-emitter capacitance	F	1.0e-15
Cpbc	Parasitic / fringing base-collector capacitance	F	1.0e-15
Lpb	Parasitic base inductance	H	0.0
Lpc	Parasitic collector inductance	H	0.0
Lpe	Parasitic emitter inductance	H	0.0
Xrb	Temperature exponent for Rbi and Rbx	None	0.0
Xrc	Temperature exponent for Rci and Rcx	None	0.0
Xre	Temperature exponent for Re	None	0.0
Tvje	Rate of change in temperature of Vje	V/K	0.0
Tvpe	Rate of change in temperature of Vpte	V/K	0.0
Tvjc	Rate of change in temperature of Vjc	V/K	0.0
Tvpc	Rate of change in temperature of Vptc	V/K	0.0
Tnf	Rate of change in temperature of Nf	K^{-1}	0.0
Tnr	Rate of change in temperature of Nr	K^{-1}	0.0
Ege	Effective emitter band gap parameter	V	1.55
Xtis	Temperature exponent for Is	None	3.0
Xtih	Temperature exponent for Ish	None	4.0
Xtie	Temperature exponent for Ise	None	3.0
Egc	Effective collector bandgap parameter	V	1.5
Xtir	Temperature exponent for Isr	None	3.0
Xtic	Temperature exponent for Isc	None	3.0
Xtirh	Temperature exponent for Isrh	None	4.0
Xtik3	Temperature exponent for Ikdc3	None	0.0
Eaa	Temperature dependence of Isa	V	0.0
Eab	Temperature dependence of Isb	V	0.0
Xtfb	Temperature exponent for Tfb	None	0.0
Xtcmin	Temperature exponent for Tcmin	None	0.0
Xtfc0	Temperature exponent for Tfc0	None	0.0
Xitc	Temperature exponent for Itc	None	0.0
Xitc2	Temperature exponent for Itc2	None	0.0
Xtkrk	Temperature exponent for Tkrk	None	0.0
Xikrk	Temperature exponent for Ikrk	None	0.0
Xvkrk	Temperature exponent for Vkrk	None	0.0

Rth1	Thermal resistance #1	K/W	1000.0
Cth1	Thermal capacitance #1	J/K	5e-10
Xth1	Temperature exponent for Rth1	None	0.0
Rth2	Thermal resistance #2	K/W	0.0
Cth2	Thermal capacitance #2	J/K	0.0
Xth2	Temperature exponent for Rth2	None	0.0
Kf	Flicker (1/f) noise coefficient	None	0.0
Af	Flicker (1/f) noise exponent	None	1.0
Ffe	Flicker (1/f) noise frequency exponent	None	1.0
Kb	Burst (popcorn) noise exponent	None	0.0
Ab	Burst (popcorn) noise corner frequency	None	1.0
Fb	Burst noise corner frequency	Hz	1
Imax	Explosion current	A	10
wBvbe	Base-emitter reverse voltage (warning)	V	0.0
wBvbc	Base-collector reverse voltage (warning)	V	0.0
wVbcfwd	Base-collector forward bias (warning)	V	0.0
wIbmax	Maximum base current (warning)	A	0.0
wIcmax	Maximum collector current (warning)	A	0.0
wPmax	Maximum power dissipation (warning)	W	0.0
Version	Model version/revision (1.0 = ADS2003C, 2.0 = ADS2004A)	None	2.0
AllParams	Data Access Component (DAC) Based Parameters	None	None

† A value of 0.0 is interpreted as infinity.

Notes/Equations

1. This model supplies values for AgilentHBT_NPN and AgilentHBT_NPN_Th devices.
2. AgilentHBT model is based on the general concepts from the UCSD HBT model [1], http://hbt.ucsd.edu (in which the charge model is originally based on [2]), and the Gummel-Poon BJT model [3].
3. The charge model contains a flexible collector transit time formulation that empirically accounts for the electric field dependent electron drift velocity in GaAs and InP collectors (based on the work from [4]). This enables accurate fits of ft vs. bias over a wide range of bias points, which improves linearity predictions [5]. The depletion and high-current charges are leveraged from HICUM [6,7] (http://www.iee.et.tu-dresden.de/iee/eb/comp_mod.html).
4. The ideal base-emitter current has its distinct saturation current (Ish) and ideality factor (Nh), similar to HICUM and VBIC [8,9] (http://www.designers-guide.com/VBIC/references.html). Therefore, the parameter *Bf* in the Gummel-Poon and UCSD HBT models is not used. This is required for a III-V HBT model because the mechanism of base current is not necessarily proportional to the collector current (due to the presence of a heterojunction between the base and emitter). The current gain (Beta) at a bias point can be viewed from the DC operating point information under Simulate > Detailed Device Operating Point.
5. Dynamic self-heating is implemented (Version 2) and can be activated (de-activated) by setting the device instance parameter *SelfTmod=1* (*SelfTmod=0*). For more information, refer to Self-Heating Model. Static temperature scaling of parameters with operating temperature (*Temp* in the device instance) applies to both cases.
6. Heterojunction effects on DC current (from the UCSD HBT model) is taken into

account by ISA and NA (through VBEi dependent Ica) in the base-emitter junction and ISB and NB (through VBCi dependent Icb) in the base-collector junction. Ica typically models the barrier effects that occur at the base-emitter heterojunction, which modifies the relationship between the collector current and VBEi. Icb typically models the influence of the barrier for electrons at the base-collector junction (which is present at zero bias and is gradually removed with reverse-bias of the base-collector junction).

7. The *soft-knee* observed in the common-emitter ICE vs. VCE curve in single heterojunction bipolar transistors at high currents and low voltages [10] can be taken into account by the parameters of q3mod. For the *soft-knee* observed in double heterojunction bipolar transistors, for example the *Tiwari effect* [11] (which is separate from the base-collector blocking accounted by ISB and NB), q3mod can also be used. *Gkdc* can be used to empirically fit the increase in base current. If a *soft-knee* is not apparent, q3mod can be turned off by setting *Ikdc2Inv=0*
8. '*Inverse*' parameters for several of the model parameters are used to enable flexibility. For example, the parameter Vkrk2Inv is used in the manner:

   $$TKRK \times (1 - V_{BCi} \times VKRK2Inv)$$

   If the standard way of normalizing VBCi were used with a parameter called Vkrk2 (which does not exist in this model), it would look like:

   $$TKRK \times \left(1 - \frac{V_{BCi}}{VKRK2}\right)$$

   Although the latter method is more intuitive because the parameter *VKRK2* is in the familiar units of voltage, it is numerically inconvenient because a divide-by-zero occurs when *VKRK2* is set to 0, which prevents parameter sweeps crossing 0. Therefore, by defining an `inverse' parameter, this numerical problem is circumvented. Another advantage of using `inverse' parameters is that setting that particular parameter to 0 can turn off its effect. Otherwise, parameters must be set to a high value to turn off the effect (e.g., Forward early voltage, *Vaf*). The only inconvenience for using `inverse' parameters is that the units of these parameters are the reciprocal of the units of the variable that it is modifying, which may be difficult to conceptualize.
9. Resistances (Re, Rci, Rcx, Rbi, Rbx). When set to 0, the nodes connected by resistors collapse to a single node. When set to a value greater than 0, the effective resistance (after temperature and area scaling) is limited to be greater than or equal to MinExtR, which can be specified in the General Simulation Options.

   When Re, Rci, Rcx, Rbi or Rbx is initially set to 0 and then swept to non-zero values, the circuit response will not change due to the node collapsing described above.
10. Zero bias junction capacitances (Cje and Cjc). When set to 0, the depletion charge is set to 0. Note that Ccmax and Cemax must be >0.
11. Junction capacitance built-in voltages (Vjc and Vje). When temperature scaled values go below 1e-6, these parameters are set to 1e-6.
12. Imax specifies the P-N junction explosion current. Imax can be specified in the device model or in the General Simulation Options; the device model value takes precedence over the Options value.
13. For the Version parameter, the default setting is 2. Setting *Version=1* selects the first AgilentHBT model release (without dynamic self-heating) in ADS2003C, for backwards compatibility. Note however, there have been a few minor bug fixes to the *Version=1* model, so it is possible that simulation results will not always be exactly identical with the ADS2003C release. If the Version parameter is within the range

[1,2], and set to any value other than 1.0 or 2.0, then it will default to 2.0 with a warning. Outside of this range, an error is returned.

Note that the dynamic self-heating option is available only in *Version=2*. The following is a brief list of enhancements for *Version=2*.

- Dynamic self-heating (self-consistent electro-thermal interaction) effects on currents, capacitances, delays, and resistances.
- Temperature scaling of *NF*, *NR*, *VPTE*, *VPTC*, *VKRK*
- Parameters *NKDC* and *GKDC* can be real values
- Parasitic inductances included at the electrical terminals

14. Use *AllParams* with a DataAccessComponent to specify file-based parameters (refer to "DataAccessComponent" in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those via *AllParams*.

Netlist Syntax

Model

```
model model_name AgilentHBT list_of_parameters
```

model_name is the user defined name for the particular AgilentHBT model which can be used in multiple instances. *list_of_parameters* is the list of the model parameters and values.

Example:

```
model hbt1 AgilentHBT Re=2 Rci=1 Rcx=5 Rbi=
```

Model name hbt1 is an AgilentHBT model with the corresponding listed parameters. hbt1 can be used in multiple instances with its area and temperature scaled independently for each instance.

Device

When the device specified by model_name is called, the syntax below is used:

```
model_name:deviceID Cnode Bnode Enode list_of_parameters
```

deviceID is the unique identification given to the particular instance with the corresponding listed parameters.

Example:

```
hbt1:q1 2 1 0 Area=1 Temp=25
```

Component q1 is defined by hbt1, which is an AgilentHBT model. The collector node is at node 2, the base node is at node 1, and the emitter node is at node 0. The area factor is set to 1 and the device (operating) temperature is at 25°C.

Large- and Small-signal Model Topologies Overview

The large-signal topology of the AgilentHBT model is given in Figure 1 . The intrinsic model (bounded by the dashed box) is shown in more detail in Figure 2 . The thermal equivalent circuit is given in Figure 8 .

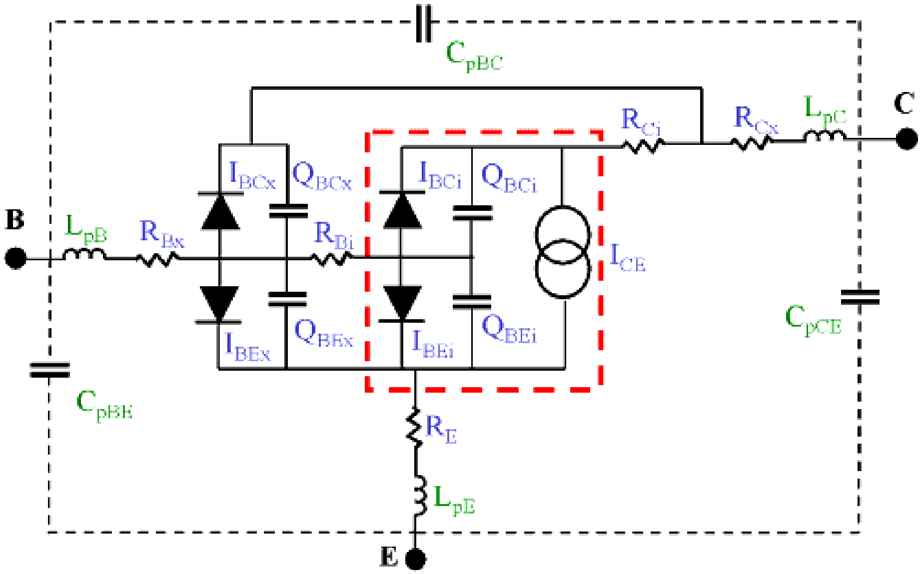


Figure 1.

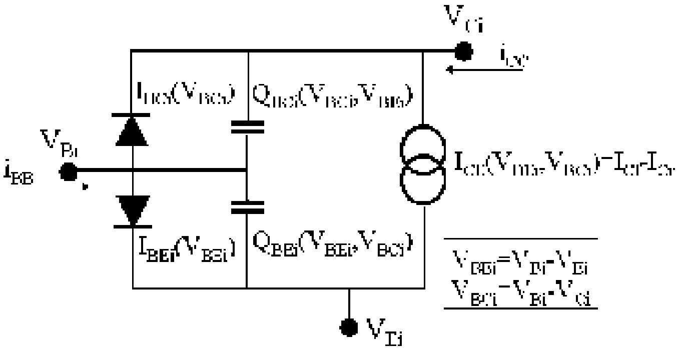


Figure 2.

The intrinsic model can be expressed in general as a 2-port network as shown in the following figure.

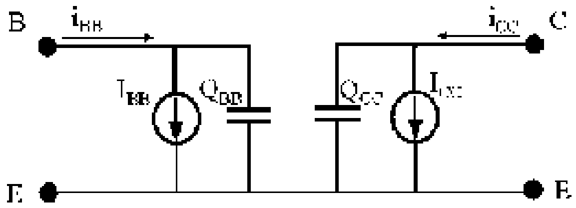


Figure 3. "2-Port Network of the Large-Signal Intrinsic Model"

In Figure 3, shown above:

$$I_{BB} = I_{BEi} + I_{BCi}$$

$$Q_{BB} = Q_{BEi} + Q_{BCi}$$

$$i_{BB} = I_{BB} + \frac{dQ_{BB}}{dt}$$

$$I_{CC} = I_{CE} - I_{BCi}$$

$$Q_{CC} = -Q_{BCi}$$

$$i_{CC} = I_{CC} + \frac{dQ_{CC}}{dt}$$

This 2-port circuit representation of the intrinsic device facilitates the calculation of the intrinsic elements of the small-signal model. This is because the intrinsic Y-parameters can be expressed using the 2- port circuit elements as follows:

$$[Y_{int}] = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} \left(\left.\frac{\partial I_{BB}}{\partial V_{BEi}}\right|_{V_{CEi}}\right) + j\omega\left(\left.\frac{\partial Q_{BB}}{\partial V_{BEi}}\right|_{V_{CEi}}\right) & \left(\left.\frac{\partial I_{BB}}{\partial V_{CEi}}\right|_{V_{BEi}}\right) + j\omega\left(\left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right|_{V_{BEi}}\right) \\ \left(\left.\frac{\partial I_{CC}}{\partial V_{BEi}}\right|_{V_{CEi}}\right) + j\omega\left(\left.\frac{\partial Q_{CC}}{\partial V_{BEi}}\right|_{V_{CEi}}\right) & \left(\left.\frac{\partial I_{CC}}{\partial V_{CEi}}\right|_{V_{BEi}}\right) + j\omega\left(\left.\frac{\partial Q_{CC}}{\partial V_{CEi}}\right|_{V_{BEi}}\right) \end{bmatrix}$$

Small-signal parameters such as the total intrinsic base-emitter and base-collector capacitances (depletion + diffusion) can be extracted directly from the intrinsic Y-parameters, as well as the transconductance (g_m) and the transcapacitance (C_m), which can then be used to calculate the small-signal time delay (SS).

The small-signal equivalent circuit approximates the time delay with a modification to the transconductance (g_m). It is represented as the circuit shown in Figure 4.

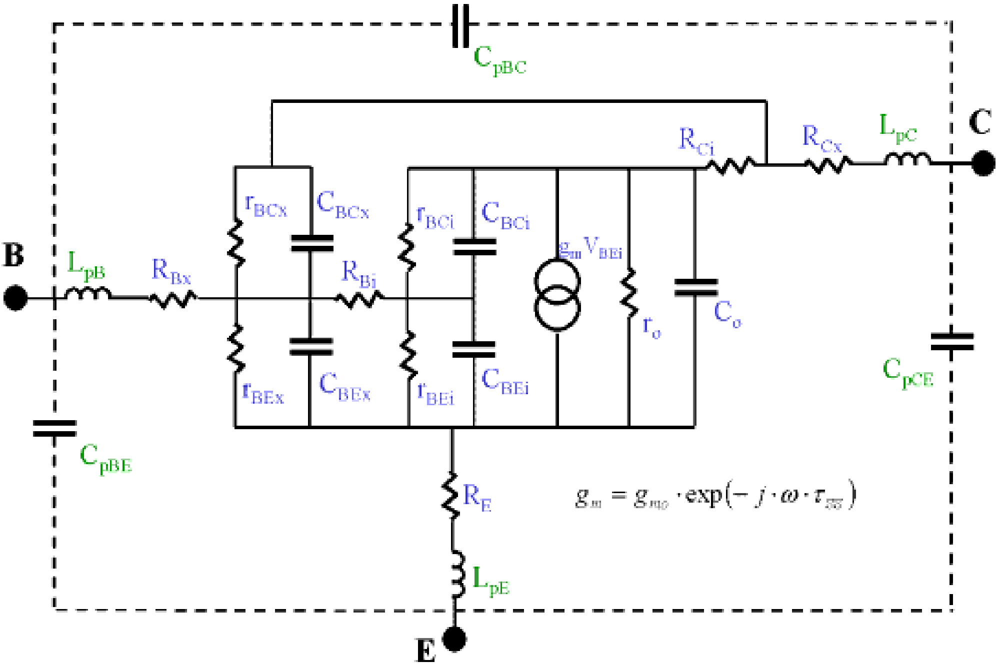


Figure 4.

In Figure 4:

$$r_{BCi} = \left(\frac{dI_{BCi}}{dV_{BCi}}\right)^{-1}$$

$$r_{BEi} = \left(\frac{dI_{BEi}}{dV_{BEi}}\right)^{-1}$$

$$C_{BCi} = -\frac{\partial Q_{BB}}{\partial V_{CEi}}\bigg|_{V_{BEi}}$$

$$C_{BEi} = \frac{\partial Q_{BB}}{\partial V_{BEi}}\bigg|_{V_{CEi}} + \frac{\partial Q_{BB}}{\partial V_{CEi}}\bigg|_{V_{BEi}}$$

$$r_{BCx} = \left(\frac{dI_{BCx}}{dV_{BCx}}\right)^{-1}$$

$$r_{BEx} = \left(\frac{dI_{BEx}}{dV_{BEx}}\right)^{-1}$$

$$C_{BCx} = \frac{dQ_{BCx}}{dV_{BCx}}$$

$$C_{BEx} = \frac{dQ_{BEx}}{dV_{BEx}}$$

$$g_{mo} = \left.\frac{\partial I_{CE}}{\partial V_{BEi}}\right|_{V_{CEi}}$$

$$r_o = \left(\left.\frac{\partial I_{CE}}{\partial V_{CEi}}\right|_{V_{BEi}}\right)^{-1}$$

$$C_o = \left.\frac{\partial Q_{CC}}{\partial V_{CEi}}\right|_{V_{BEi}} + \left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right|_{V_{BEi}}$$

$$C_m = -\left.\frac{\partial Q_{CC}}{\partial V_{BEi}}\right|_{V_{CEi}} + \left.\frac{\partial Q_{BB}}{\partial V_{CEi}}\right|_{V_{BEi}}$$

$$\tau_{SS} = \frac{C_m}{g_{mo}}$$

Collector-Emitter Current Equations

The collector-emitter current (i.e., main collector current) is composed of the forward and reverse currents (Icf and Icr). The formulation for the modification factor DD is based on the UCSD HBT model. q1 and q2 (contained in qb) are originally from the Gummel-Poon model where they model the Early and high-current roll-off effects, respectively. Ica and Icb model the heterojunction effects on the collector current for the base-emitter and base-collector junctions, respectively. q3mod is a function that empirically models the drop in current gain at high currents and low collector voltages that results in a softening of the knee behavior of a common-emitter I-V plot. In the following equations, T represents Tdev, defined in terms of the ambient or dynamical temperature, as described in Self-Heating Model.

$$I_{CE} = I_{cf} - I_{cr}$$

$$I_{cf} = \frac{IS \times \left(\exp\left(\frac{qV_{BEi}}{NF \times k \times T}\right) - 1\right)}{DD \times q3mod}$$ (total forward collector current)

$$I_{cr} = \frac{ISR \times \left(\exp\left(\frac{qV_{BCi}}{NR \times k \times T}\right) - 1\right)}{DD}$$ (total reverse emitter current)

$$DD = qb + Ica + Icb$$

$$qb = \frac{q1 \times (1 + \sqrt{1 + 4 \times q2})}{2}$$

$$q1 = \frac{1}{1 - \frac{V_{BEi}}{VAR} + \frac{V_{BCi}}{VAF}}$$ (Early effect)

(A limiting function is used in the model implementation to prevent divide-by-zero error when the denominator is equal to zero)

$$q2 = \frac{IS\exp\left(\frac{qV_{BEi}}{NF\times k\times T}\right)}{IK}$$ (high current Beta roll-off)

(The numerator is slightly modified from the diode equation by removing the -1 term)

$$Ica = \frac{IS}{ISA}\exp\left(\frac{qV_{BEi}}{NA\times k\times T}\right)$$ (BE heterojunction effect)

$$Icb = \frac{IS}{ISB}\exp\left(\frac{qV_{BCi}}{NB\times k\times T}\right)$$ (BC heterojunction effect)

$$q3mod = \frac{NKDC\times q3}{(NKDC-1)+q3}$$ (*Soft-knee* effect)

$$q3 = trans2\left(IS\left(\exp\left(\frac{qV_{BEi}}{NF\times k\times T}\right)-1\right)\right) - trans2(0) + 1$$

$$trans2(I) = \frac{IKDC2Inv(\sqrt{(I-Icrit1)2+IKDC^2}+I-Icrit1-IKDC1)}{2}$$

$$Icrit1 = IKDC3(1-(V_{BCi}-VJC)\times VKDCInv)$$

Explanation of q3mod

Because q3mod divides the forward collector current (I_{cf}), it remains a value of 1 when its effect is not present. Figure 5 shows the behavior of *q3mod* versus the collector current at various V_{BCi} values.

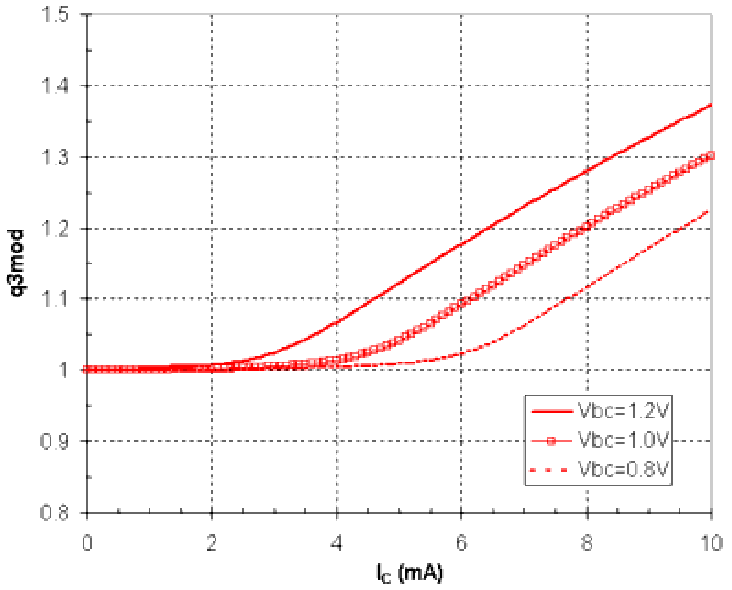


Figure 5. *q3mod* Behavior versus Collector Current (Ikdc1=0.001; Ikdc2Inv=100; kdc3=0.00; VkdcInv=5.26; Nkdc=3; Vjc=1.4)

Ikdc1 defines the 'width' in current of the transition region, *Ikdc2Inv* defines the 'slope', and *Ikdc3* defines the 'turn-on' current of q3mod. *VkdcInv* defines the voltage dependence of the 'turn-on' current and *Nkdc* sets the limit to the value of *q3mod*. It should be noted that the parameter *Vjc* is used in the equation for *q3mod*. Because *Vjc* is primarily used to define the base-collector depletion charge (or capacitance), the base-collector capacitance should be extracted first before the parameters of *q3mod* are extracted.

Base-Emitter Current Equations

In the following equations, T represents Tdev, defined in terms of the ambient or dynamical temperature, as described in Self-Heating Model.

$$I_{BEi} = (1-ABEL)\times\left((q3mod)^{GKDC}\times ISH\left(\exp\left(\frac{qV_{BEi}}{NH\times k\times T}\right)-1\right)+ISE\left(\exp\left(\frac{qV_{BEi}}{NE\times k\times T}\right)-1\right)\right)$$

$$I_{BEx} = (ABEL)\times\left((q3mod)^{GKDC}\times ISH\left(\exp\left(\frac{qV_{BEx}}{NH\times k\times T}\right)-1\right)+ISE\left(\exp\left(\frac{qV_{BEx}}{NE\times k\times T}\right)-1\right)\right)$$

q3mod is in the I_{BE} equations to empirically model any increase in base current due to the *soft-knee* effect, which occurs at high collector currents and low collector voltages. If this feature is not needed, set *Gkdc=0* (default).

Abel is used as a partitioning factor of the total base-emitter current to separate extrinsic and intrinsic components.

Base-Collector Current Equations

In the following equations, T represents Tdev, defined in terms of the ambient or dynamical temperature, as described in Self-Heating Model.

$$I_{BCi} = (1-ABCX)\times\left(ISRH\left(\exp\left(\frac{qV_{BCi}}{NRH\times k\times T}\right)-1\right)+ISC\left(\exp\left(\frac{qV_{BCi}}{NC\times k\times T}\right)-1\right)\right)$$

$$I_{BCx} = ABCX\times\left(ISRH\left(\exp\left(\frac{qV_{BCx}}{NRH\times k\times T}\right)-1\right)+ISC\left(\exp\left(\frac{qV_{BCx}}{NC\times k\times T}\right)-1\right)\right)$$

Abcx is used as a partitioning factor for the total base-collector current to separate the extrinsic and intrinsic components. It is also the same parameter that is used to partition the intrinsic and extrinsic base-collector depletion charges.

Depletion Capacitance/Charge

The depletion charge functions for both the base-emitter and base-collector junctions are based on the formulation from HICUM (version 2.1). This formulation and its derivatives are fully continuous for all regions of bias, and therefore appropriate for a large-signal model for CAD. The original documentation which can be found at: "http://www.iee.et.tu-dresden.de/iee/eb/comp_mod.html" describes this function in more detail.

Modifications made for the AgilentHBT_Model from the original HICUM formulation are:

- Specification of a maximum capacitance (i.e., *Ccmax*, *Cemax* in the AgilentHBT_Model), rather than the ratio of the maximum to zero bias capacitance (e.g., Aljei in HICUM).
- Specification of grading factors Mjcr and Mjer in the punchthrough, or fully-depleted, region (which are fixed values in HICUM).
- Computationally efficient transition functions between the three regions of biases (i.e., vjxm and vjxr).
  Because the same depletion charge functions are used for the base-emitter and base-collector charges, the following equations apply to both junctions. The variable x is used to denote either base-collector (*C*) or base-emitter (*E*).

$$Q_{xd}(V_x) = Q_{jxf} + Q_{jxm} + Q_{jxr} - Q_{jxcorr}$$

- The depletion capacitance can be derived in a straightforward manner (in concept) by taking the derivative of the total depletion charge (Qxd) with respect to Vx , given by the expression:

$$C_{xd}(V_x) = \frac{dQ_{xd}}{dV_x} = \frac{dQ_{jxf}}{dV_x} + \frac{dQ_{jxm}}{dV_x} + \frac{dQ_{jxr}}{dV_x} - \frac{dQ_{jxcorr}}{dV_x}$$

The derivatives of each of the four terms are provided:

$$\frac{dQ_{jxf}}{dV_x} = CxMAX\left(1 - \frac{d(\nu_{jxr})}{dV_x}\right)$$ (forward-bias case)

$$\frac{dQ_{jxm}}{dV_x} = CJx\left(1 - \frac{\nu_{jxm}}{VJx}\right)^{-MJx} \times \frac{d(\nu_{jxm})}{dV_x}$$ (partially-depleted case)

$$\frac{dQ_{jxr}}{dV_x} = C_{jx0r}\left(1 - \frac{\nu_{jxr}}{VJx}\right)^{-MJxR} \times \frac{d(\nu_{jxr})}{dV_x}$$ (fully-depleted case)

$$\frac{dQ_{jxcorr}}{dV_x} = C_{jx0r}\left(1 - \frac{\nu_{jxm}}{VJx}\right)^{-MJxR} \times \frac{d(\nu_{jxm})}{dV_x}$$ (correction term)

where:

$$\nu_{jxm} = \frac{1}{2}\left(\nu_{jxr} - V_{jPxi} + \sqrt{(V_{jPxi} + \nu_{jxr})^2 + V_r^2}\right)$$

$$V_r = 0.1V_{jPxi} + 4\left(\frac{k \times Temp}{q}\right)$$

$$V_{jPxi} = VPTx - VJx$$

$$\nu_{jxr} = -0.5\left(-V_x - V_{fxi} + \sqrt{(V_{fxi} - V_x)^2 + \left(\frac{k \times Temp}{q}\right)^2}\right)$$

$$V_{fxi} = VJx\left[1-\left(\frac{CxMAX}{CJx}\right)^{-(1/MJx)}\right]$$

$$C_{jx0r} = CJx\left(\frac{VJx}{VPTx}\right)^{MJx-MJx.}$$

$$\frac{d(v_{jxr})}{dV_x} = \frac{1}{2}\left(1-\frac{V_x-V_{fxi}}{\sqrt{(V_x-V_{fxi})^2+\left(\frac{k\times Temp}{q}\right)^2}}\right)$$

$$\frac{d(v_{jxm})}{dV_x} = \frac{d(v_{jxr})}{dV_x}\times\frac{1}{2}\left(1+\frac{V_{jPxi}+v_{jxr}}{\sqrt{(V_{jPxi}-v_{jxr})^2+V_r^2}}\right)$$

- *Vx* is the junction voltage (e.g., VBEi or VBCi).
- *Vpte* and *Vptc* are the punchthrough voltages for the base-emitter and base-collector junctions, respectively.
- *Cemax* and *Ccmax* are the maximum depletion capacitances when forward biased for the base-emitter and base-collector junctions, respectively.
- *Mjer* and *Mjcr* are parameters that describe the slope of the punchthrough region for the base-emitter and base-collector junctions, respectively.

The total base-emitter depletion charge is denoted Q_{BEd} and the corresponding capacitance is denoted C_{BEd}. Likewise, the total base-collector depletion capacitance is denoted Q_{BCd} and its corresponding capacitance is denoted as C_{BCd}.

An example plot of the analytical equation for the base-collector capacitance (C_{BC}) versus V_{BCi} is shown in Figure 6, with some of the notable parameters.

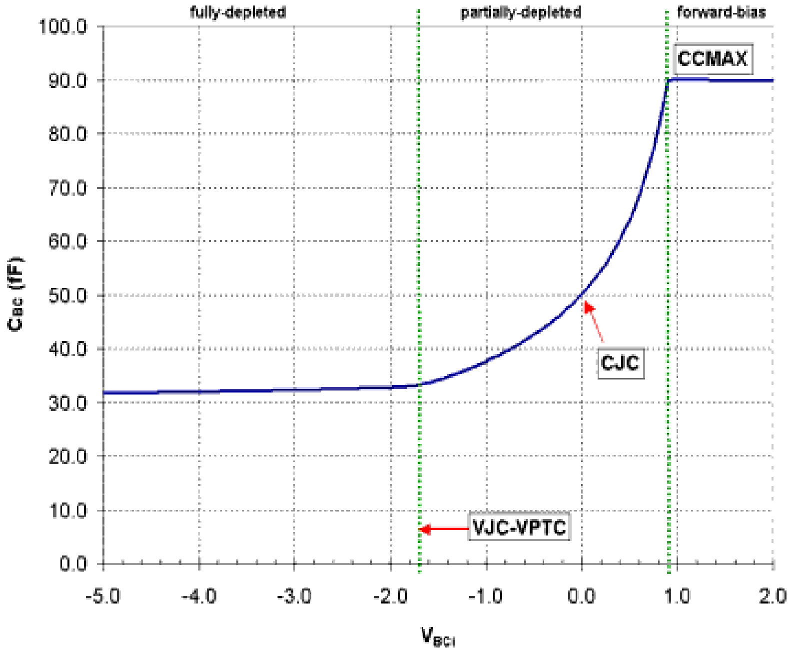


Figure 6.

Delay Charge Equations

The delay (or *diffusion*) charge equations account for the intrinsic delay of the device. They are grouped into three separate components: base delay charge (QtB), Kirk effect charge (Qkrk), and collector delay charge (QtC). They are expressed in terms of the bias dependence of the forward collector current (Icfq) and the intrinsic base-collector voltage (VBCi). Icfq is a slightly modified version of the DC forward collector current (Icf), which is used to improve computational robustness by avoiding negative values for any bias voltage.

The base transit time (*Tfb*) is assumed to be constant due to the highly doped metallurgical base region of III-V HBTs. The increase in transit time at high currents is accounted for by Qkrk. The general form of Qkrk is leveraged from the HICUM model with some modifications. Note that Qkrk should generally account for any increase in transit time at high currents; for example, the f_t roll-off in DHBTs (which is not necessarily due to Kirk effect (or base pushout).

The collector delay charge, QtC, is a flexible function that empirically models the field-dependent electron drift velocity in the collector depletion region (modified from [4] for computational robustness). Because the depletion charge function of the base-collector junction does not contain a current dependence, QtC (in addition to Qkrk at very high currents) should be used to fit the current dependence of the intrinsic base-collector capacitance (CBCi). The *capacitance cancellation* (described in [13]) is taken into account by QtC because of its dependence with VBCi.

The delay due to the three *diffusion* charges can be expressed by taking the derivatives with respect to the forward current Icfq. Expressions for the delays and a graphical representation of them (see Figure 7) are given:

$$\tau_B = \frac{dQ_{tB}}{dI_{cfq}} = TFB$$

(base transit time)

$$\tau_{KE} = \left.\frac{\partial Q_{krk}}{\partial I_{cfq}}\right|_{V_{BCi}} = TKRK(1 - V_{BCi} \times VKRK2Inv)\left(\frac{I_{cfq}}{Ikirk2}\right)^{gKRK}$$

(Kirk effect delay)

$$Ikirk2 = IKRK \times \left(1 - \frac{V_{BCiKE}}{VKRK}\right)$$

Note that *IKRKtr* is used in the implementation of Ikirk2 to define the *transition width* in current to a 0 value. By default, *IKRKtr* is set to 1e-6; it is recommended to not change this parameter.

$$V_{BCiKE} = trans3(V_{BCi}, VKTR, VKMX)$$

$$trans3(x, x_{ir}, x_{max}) = \frac{\sqrt{(x + x_{max})^2 + {x_{tr}}^2} + x - x_{max}}{2}$$

$$\tau_C = \left.\frac{\partial Q_{IC}}{\partial I_{cfq}}\right|_{V_{BCi}} = 0.5$$

$$\Bigg((TFC0(1 - VTC0Inv \times trans3(V_{BCi}, VTR0, VMX0)))$$

$$+ 2 \times TCMIN(1 - VTCMINInv \times trans3(V_{BCi}, VTRMIN, VMXMIN))$$

$$- \frac{(TFC0(1 - VTC0Inv \times trans3(V_{BCi}, VTR0, VMX0)) \times (I_{cfq} - ITC(1 - V_{BCi} \times VTCInv)))}{\sqrt{(ITC(1 - V_{BCI} \times VTCInv) - I_{cfq})^2 + (ITC2(1 - V_{BCI} \times VTC2Inv))^2}}\Bigg)$$

(collector transit time)

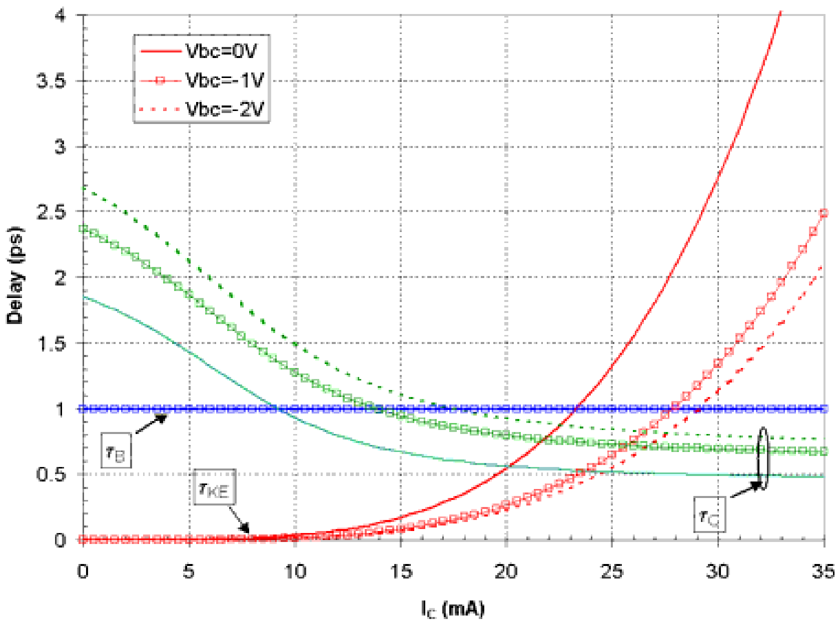


Figure 7.

A very simple reverse delay charge is implemented by a constant reverse transit time parameter *TR*. The charge associated with this delay is equal to:

$$Q_{tR} = TR \times I_{crq}$$

Total Charge Formulation

Implementations of the base-emitter depletion charge (QBEd) and the base-collector depletion charge (QBCd) are straightforward because they solely reside between the base-emitter and base-collector junctions, respectively. Partitioning between the intrinsic and extrinsic portion of the device is accomplished by the parameters *Abex* and *Abcx*. Therefore, the intrinsic depletion charges are defined as:

$$Q_{BEid} = (1 - ABEX) \times Q_{BEd}(V_{BEi})$$

$$Q_{BCid} = (1 - ABCX) \times Q_{BCd}(V_{BCi})$$

and in turn, the extrinsic depletion charges are defined as:

$$Q_{BEx} = Q_{BExd} = (ABEX) \times Q_{BEd}(V_{BEx})$$

$$Q_{BCx} = Q_{BCxd} = (ABCX) \times Q_{BCd}(V_{BCx})$$

The delay charges (Qtb, Qtc, and Qkrk) reside only in the intrinsic region of the device (because they physically represent the time it takes for electrons to traverse the intrinsic base region and the intrinsic portion of the collector depletion region). These delay charges can be independently partitioned between the base-emitter and base-collector junctions by the partitioning factors *Fextb*, *Fextc*, and *Fexke*. These partitioning factors play an important role in defining the phase characteristics of the device at high frequencies [1,12].

The total intrinsic base-emitter and base-collector charges are defined as:

$$Q_{BEi} = Q_{BEid} + (1 - FEXTB)Q_{tB} + (1 - FEXTC)Q_{tC} + (1 - FEXKE)Q_{krk}$$

$$Q_{BCi} = Q_{BCid} + FEXTB \times Q_{tB} + FEXTC \times Q_{tC} + FEXKE \times Q_{krk} + Q_{tR}$$

The total charge at the intrinsic base (Q_{BB}) and collector (Q_{CC}) branches (as illustrated in Figure 3) are defined as:

$$Q_{BB} = Q_{BEi} + Q_{BCi} = Q_{BEid} + Q_{BCid} + Q_{tB} + Q_{tC} + Q_{krk} + Q_{tR}$$

$$Q_{CC} = -Q_{BCi} = -Q_{BCid} - FEXTB \times Q_{tB} - FEXTC \times Q_{tC} - FEXKE \times Q_{krk} - Q_{tR}$$

Noise Model

Thermal noises generated by resistors *Rbi*, *Rbx*, *Rci*, *Rcx*, and *Re* are represented by the spectral densities:

$$\frac{\langle i_{Rbi}^2 \rangle}{\Delta f} = \frac{4 \times k \times T}{RBI}$$

$$\frac{\langle i_{Rci}^2 \rangle}{\Delta f} = \frac{4 \times k \times T}{RCI}$$

$$\frac{\langle i_{Re}^2 \rangle}{\Delta f} = \frac{4 \times k \times T}{RE}$$

$$\frac{\langle i_{RBx}^2 \rangle}{\Delta f} = \frac{4 \times k \times T}{RBX}$$

$$\frac{\langle i_{Rcx}^2 \rangle}{\Delta f} = \frac{4 \times k \times T}{RCX}$$

The DC collector current generates shot noise represented by the spectral density:

$$\frac{\langle i_c^2 \rangle}{\Delta f} = 2qI_C$$

The DC base current generates shot noise represented by the spectral density:

$$\frac{\langle i_b^2\rangle}{\Delta f} = 2qI_B$$

The DC base-emitter currents (IBEi and IBEx) generate flicker (1/f) noise (parameters Kf, Af, Ffe), and burst noise (parameters *Kb*, *Ab*, *Fb*) which are represented by the spectral densities:

$$\frac{\langle i_{bei}^2\rangle}{\Delta f} = (KF)\frac{I_{BEi}^{AF}}{f^{FFE}} + (Kb)\frac{I_{BEi}^{AB}}{1+\left(\frac{f}{FB}\right)^2}$$

$$\frac{\langle i_{bex}^2\rangle}{\Delta f} = (KF)\frac{I_{BEx}^{AF}}{f^{FFE}} + (Kb)\frac{I_{BEx}^{AB}}{1+\left(\frac{f}{FB}\right)^2}$$

Self-Heating Model

In an isothermal model (e.g., Version 1), the electrical constitutive relations, such as the collector forward current function, and their associated parameter values, such as IS (for details, refer to Collector-Emitter Current Equations), depend on temperature only through the static value specified by Temp (defined at the device instance, *AgilentHBT_NPN (Agilent Heterojunction Bipolar Transistor, NPN)AgilentHBT_NPN_Th Agilent Heterojunction Bipolar Transistor w/ Thermal Node, NPN)* (ccnld)).

In a real device, temperature is constantly changing in time. This is due to the interplay between electrical energy conversion into heat, as a function of signal (level and frequency, waveform, and load), and the diffusion and other mechanisms of heat transfer, including thermal coupling to other heat sources or sinks. This changing of temperature with time, in turn, changes the electrical behavior of the device, which modifies the generation of heat etc., all in a self-consistent way.

In order to model these important effects, the self-heating (dynamic electro-thermal) model (Version 2) treats temperature as a dynamical variable, on the same footing as the time-dependent voltages and currents of the electrical part of the model. To select the self-heating model, set SelfTmod=1 at the device instance. The default is SelfTmod=0. That is, self-heating is not invoked as the default. Specifically, the self-heating switch behaves in the following way:

```
If SelfTmod=0 Then
Tdev=Temp
(self-heating is OFF. The ambient temperature, Temp, is used)
ElseIf SelfTmod=1 Then
Tdev=Temp+deltaT
(self-heating is ON. All temperature dependent equations use dynamic
temperature)
ElseIf SelfTmod >0 and <1 Then
Tdev=Temp+deltaT
(if not set to 0 or 1, the model turns self-heating is ON in the range
(0,1))
Else
```

```
Error returned (out of range)
EndIf
```

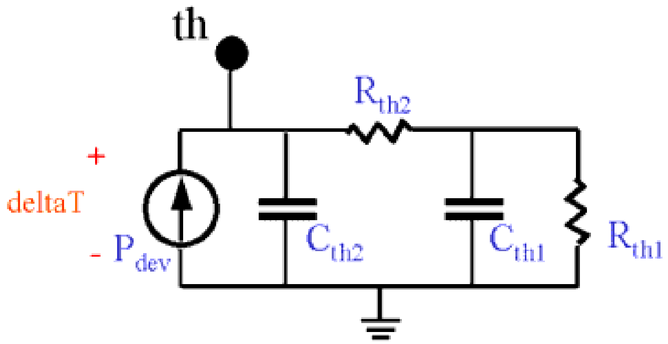


Figure 8.

The electrical constitutive relations depend on the dynamical variable Tdev = Temp + deltaT(t), when SelfTmod=1, rather than just Temp, when SelfTmod=0. deltaT(t) represents the time-dependent temperature rise above ambient temperature. It is computed by a thermal evolution equation, which relates the total dissipated electrical power to the generation of heat, which then causes a time-dependent temperature rise based on thermal resistance and thermal capacitance. The thermal evolution equation is modeled by a thermal equivalent circuit, shown in AgilentHBT Model (Agilent Heterojunction Bipolar Transistor Model). The circuit is in general a two-pole approximation to the diffusion equation, which governs the propagation of heat. A minimum of two poles has been shown to be needed in many practical cases for III-V devices [14].

The current source element of the thermal equivalent circuit is set equal to the total dissipated power in the device model, including contributions from the intrinsic and extrinsic active device, and all parasitic resistors. The thermal node voltage represents the time-dependent deltaT(t). A voltage probe attached to the thermal node will return the value of deltaT(t). A (dc) voltage source added between the thermal node and ground will fix the value of deltaT. If the thermal node voltage is shorted to ground, the self-heating model is de-activated, which is equivalent to setting SelfTmod=0.

The electrical constitutive relations and their associated electrical parameters are evaluated at the temperature LimitT(Temp + deltaT(t)). The LimitT function limits the time-dependent temperature to a range [-200, 500] in degrees centigrade. This limiting function prevents the device model from thermally running away to infinity, and hence not-converging. If the device instance senses a temperature at the limits, a warning will be returned indicating that the device being modeled is potentially thermally unstable at the operating conditions being simulated. It should be noted that the model is not necessarily accurate over such a wide temperature range. Typically, the model is extracted from measurements over a temperature range approximately from 20 to 100 degrees centigrade, but is typically accurate over a wider range (e.g., -50 to 0 degrees centigrade).

The temperature limiting function may cause a very slight (e.g., 10-3) fractional modification to the value Temp + deltaT(t). Therefore the temperature value used to evaluate the electrical constitutive equations and parameters is not exactly equal the value Temp + deltaT(t). The actual value of the limited temperature is reported by the DC Operating Point parameter Teff, in *DC Operating Point Parameters* (ccnld).

By default, the general two-pole thermal equivalent circuit is reduced to a single pole thermal equivalent circuit. That is, by default, *Cth2* and *Rth2* are zero. *Cth2* and *Cth1* can be set equal to zero, even if *Rth2* and *Rth1* are non-zero. *Rth1* can be set to zero, but this completely de-activates the self-heating model and is equivalent to setting SelfTmod=0.

Under some conditions, it may be desirable to use a more complicated thermal network for the device than provided by the two-pole thermal equivalent circuit. This can be done by setting *Rth2=0*, *Cth2=0* (making sure the second pole is removed), setting *Cth1=0*, and setting Rth1 to a very large resistance (e.g., 1e9) (to make it irrelevant once a substitute thermal network is added). Then users can attach their own thermal network from the thermal terminal (fourth device terminal) to ground and/or to any other thermal terminals of other device instances.

It is important to note that the thermal resistance parameters, *Rth1* and *Rth2*, themselves are functions of the time-dependent temperature variable Tdev = Temp + deltaT(t). The temperature dependence of thermal resistance is an important property of III-V HBTs, and the modeling of it enables improved model fits.

Temperature Scaling Equations

The temperature scaling equations allow simulations at various operating temperatures, specified by Temp (defined at the device instance). The change in temperature from the operating temperature can also be specified by the parameter Trise. Tnom is defined as the nominal temperature at which the room temperature parameters are extracted. The device temperature Tdev is defined in the section Self-Heating Model.

$$rTemp = \frac{ZeroCKelvin + Tdev}{ZeroCKelvin + Tnom} \qquad ZeroCKelvin = 273.15$$

$$RBI_{Temp} = RBI \times (rTemp)^{XRB}$$

$$RBX_{Temp} = RBX \times (rTemp)^{XRB}$$

$$RCI_{Temp} = RCI \times (rTemp)^{XRC}$$

$$RCX_{Temp} = RCX \times (rTemp)^{XRC}$$

$$RE_{Temp} = RE \times (rTemp)^{XRE}$$

$$VJE_{Temp} = VJE - TVJE \times (Tdev - Tnom)$$

$$VJC_{Temp} = VJC - TVJC \times (Tdev - Tnom)$$

$$VPTE_{Temp} = (VPTE - TVPE)(Tdev - Tnom)$$

$$VPTC_{Temp} = (VPTC - TVPC)(Tdev - Tnom)$$

$$CJE_{Temp} = CJE \times \left(\frac{VJE}{VJE_{Temp}}\right)^{MJE}$$

$$CJC_{Temp} = CJC \times \left(\frac{VJC}{VJC_{Temp}}\right)^{MJC}$$

$$NF_{Temp} = NF + TNF \cdot (Tdev - Tnom)$$

$$NR_{Temp} = NR + TNR \cdot (Tdev - Tnom)$$

$$IS_{Temp} = IS \times (rTemp)^{(XTIS/NF)} \exp\left((1 - rTemp)\frac{(-EGE)}{NF \times k \times Tdev}\right)$$

$$ISH_{temp} = ISH \times (rTemp)^{(XTIH/NH)} \exp\left((1 - rTemp)\frac{(-EGE)}{NH \times k \times Tdev}\right)$$

$$ISE_{Temp} = ISE \times (rTemp)^{(XTIE/NE)} \exp\left((1 - rTemp)\frac{(-EGE)}{NE \times k \times Tdev}\right)$$

$$ISR_{Temp} = ISR \times (rTemp)^{(XTIR/NR)} \exp\left((1 - rTemp)\frac{(-EGC)}{NR \times k \times Tdev}\right)$$

$$ISC_{Temp} = ISC \times (rTemp)^{(XTIC/NC)} \exp\left((1 - rTemp)\frac{(-EGC)}{NC \times k \times Tdev}\right)$$

$$ISRH_{Temp} = ISRH \times (rTemp)^{(XTIRH/NRH)} \exp\left((1 - rTemp)\frac{(-EGC)}{NRH \times k \times Tdev}\right)$$

$$ISA_{Temp} = ISA \times (rTemp)^{(XTIS/NF)} \exp\left((1 - rTemp)\frac{(-EGE)}{NF \times k \times Tdev} + \frac{EAA}{k \times Tdev}\right)$$

$$ISB_{Temp} = ISB \times (rTemp)^{(XTIS/NF)} \exp\left((1 - rTemp)\frac{(-EGE)}{NF \times k \times Tdev} + \frac{EAB}{k \times Tdev}\right)$$

$$IKDC3_{Temp} = IKDC3 \times (rTemp)^{XTIK3}$$

$$TFB_{Temp} = TFB \times (rTemp)^{XTFB}$$

$$TCMIN_{Temp} = TCMIN \times (rTemp)^{XTCMIN}$$

$$TFC0_{Temp} = TFC0 \times (rTemp)^{XTFC0}$$

$$ITC_{Temp} = ITC \times (rTemp)^{XITC}$$

$$ITC2_{Temp} = ITC2 \times (rTemp)^{XITC2}$$

$$TKRK_{Temp} = TKRK \times (rTemp)^{XTKRK}$$

$$IKRK_{Temp} = IKRK \times (rTemp)^{XIKRK}$$

$$VKRK_{Temp} = VKRK \times (rTemp)^{XVKRK}$$

$$RTH1_{Temp} = RTH1 \times (rTemp)^{XTH1}$$

$$RTH2_{Temp} = RTH2 \times (rTemp)^{XTH2}$$

Area Scaling Equations

The Area factor (specified in the device instance) scales the device resistances, currents, and capacitances. In general, the currents and capacitances are multiplied, and the resistances are divided by the area factor.

$$RBI_{Area} = \frac{RBI}{Area}$$

$$RBX_{Area} = \frac{RBX}{Area}$$

$$RCI_{Area} = \frac{RCI}{Area}$$

$$RCX_{Area} = \frac{RCX}{Area}$$

$$RE_{Area} = \frac{RE}{Area}$$

$$CJE_{Area} = CJE \times Area$$

$$CEMAX_{Area} = CEMAX \times Area$$

$$CJC_{Area} = CJC \times Area$$

$$CCMAX_{Area} = CCMAX \times Area$$

$$IS_{Area} = IS \times Area$$

$$ISR_{Area} = ISR \times Area$$

$$ISH_{Area} = ISH \times Area$$

$$ISRH_{Area} = ISRH \times Area$$

$$ISE_{Area} = ISE \times Area$$

$$ISC_{Area} = ISC \times Area$$

$$IKDC1_{Area} = IKDC1 \times Area$$

$$IKDC2Inv_{Area} = \frac{IKDC2Inv}{Area}$$

$$IKDC3_{Area} = IKDC3 \times Area$$

$$ITC_{Area} = ITC \times Area$$

$$ITC2_{Area} = ITC2 \times Area$$

$$IKRK_{Area} = IKRK \times Area$$

$$ISA_{Area} = ISA \times Area$$

$$ISB_{Area} = ISB \times Area$$

> **Note**
> There are several parameters that are not scaled with the Area factor. These parameters are Rth1, Cth1, Rth2, Cth2, Cpbe, Cpbc, Cpce, Lpb, Lpc, and Lpe.

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13. L.H. Camnitz and N. Moll, "An Analysis of the Cutoff-Frequency Behavior of Microwave Heterostructure Bipolar Transistors," in Compound Semiconductor Transistors, Physics and Technology, IEEE Press, pp.21-46, 1993.
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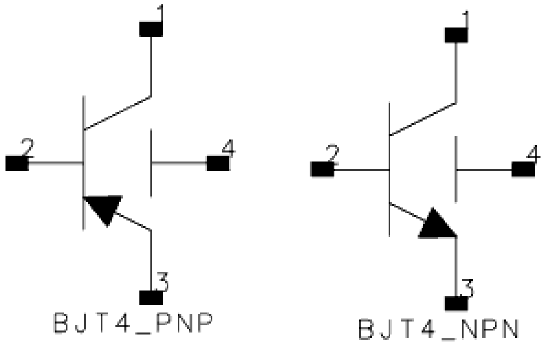
BJT4_NPN, BJT4_PNP (Bipolar Junction Transistors w/Substrate Terminal, NPN, PNP)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	BJTM1
Area	Scaling Factor	None	1
Region	DC operating region: off=0, on=1, rev=2, sat=3	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device; if different than the temperature at which the model parameters are valid or extracted (specified by Tnom of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the model to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The fourth terminal (substrate) is available for connection to an external circuit.
4. DC Operating Point Information Model = BJT_Model or EE_BJT2_Model, DC Operating Point Information Model = STBJT_Model, and DC Operating Point Information Model = MEXTRAM_Model (503) list the DC operating point parameters that can be sent to

the dataset.

DC Operating Point Information Model = BJT_Model or EE_BJT2_Mode

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipation	watts
BetaDc	DC current gain	
Gm	Forward transconductance (dIce/dVbe)	siemens
Rpi	Input resistance 1/(dIbe/dVbe)	ohms
Rmu	Feedback resistance 1/(dIbe/dVbc)	ohms
Rx	Base resistance	ohms
Ro	Output resistance 1/(dIbe/dVbc - dIce/dVbc)	ohms
Cpi	Base-emitter capacitance	farads
Cmu	Base-internal collector capacitance	farads
Cbx	Base-external collector capacitance	farads
Ccs	Substrate capacitance	farads
BetaAc	AC current gain	
Ft	Unity current gain frequency	hertz
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

DC Operating Point Information Model = STBJT_Model

Name	**Description**	**Units**
Ic	Collector current	amperes
Is	Substrate current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Power	DC power dissipation	watts
BetaDc	DC current gain	
BetaAc	AC current gain	
fTreal	Unity current gain frequency, full formula	hertz
fTappr	Unity current gain frequency, approximate formula gm/(2*PI*C)	hertz
Gm	Forward transconductance (dIce/dVbe)	siemens
Rpi	Input resistance 1/(dIbe/dVbe)	ohms
Rmu	Reedback resistance 1/(dIbe/dVbc)	ohms
Rx	Base resistance	ohms
Ro	Output resistance 1/(dIbe/dVbc - dIce/dVbc)	ohms
Rcv	Collector resistance	ohms
Cpi	Base-emitter capacitance	farads
Cmu	Base-internal collector capacitance	farads
Cbx	Base-external collector capacitance	farads
Ccs	Internal collector-substrate capacitance	farads
Cbs	Internal base-substrate capacitance	farads
Cxs	External base-substrate capacitance	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

DC Operating Point Information Model = MEXTRAM_Model (503)

Name	**Description**	**Units**
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
dIc2e1_dVb2e1	(dIc2e1/dVb2e1)	siemens
Gb2e1	(dIb2e1/dVb2e1)	siemens
Gb1b2	(dIb1b2/dVb1b2)	siemens
Gb1c1	(dIb1c1/dVb1c1)	siemens
Gbc1	(dIbc1/dVbc1)	siemens
Gb2c2	(dIb2c2/dVb2c2)	siemens
Cb2e1	(dIb2e1/dVb2e1)	siemens
Cb2c2	(dIb2c2/dVb2c2)	siemens
Gb1e1	(dIb1e1/dVb1e1)	siemens
Gc1s	(dIc1s/dVc1s)	siemens
dIc2e1_dVb2c2	(dIc2e1/dVb2c2)	siemens
dIc2e1_dVb2c1	(dIc2e1/dVb2c1)	siemens
dIc1c2_dVb2e1	(dIc1c2/dVb2e1)	siemens
dIc1c2_dVb2c2	(dIc1c2/dVb2c2)	siemens
dIc1c2_dVb2c1	(dIc1c2/dVb2c1)	siemens
dIb2c2_dVb2e1	(dIb2c2/dVb2e1)	siemens
dIb2c2_dVb2c1	(dIb2c2/dVb2c1)	siemens
dIb1b2_dVb2e1	(dIb1b2/dVb2e1)	siemens
dIb1b2_dVb2c2	(dIb1b2/dVb2c2)	siemens
dIb1b2_dVb2c1	(dIb1b2/dVb2c1)	siemens
dIc1s_dVb1c1	(dIc1s/dVb1c1)	siemens
dIc1s_dVbc1	(dIc1s/dVbc1)	siemens
Cb1b2	(dQb1b2/dVb1b2)	farads
Cc1s	(dQc1s/dVc1s)	farads
Cb1c1	(dQb1c1/dVb1c1)	farads
Cbc1	(dQbc1/dVbc1)	farads
dQb2e1_dVb2c2	(dQb2e1/dVb2c2)	farads
dQb2e1_dVb2c1	(dQb2e1/dVb2c1)	farads
dQc2b2_dVb2e1	(dQc2b2/dVb2e1)	farads
dQb2c2_dVb2c1	(dQb2c2/dVb2c1)	farads
dQb1b2_dVb2e1	(dQb1b2/dVb2e1)	farads
dQb1e1_dVb2e1	(dQb1e1/dVb2e1)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

5. This device has no default artwork associated with it.

References

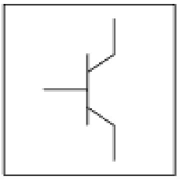
1. I. E. Getreu, *CAD of Electronic Circuits, 1; Modeling the Bipolar Transistor,* Elsevier

Scientific Publishing Company, 1978.

2. P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE,* Second Edition, McGraw-Hill, Inc., 1993.

BJT_Model (Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NPN	Model type (NPN bipolar transistor): YES or NO	None	yes
PNP	Model type (PNP bipolar transistor): YES or NO	None	no
Is (Js)	Transport Saturation Current	A	1.0e-16
Bf	Ideal Maximum Forward Beta	None	100
Nf	Forward Current Emission Coefficient	None	1.0
Vaf (Vbf)	Forward Early Voltage	V	fixed at infinity †
Ikf (Jbf)	Corner for Forward Beta High Current Roll-off	A	fixed at infinity †
Ise (Jle)	base-emitter leakage saturation current	A	0.0
C2	forward leakage saturation current coefficient. If Ise is not given, Ise= C2 x Is	None	0.0
Ne (Nle)	base-emitter leakage emission coefficient	None	1.5
Br ††	Ideal Maximum Reverse Beta	None	1.0 ††
Nr	reverse current emission coefficient	None	1.0
Var (Vbr)	reverse early voltage	V	fixed at infinity †
Ikr (Jbr)	Corner for Reverse Beta High Current Roll-off	A	fixed at infinity †
Ke	base-emitter space charge integral multiplier	1/V	0.0
Kc	base-collector space charge integral multiplier	1/V	0.0
Isc (Jlc) ††, †††	base-collector leakage saturation current	A	0.0
C4	reverse leakage saturation current coefficient. If Isc is not given, Isc = C4 x Is.	None	0.0
Nc (Nlc)	base-collector leakage emission coefficient	None	2.0
Cbo †††	extrapolated 0-volt base-collector leakage current	A	0.0

Gbo †††	slope of Icbo vs. Vbc above Vbo	S	0.0
Vbo	slope of Icbo vs. Vbc at Vbc=0	V	0.0
Rb ††	zero-bias base resistance (Rb may be high-current dependent)	Ohm	fixed at 0
Irb (Jrb)	Current When Base Resistance Falls Halfway to Its Minimum Value	A	fixed at infinity †
Rbm	Minimum base resistance at high currents	Ohm	fixed at 0
Re ‡	emitter resistance	Ohm	fixed at 0
Rc ‡	collector resistance	Ohm	fixed at 0
Rcv ‡	variable collector resistance	Ohm	0.0
Rcm ‡	minimum collector resistance	Ohm	0.0
Dope	collector background doping concentration	cm^{-3}	1e15
Cex	current crowding exponent	None	1.0
Cco †††	current crowding normalization constant	A	1.0
Imax	explosion current beyond which diode junction current is linearized	A	1.0
Imelt	Explosion current; defaults to Imax (refer to note 3)	A	defaults to Imax
Cje ††, †††	base-emitter zero-bias depletion capacitance (Cje, Vje and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	F	0.0
Vje ††	base-emitter junction built-in potential (Cje, Vje and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	V	0.75
Mje	base-emitter junction exponential factor (Cje, Vje and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	None	fixed at 1/3
Cjc ††, †††	base-collector zero-bias depletion capacitance (Cjc, Vjc and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	F	0.0
Vjc ††	base-collector junction built-in potential (Cjc, Vjc and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	V	0.75
Mjc	base-collector junction exponential factor (Cjc, Vjc and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	None	fixed at 1/3
Xcjc (Cdis)	fraction of Cjc that goes to internal base pin	F	1.0
Cjs ††, †††	zero-bias collector substrate (ground) capacitance (Cjs, Mjs and Vjs determine nonlinear depletion-layer capacitance for C-S junction)	F	0.0
Vjs ††	substrate junction built-in potential (Cjs, Vjs, Mjs determine nonlinear depletion-layer capacitance for C-S junction)	V	0.75
Mjs	substrate junction exponential factor (Cjs, Vjs, Mjs determine nonlinear depletion-layer capacitance for C-S junction)	None	fixed at 0
Fc	forward-bias depletion capacitance coefficient	None	0.5
Xtf	coefficient of bias-dependence for Tf	None	0.0
Tf	ideal forward transit time (Tr and Tf, along with the depletion-layer capacitances model base charge storage effects; Tf may be bias-dependent)	sec	0.0
Vtf	voltage dependence of Tf on base-collector voltage	V	fixed at infinity‡
Itf (Jtf) †††	high-current effect on Tf	A	0.0
Ptf	excess phase at frequency = 1 / (Tf × 2π)	deg	0.0
Tr	ideal reverse transit time (Tr, Tf, and depletion-layer capacitances	sec	0.0

	model base charge storage effects)		
Kf	flicker-noise coefficient	None	0.0
Af	flicker-noise exponent	None	1.0
Kb (Bnoisefc)	burst noise coefficient	None	0.0
Ab	burst noise exponent	None	1.0
Fb	burst noise corner frequency	Hz	1.0
Rbnoi	effective base noise resistance; defaults to Rb	Ohm	defaults to Rb
Iss ††, †††	collector-substrate P-N junction saturation current	A	0.0
Ns	collector-substrate P-N junction emission coefficient	None	1.0
Nk	high-current roll-off coefficient	None	0.5
Ffe	flicker noise frequency exponent	None	1.0
Lateral	lateral substrate geometry type: yes, no	None	no
RbModel	base resistance model: Spice=1, MDS=0	None	MDS
Approxqb	use the approximation for Qb vs early voltage: yes, no	None	yes
Tnom	nominal ambient temperature	°C	25
Trise	temperature rise over ambient	°C	0
Tlev	temperature equation selector (0/1/2/3)	None	0
Tlevc	temperature equation selector for capacitance (0/1/2/3)	None	0
Eg	energy gap for temperature effect on Is	eV	1.11
EgAlpha (Gap1)	energy gap temperature coefficient alpha	V/°C	7.04e-4
EgBeta (Gap2)	energy gap temperature coefficient beta	K	1108
Tbf1	Bf linear temperature coefficient	1/°C	0
Tbf2	Bf quadratic temperature coefficient	$1/(°C)^2$	0
Tbr1	Br linear temperature coefficient	1/°C	0
Tbr2	Br quadratic temperature coefficient	$1/(°C)^2$	0
Tcbc (Ctc)	Cbc linear temperature coefficient	1/°C	0
Tcbe (Cte)	Cbe linear temperature coefficient	1/°C	0
Tcbo	Cbo linear temperature coefficient	1/°C	0
Tccs (Cts)	Ccs linear temperature coefficient	1/°C	0
Tgbo	Gbo linear temperature coefficient	1/°C	0
Tikf1	Ikf linear temperature coefficient	1/°C	0
Tikf2	Ikf quadratic temperature coefficient	$1/(°C)^2$	0
Tikr1	Ikr linear temperature coefficient	1/°C	0
Tikr2	Ikr quadratic temperature coefficient	$1/(°C)^2$	0
Tirb1	Irb linear temperature coefficient	1/°C	0
Tirb2	Irb quadratic temperature coefficient	$1/(°C)^2$	0
Tis1	Is/Ibe/Ibc linear temperature coefficient	1/°C	0
Tis2	Is/Ibe/Ibc quadratic temperature coefficient	$1/(°C)^2$	0
Tisc1	Isc linear temperature coefficient	1/°C	0
Tisc2	Isc quadratic temperature coefficient	$1/(°C)^2$	0
Tise1	Ise linear temperature coefficient	1/°C	0

Tise2	Ise quadratic temperature coefficient	$1/(°C)^2$	0
Tiss1	Iss linear temperature coefficient	1/°C	0
Tiss2	Iss quadratic temperature coefficient	$1/(°C)^2$	0
Titf1	Itf linear temperature coefficient	1/°C	0
Titf2	Itf quadratic temperature coefficient	$1/(°C)^2$	0
Tmjc1	Mjc linear temperature coefficient	1/°C	0
Tmjc2	Mjc quadratic temperature coefficient	$1/(°C)^2$	0
Tmje1	Mje linear temperature coefficient	1/°C	0
Tmje2	Mje quadratic temperature coefficient	$1/(°C)^2$	0
Tmjs1	Mjs linear temperature coefficient	1/°C	0
Tmjs2	Mjs quadratic temperature coefficient	$1/(°C)^2$	0
Tnc1	Nc linear temperature coefficient	1/°C	0
Tnc2	Nc quadratic temperature coefficient	$1/(°C)^2$	0
Tne1	Ne linear temperature coefficient	1/°C	0
Tne2	Ne quadratic temperature coefficient	$1/(°C)^2$	0
Tnf1	Nf linear temperature coefficient	1/°C	0
Tnf2	Nf quadratic temperature coefficient	$1/(°C)^2$	0
Tnr1	Nr linear temperature coefficient	1/°C	0
Tnr2	Nr quadratic temperature coefficient	$1/(°C)^2$	0
Tns1	Ns linear temperature coefficient	1/°C	0
Tns2	Ns quadratic temperature coefficient	$1/(°C)^2$	0
Trb1	Rb linear temperature coefficient	1/°C	0
Trb2	Rb quadratic temperature coefficient	$1/(°C)^2$	0
Trc1	Rc linear temperature coefficient	1/°C	0
Trc2	Rc quadratic temperature coefficient	$1/(°C)^2$	0
Tre1	Re linear temperature coefficient	1/°C	0
Tre2	Re quadratic temperature coefficient	$1/(°C)^2$	0
Trm1	Rbm linear temperature coefficient	1/°C	0
Trm2	Rbm quadratic temperature coefficient	$1/(°C)^2$	0
Ttf1	Tf linear temperature coefficient	1/°C	0
Ttf2	Tf quadratic temperature coefficient	$1/(°C)^2$	0
Ttr1	Tr linear temperature coefficient	1/°C	0
Ttr2	Tr quadratic temperature coefficient	$1/(°C)^2$	0
Tvaf1	Vaf linear temperature coefficient	1/°C	0
Tvaf2	Vaf quadratic temperature coefficient	$1/(°C)^2$	0
Tvar1	Var linear temperature coefficient	1/°C	0
Tvar2	Var quadratic temperature coefficient	$1/(°C)^2$	0
Tvjc	Vjc linear temperature coefficient	1/°C	0
Tvje	Vje linear temperature coefficient	1/°C	0
Tvjs	Vjs linear temperature coefficient	1/°C	0
Tvtf1	Vtf linear temperature coefficient	1/°C	0

Tvtf2	Vtf quadratic temperature coefficient	$1/(°C)^2$	0
Txtf1	Xtf linear temperature coefficient	1/°C	0
Txtf2	Xtf quadratic temperature coefficient	$1/(°C)^2$	0
Xtb (Tb)	temperature exponent for forward- and reverse-beta. Xtb partly defines dependence of base current on temp.	None	0.0
Xti (Pt)	temperature exponent for saturation current	None	3.0
wVsubfwd (Vsubfwd)	substrate junction forward bias (warning)	V	None
wBvsub (Bvsub)	substrate junction reverse breakdown voltage (warning)	V	None
wBvbe (Bvbe)	base-emitter reverse breakdown voltage (warning)	V	None
wBvbc (Bvbc)	base-collector reverse breakdown voltage (warning)	V	None
wVbcfwd (Vbcfwd)	base-collector forward bias (warning)	V	None
wIbmax	maximum base current (warning)	A	None
wIcmax	maximum collector current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None
† A value of 0.0 is interpreted as infinity. †† This parameter value varies with temperature based on model Tnom and device Temp. ††† This parameter value scales with Area.‡ This parameter value scales with 1/Area.			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model  modelname  BJT [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *BJT*. Use either parameter NPN=yes or PNP=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn1  BJT  \
 NPN=yes Is=1.5e- Cjc=2.0e-13
```

Notes/Equations

1. BJT_Model supplies values for BJT devices (BJT4 devices include a substrate terminal). Adapted from the integral charge control model of Gummel and Poon, it includes several effects at high bias levels. It reduces to the simpler Ebers-Moll model when certain parameters required for Gummel-Poon are not specified.
   The DC characteristics of a modified Gummel-Poon BJT are defined by:
   - Is, Bf, Ikf, Nf, Ise, and Ne, which determine forward-current gain characteristics.
   - Is, Br, Ikr, Nr, Isc, and Nc, which determine reverse-current gain characteristics
   - Vaf and Var, which determine output conductances for forward and reverse regions.
   - Is (saturation current). Eg and Xti partly determine temperature dependence of Is.
   - Xtb determines base current temperature dependence.
   - Rb, Rc, and Re are ohmic resistances. Rb is current dependent.
     The nonlinear depletion layer capacitances are determined by:
   - Cje, Vje, and Mje for the base-emitter junction.
   - Cjc, Vjc, and Mjc for the base-collector junction.
   - Cjs, Vjs, and Mjs for the collector-substrate junction (if vertical BJT), or for the base-substrate junction (if lateral BJT)
     The collector or base to substrate junction is modeled as a PN junction.
2. Substrate Terminal
   Five model parameters control the substrate junction modeling: Cjs, Vjs and Mjs model the nonlinear substrate junction capacitance; Iss and Ns model the nonlinear substrate P-N junction current.
   When BJT4_NPN or BJT4_PNP devices are used, explicitly connect the substrate terminal as required. When 3-terminal BJT_NPN or BJT_PNP devices are used, the substrate terminal is implicitly grounded. This should not affect the simulation if the substrate model parameters Cjs and Iss are not specified, as they default to 0.
   The model Lateral parameter changes the connection of the substrate junction. At its default setting of no, the substrate junction models a vertical bipolar transistor with the substrate junction connected to the collector. When Lateral=yes, a lateral bipolar transistor is modeled with the substrate junction connected to the base.
3. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).

DC Equations

There are two components of base current associated with the bias on each junction. For the emitter junction, an ideal exponential voltage term *Ibei* arises due to recombination in the inactive base region and carrier injected into the emitter. A non-ideal exponential voltage term *Iben* predominates at low bias due to recombination in the emitter junction spaced charge region.

$$Ibei = Is\left(\exp\left(\frac{Vbe}{Nf \times V_T}\right) - 1\right)$$

$$Iben = Ise\left(\exp\left(\frac{Vbe}{Ne \times V_T}\right) - 1\right)$$

Similarly, emission and recombination near the collector junction result in similar terms.

$$Ibci = Is\left(\exp\left(\frac{Vbc}{Nr \times V_T}\right) - 1\right)$$

$$Ibcn = Isc\left(\exp\left(\frac{Vbc}{Nc \times V_T}\right) - 1\right)$$

Collector Leakage Current

If Vbo is specified, when Vbc < 0 the collector leakage current Icbo is modeled by

$$Icbo = (-Cbo + Gbo \times Vbc)\left[1 - \exp\left(\frac{Vbc}{Vbo}\right)\right]$$

Base Terminal Current (without substrate current)

$$Ib = \frac{Ibei}{Bf} + Iben + \frac{Ibci}{Br} + Ibcn$$

Collector Terminal Current (without substrate current)

$$Ic = \frac{Ibei - Ibci}{Qb} - \frac{Ibci}{Br} - Ibcn$$

Collector-Emitter Current

$$Ice = \frac{Ibei - Ibci}{Qb}$$

where the normalized base charge is Qb.
If Approxqb = yes

$$Qb = \frac{Q1}{2} \times \left(1 + \left(1 + 4\left(\frac{Ibei}{Ikf} + \frac{Ibci}{Ikr}\right)\right)^{Nk}\right)$$

where

$$Q1 = \frac{1}{1 - \frac{Vbc}{Vaf} - \frac{Vbe}{Var}}$$

if neither Ke nor Kc is specified
otherwise

$$Q1 = 1 + \int_0^{Vbe} f(Ke, Vje, Mje)dv + \int_0^{Vbc} f(Kc, Vjc, Mjc)dv$$

where *f*( ) is defined as:

$$f(K, V, M) = \begin{cases} K\left(1 - \frac{v}{V}\right)^{-M} & \text{if } v < Fc \times V \\ K\left(\frac{1 - Fc(1+M) + M\left(\frac{v}{V}\right)}{(1-Fc)^{(1+M)}}\right) & \text{if } v \geq Fc \times V \end{cases}$$

If Approxqb = no

$$Qb = \frac{1 + \frac{Vbc}{Vaf} + \frac{Vbc}{Var}}{2} \times \left(1 + \left(1 + 4\left(\frac{Ibei}{Ikf} + \frac{Ibci}{Ikr}\right)\right)^{Nk}\right)$$

Substrate Current

Lateral = no (Vertical BJT)

$$Isc = Iss\left(\exp\left(\frac{Vsc}{Ns \times V_T}\right) - 1\right)$$

Lateral = yes (Lateral BJT)

$$Ibs = Iss\left(\exp\left(\frac{Vbs}{Ns \times V_T}\right) - 1\right)$$

Base Resistance

The base resistance *RBb* consists of two separate resistances. The contact and sheet resistance *Rbm* and the resistance of the internal (active) base register, *vbi,* which is a function of the base current.

If Rbm is zero or IB < 0, RBb = Rb

If *Ivb* is not specified

$$RBb = Rbm + \frac{Rb - Rbm}{Qb}$$

If *Ivb* is specified

RBb = Rbm + vbi

There are two equations for vbi; *RbModel* determines which equations to use.

If RbModel = Spice

$$vbi = 3(Rb - Rbm)\left(\frac{\tan(z) - z}{z\tan^2(z)}\right)$$

where

$$z = \frac{\sqrt{1 + \frac{144}{\pi^2} \times \frac{Ib}{Irb}} - 1}{\frac{24}{\pi^2}\sqrt{\frac{Ib}{Irb}}}$$

If RbModel = MDS

$$vbi = \frac{Rb - Rbm}{\sqrt{1 + 3\left(\frac{Ib}{Irb}\right)^{0.852}}}$$

Nonlinear Collector Resistance

If Rcv is specified

$$Rc = Rcv\left(\frac{1 + \left(\frac{Ic}{CCo}\right)^{Cex}}{1 + \left(\frac{ni}{Dope}\right)^{2} \exp\left(\frac{Vbc}{vt}\right)}\right) + Rcm$$

where
ni is intrinsic carrier concentration for _Si
vt_ is thermal voltage

Capacitance Equations

Capacitances in the small-signal model contain the junction depletion layer capacitance and the diffusion capacitance due to the minority charge storage in the base region.

Base-Emitter Depletion Capacitances

Vbe < Fc x Vje

$$Cbedep = Cje\left(1 - \frac{Vbe}{vje}\right)^{-Mje}$$

Vbe ≥ Fc x Vje

$$Cbedep = Cje\left(\frac{1 - Fc(1 + Mje) + Mje\left(\frac{Vbe}{Vje}\right)}{(1 - fc)^{(1 + Mje)}}\right)$$

Base-Emitter Diffusion Capacitance

$$Cbediff = \frac{d(Qbediff)}{d(Vbe)}$$

where the transit charge

$$Qbdiff = Tf\left(1 + xtf \times \exp\left(\frac{Vbc}{1.442695Vtf}\right)\left(\frac{Ibei}{Ibei + Itf}\right)^{2} \times \frac{Ibei}{Qb}\right)$$

Cbe = Cbedep + Cbediff

Base-Collector Depletion Capacitances

When Xcjc is not equal to one, the base-collector depletion capacitance is modeled as a distributed capacitance.
The internal base-internal collector depletion capacitance
Vbc < Fc x Vjc

$$Cbcdep = Xcjc \times Cjc\left(1 - \frac{Vbc}{Vjc}\right)^{-Mjc}$$

Vbc ≥ Fc x Vjc

$$Cbcdep = Xcjc \times Cje\left(\frac{1 - Fc(1 + Mjc) + Mjc\left(\frac{Vbc}{Vjc}\right)}{(1 - fc)^{(1 + Mjc)}}\right)$$

The external base-internal collector depletion capacitance
VBc < fc x Vjc

$$Cbcdep = (1 - Xcjc)Cjc\left(1 - \frac{Vbc}{Vjc}\right)^{-Mjc}$$

VBc ≥ Fc x Vjc

$$Cbcdep = (1 - Xcjc)Cjc\left(\frac{1 - Fc(1 + Mjc) + Mjc\left(\frac{Vbc}{Vjc}\right)}{(1 - fc)^{(1 + Mjc)}}\right)$$

CBc = CBcdep

Base-Collector Diffusion Capacitances

$$Cbcdiff = \frac{d(Qbcdiff)}{d(Vbc)}$$

where the transit charge
Qbcdiff = Tr × Ibci
Cbc = Cbcdep + Cbcdiff

Base-Collector Substrate Capacitance

Lateral = no (vertical BJT)
Vsc < 0

$$Csc = Cjs\left(1 - \frac{Vsc}{Vjs}\right)^{-Mjs}$$

$Vsc \geq 0$

$$Csc = Cjs\left(1 + Mjs \times \frac{Vsc}{Vjs}\right)$$

Lateral = yes (Lateral BJT)
$Vbs < 0$

$$Cbs = Cjs\left(1 - \frac{Vbs}{Vjs}\right)^{-Mjs}$$

$Vbs \geq 0$

$$Cbs = Cjs\left(1 + Mjs \times \frac{Vbs}{Vjs}\right)$$

Excess Phase

An additional phase shift at high frequencies is added to the transconductance model to account for the distributed phenomena in the transistor. The effective phase shift added to the *Ibei* item in the *Ic* equation is calculated as follows for *Ibei* (with excess phase):

$$Ibei = \frac{3\omega_0^{\ 2}}{s^2 + 3\omega_0 s + 3\omega_0^{\ 2}} \times Ibei$$

where

$$\omega_0 = \frac{1}{Ptf \times Tf \times \frac{\pi}{180}}$$

The current implementation in ADS applies the shifting factor to collector current IC.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device Temp parameter. (Temperatures in the following equations are in Kelvin.)
The energy bandgap E_G varies as:

$$E_G(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108}$$

Tlev = 0, 1, 3

$$E_G(T) = Eg - \frac{EgAlphaT^2}{T + EgBeta}$$

Tlev = 2
The intrinsic carrier concentration n_i for silicon varies as:

$$n_i(T) = 1.45 \times 10^{10}\left(\frac{T}{300.15}\right)^{3/2} \exp\left(\frac{E_G(300.15)}{2k300.15/q} - \frac{E_G(T)}{2k(T/q)}\right)$$

Saturation currents Is, Ise, Isc, and Iss scale as:
if Tlev=0

$$Ise^{NEW} = Ise\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{Eg}{NekTnom/q} - \frac{Eg}{NekTemp/q} + \frac{Xti}{Ne}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isc^{NEW} = Isc\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{Eg}{NckTnom/q} - \frac{Eg}{NckTemp/q} + \frac{Xti}{Nc}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Iss^{NEW} = Iss\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{Eg}{NskTnom/q} - \frac{Eg}{NskTemp/q} + \frac{Xti}{Ns}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Is^{NEW} = Is\exp\left[\frac{E_G}{kTnom/q} - \frac{E_G}{kTemp/q} + Xti\ln\left(\frac{Temp}{Tnom}\right)\right]$$

if Tlev=1

$$Ise^{NEW} = \frac{Ise}{1 + Xtb(Temp - Tnom)}\exp\left[\frac{Eg}{NekTnom/q} - \frac{Eg}{NekTemp/q} + \frac{Xti}{Ne}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isc^{NEW} = \frac{Isc}{1 + Xtb(Temp - Tnom)}\exp\left[\frac{Eg}{NckTnom/q} - \frac{Eg}{NckTemp/q} + \frac{Xti}{Nc}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Iss^{NEW} = \frac{Iss}{1 + Xtb(Temp - Tnom)}\exp\left[\frac{Eg}{NskTnom/q} - \frac{Eg}{NskTemp/q} + \frac{Xti}{Ns}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Is^{NEW} = Is\exp\left[\frac{Eg}{kTnom/q} - \frac{Eg}{kTemp/q} + Xti\ln\left(\frac{Temp}{Tnom}\right)\right]$$

if Tlev=2

$$Ise^{NEW} = Ise\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{E_G(Tnom)}{NekTnom/q} - \frac{E_G(Temp)}{NekTemp/q} + \frac{Xti}{Ne}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isc^{NEW} = Isc\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{E_G(Tnom)}{NckTnom/q} - \frac{E_G(Temp)}{NckTemp/q} + \frac{Xti}{Nc}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Iss^{NEW} = Iss\left(\frac{Temp}{Tnom}\right)^{-Xtb} \exp\left[\frac{E_G(Tnom)}{NskTnom/q} - \frac{E_G(Temp)}{NskTemp/q} + \frac{Xti}{Ns}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Is^{NEW} = Is\exp\left[\frac{E_G(Tnom)}{kTnom/q} - \frac{E_G(Temp)}{kTemp/q} + Xti\ln\left(\frac{Temp}{Tnom}\right)\right]$$

if Tlev=3

$$Ise^{NEW} = Ise^{(1 + Tise1(Temp - Tnom) + Tise2(Temp - Tnom)^2)}$$

$$Isc^{NEW} = Isc^{(1 + Tisc1(Temp - Tnom) + Tisc2(Temp - Tnom)^2)}$$

$$Iss^{NEW} = Iss^{(1 + Tiss1(Temp - Tnom) + Tiss2(Temp - Tnom)^2)}$$

$$Is^{NEW} = Is^{(1 + Tis1(Temp - Tnom) + Tis2(Temp - Tnom)^2)}$$

Series resistances Rc, Re, Rb, and Rbm scale as:

$$Rc^{NEW} = Rc[1 + Trc1(Temp - Tnom) + Trc2(Temp - Tnom)^2]$$

$$Re^{NEW} = Re[1 + Tre1(Temp - Tnom) + Tre2(Temp - Tnom)^2]$$

$$Rb^{NEW} = Rb[1 + Trb1(Temp - Tnom) + Trb2(Temp - Tnom)^2]$$

$$Rbm^{NEW} = Rbm[1 + Trm1(Temp - Tnom) + Trm2(Temp - Tnom)^2]$$

Emission coefficients Nc, Ne, Nf, Nr, and Ns scale as:

$$Nc^{NEW} = Nc[1 + Tnc1(Temp - Tnom) + Tnc2(Temp - Tnom)^2]$$

$$Ne^{NEW} = Ne[1 + Tne1(Temp - Tnom) + Tne2(Temp - Tnom)^2]$$

$$Nf^{NEW} = Nf[1 + Tnf1(Temp - Tnom) + Tnf2(Temp - Tnom)^2]$$

$$Nr^{NEW} = Nr[1 + Tnr1(Temp - Tnom) + Tnr2(Temp - Tnom)^2]$$

$$Ns^{NEW} = Ns[1 + Tns1(Temp - Tnom) + Tns2(Temp - Tnom)^2]$$

Transmit times Tf and Tr scale as:

$$Tf^{NEW} = Tf[1 + Ttf1(Temp - Tnom) + Ttf2(Temp - Tnom)^2]$$

$$Tr^{NEW} = Tr[1 + Ttr1(Temp - Tnom) + Ttr2(Temp - Tnom)^2]$$

High current effect on transit time Itf scales as:

$$Itf^{NEW} = Itf[1 + Titf1(Temp - Tnom) + Titf2(Temp - Tnom)^2]$$

Vbc dependence on transmit time Vtf scales as:

$$Vtf^{NEW} = Vtf[1 + Tvtf1(Temp - Tnom) + Tvtf2(Temp - Tnom)^2]$$

Bias dependence on transmit time Xtf scales as:

$$Xtf^{NEW} = Xtf[1 + Txtf1(Temp - Tnom) + Txtf2(Temp - Tnom)^2]$$

Early voltage Vaf and Var scale as:

$$Vaf^{NEW} = Vaf[1 + Tvaf1(Temp - Tnom) + Tvaf2(Temp - Tnom)^2]$$

$$Var^{NEW} = Var[1 + Tvar1(Temp - Tnom) + Tvar2(Temp - Tnom)^2]$$

Forward and reverse beta Bf and Br scale as:
if Tlev = 0

$$Bf^{NEW} = Bf\left(\frac{Temp}{Tnom}\right)^{Xtb}(1 + Tbf1(Temp - Tnom) + Tbf2(Temp - Tnom)^2)$$

$$Br^{NEW} = Br\left(\frac{Temp}{Tnom}\right)^{Xtb}(1 + Tbr1(Temp - Tnom) + Tbr2(Temp - Tnom)^2)$$

if Tlev = 1

$$Bf^{NEW} = Bf(1 + Xtb(Temp - Tnom))(1 + Tbf1(Temp – Tnom) + Tbf2(Temp - Tnom)^2)$$

$$Br^{NEW} = Br(1 + Xtb(Temp - Tnom))(1 + Tbr1(Temp – Tnom) + Tbr2(Temp - Tnom)^2)$$

if Tlev = 2

$$Bf^{NEW} = Bf\left(\frac{Temp}{Tnom}\right)^{Xtb}(1 + Tbf1(Temp – Tnom) + Tbf2(Temp - Tnom)^2)$$

$$Br^{NEW} = Br\left(\frac{Temp}{Tnom}\right)^{Xtb}(1 + Tbr1(Temp – Tnom) + Tbr2(Temp - Tnom)^2)$$

if Tlev = 3

$$Bf^{NEW} = Bf(1 + Tbf1(Temp – Tnom) + Tbf2(Temp - Tnom)^2)$$

$$Br^{NEW} = Br(1 + Tbr1(Temp – Tnom) + Tbr2(Temp - Tnom)^2)$$

Currents Ikf, Ikr, and Irb scale as:
if Tlev = 0, 1, 2

$$Ikf^{NEW} = Ikf(1 + Tikf1(Temp – Tnom) + Tikf2(Temp - Tnom)^2)$$

$$Ikr^{NEW} = Ikr(1 + Tikr1(Temp – Tnom) + Tikr2(Temp - Tnom)^2)$$

$$Irb^{NEW} = Irb(1 + Tirb1(Temp – Tnom) + Tirb2(Temp - Tnom)^2)$$

if Tlev = 3

$$Ikf^{NEW} = Ikf^{(1 + Tikf1(Temp – Tnom) + Tikf2(Temp - Tnom)^2)}$$

$$Ikr^{NEW} = Ikr^{(1 + Tikr1(Temp – Tnom) + Tikr2(Temp - Tnom)^2)}$$

$$Irb^{NEW} = Irb^{(1 + Tirb1(Temp – Tnom) + Tirb2(Temp - Tnom)^2)}$$

Junction depletion capacitance Cjo and Cjsw and junction potentials Vje, Vjc, and Vjs vary as:
if Tlevc = 0

$$Vje^{NEW} = Vje\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Vjc^{NEW} = Vjc\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Vjcs^{NEW} = Vjs\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Cje^{NEW} = Cje\left(1 + Mje\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Vje^{NEW}}{Vje}\right]\right)$$

$$Cjc^{NEW} = Cjc\left(1 + Mjc\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Vjc^{NEW}}{Vjc}\right]\right)$$

$$Cjs^{NEW} = Cjs\left(1 + Mjs\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Vjs^{NEW}}{Vjs}\right]\right)$$

if Tlevc = 1

$$Vje^{NEW} = Vje - Tvje(Temp - Tnom)$$

$$Vjc^{NEW} = Vjc - Tvjc(Temp - Tnom)$$

$$Vjs^{NEW} = Vjs - Tvjs(Temp - Tnom)$$

$$Cje^{NEW} = Cje[1 + Tcje(Temp - Tnom)]$$

$$Cjc^{NEW} = Cjc[1 + Tcjc(Temp - Tnom)]$$

$$Cjs^{NEW} = Cjs[1 + Tcjs(Temp - Tnom)]$$

if Tlevc = 2

$$Vje^{NEW} = Vje - Tvje(Temp - Tnom)$$

$$Vjc^{NEW} = Vjc - Tvjc(Temp - Tnom)$$

$$Vjs^{NEW} = Vjs - Tvjs(Temp - Tnom)$$

$$Cje^{NEW} = Cje\left(\frac{Vje}{Vje^{NEW}}\right)^{Mjc}$$

$$Cjc^{NEW} = Cjc\left(\frac{Vjc}{Vjc^{NEW}}\right)^{Mjc}$$

$$Cjs^{NEW} = Cjs\left(\frac{Vjs}{Vjs^{NEW}}\right)^{Mjs}$$

if Tlevc = 3
if Tlev = 0, 1, 3

$$dVjedT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Vje\right)\frac{1}{Tnom}$$

$$dVjcdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Vjc\right)\frac{1}{Tnom}$$

$$dVjsdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Vjs\right)\frac{1}{Tnom}$$

if Tlev = 2

$$dVjedT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2EgBeta}{Tnom + EgBeta} - Vje\right)\frac{1}{Tnom}$$

$$dVjcdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2EgBeta}{Tnom + EgBeta} - Vjc\right)\frac{1}{Tnom}$$

$$dVjsdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2EgBeta}{Tnom + EgBeta} - Vjs\right)\frac{1}{Tnom}$$

$$Vje^{NEW} = Vje + dVjedT(Temp - Tnom)$$

$$Vjc^{NEW} = Vjc + dVjcdT(Temp - Tnom)$$

$$Vjs^{NEW} = Vjs + dVjsdT(Temp - Tnom)$$

$$Cje^{NEW} = Cje\left(1 - \frac{dVjedT(Temp - Tnom)}{2Vje}\right)$$

$$Cjc^{NEW} = Cjc\left(1 - \frac{dVjcdT(Temp - Tnom)}{2Vjc}\right)$$

$$Cjs^{NEW} = Cjs\left(1 - \frac{dVjsdT(Temp - Tnom)}{2Vjs}\right)$$

Junction grading coefficients Mje, Mjc, and Mjs scale as:

$$Mje^{NEW} = Mje[1 + Tmje1(Temp - Tnom) + Tmje2(Temp - Tnom)^2]$$

$$Mjc^{NEW} = Mjc[1 + Tmjc1(Temp - Tnom) + Tmjc2(Temp - Tnom)^2]$$

$$Mjs^{NEW} = Mjs[1 + Tmjs1(Temp - Tnom) + Tmjs2(Temp - Tnom)^2]$$

Base-collector leakage current parameters Cbo and Gbo scale as:

$$Cbo^{NEW} = Cbo \times Exp[Tcbo(Temp - Tnom)]$$

$$Gbo^{NEW} = Gbo \times Exp[Tgbo(Temp - Tnom)]$$

Noise Model

Thermal noise generated by resistors Rb, Rc, and Re is characterized by the spectral density:

$$\frac{<i_{Rc}{}^2>}{\Delta f} = \frac{4kT}{Rc}$$

$$\frac{<i_{Rb}{}^2>}{\Delta f} = \frac{4kT}{Rb}\,\frac{Rbnoi}{Rb}$$

$$\frac{<i_{Re}^{2}>}{\Delta f} = \frac{4kT}{Re}$$

Shot noise, flicker noise (Kf, Af, Ffe), and burst noise (Kb, Ab, Fb) generated by the DC base current is characterized by the spectral density:

$$\frac{<i_{be}^{2}>}{\Delta f} = 2qI_{BE} + Kf\frac{I_{BE}^{Af}}{f^{Ffe}} + Kb\frac{IBE^{Ab}}{1+(f/Fb)^{2}}$$

Shot noise generated by the DC collector-to-emitter current is characterized by the spectral density:

$$\frac{<i_{ce}^{2}>}{\Delta f} = 2qI_{CE}$$

Shot noise generated by the DC collector-to-substrate current (BJT4 only) is characterized by the spectral density:

$$\frac{<i_{cs}^{2}>}{\Delta f} = 2qI_{CS}$$

In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, k_f, a_f, f_{fe}, k_b, a_b, and f_b are model parameters, *f* is the simulation frequency, and Δ*f* is the noise bandwidth.

Area Dependence of the BJT Model Parameters

The AREA factor used for the BJT model determines the number of equivalent parallel devices of a specified model. The BJT model parameters affected by the AREA factor are:

Is = Is × AREA
Ise = Ise × AREA
Isc = Isc × AREA
Ikf = Ikf × AREA
Ikr = Ikr × AREA
Irb = Ibr × AREA
Itf = Itf × AREA
Cjc(0) = Cjc(0) × AREA
Cje(0) = Cje(0) × AREA
Cjs(0) = Cjs(0) × AREA
Rb = Rb/AREA
Rbm = Rbm/AREA
Rbnoi = Rbnoi/AREA
Re = Re/AREA
Rc = Rc/AREA

The default value for the AREA parameter is 1.

DC Operating Point Device Information

Definitions

- Ic (collector current)
- Ib (base current)
- Ie (emitter current)
- Is (substrate current)
- Ice (collection-emitter current)
- power (dissipated power)
  BetaDc Ic/Ib
  where
  Ib = sign(ib) x Max (Abs(Ib), ie-20)
  $$Gm = \frac{dIce}{dVbe} + \frac{dIce}{dVbc}$$

$$Rpi = \frac{1}{\left(\frac{dIb}{dVbc}\right)}$$

$$Rmu = \frac{1}{\left(\frac{dIb}{dVbc}\right)}$$

Rx = RBb

$$Ro = \frac{-1}{\left(\frac{dIce}{dVbc}\right)}$$

Cpi = Cbe
Cmu = Cbc
Cbx = CBx
Ccs = Ccs if vertical BJT
= Cbs if lateral BJT
BetAc = Gm x Rpi

$$Ft = \frac{1}{(2\pi(tau + (Rc + Re)(Cmu + Cbx)))}$$

where

$$tau = \frac{Max(Cpi + Cnm + Cbx, ie - 20)}{Max(Gm, ie - 20)}$$

$$Vbe = v(B) - v(E)$$

$$Vbc = v(B) - v(C)$$

$$Vce = v(BC) - v(E)$$

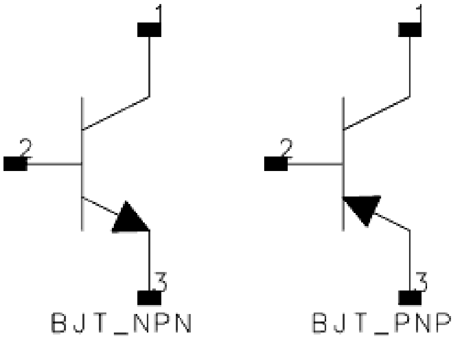
References

1. P. Antognetti and G. Massobrio, *Semiconductor device modeling with SPICE*, New

York: McGraw-Hill, Second Edition 1993.

BJT_NPN, BJT_PNP (Bipolar Junction Transistors NPN, PNP)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	BJTM1
Area	Scaling Factor	None	1.0
Region	DC operating region: 0 = off, 1 = on, 2 = rev, 3 = sat	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to *note 2*)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device; if different than the temperature at which the model parameters are valid or extracted (specified by Tnom of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the model to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The substrate terminal is connected to ground. The substrate current is affected by the ISS and CJS model parameters. There should be no problems with this except perhaps in a PNP transistor where the ISS model parameter is specified. This could cause excess current flow as the substrate PN junction might end up being forward biased. If the connection of the substrate terminal to ground is not acceptable, use

the BJT4 component and connect its substrate terminal to the appropriate place.

4. For information on area dependence, refer to the section *Area Dependence of the BJT Model Parameters* (ccnld).
5. DC operating point parameters that can be sent to the dataset are listed in the following tables according to model.

DC Operating Point Information Model = BJT_Model or EE_BJT2_Model

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipation	watts
BetaDc	DC current gain	
Gm	Forward transconductance (dIce/dVbe)	siemens
Rpi	Input resistance 1/(dIbe/dVbe)	ohms
Rmu	Feedback resistance 1/(dIbe/dVbc)	ohms
Rx	Base resistance	ohms
Ro	Output resistance 1/(dIbe/dVbc - dIce/dVbc)	ohms
Cpi	Base-emitter capacitance	farads
Cmu	Base-internal collector capacitance	farads
Cbx	Base-external collector capacitance	farads
Ccs	Substrate capacitance	farads
BetaAc	AC current gain	
Ft	Unity current gain frequency	hertz
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

DC Operating Point Information Model = STBJT_Model

Name	Description	Units
Ic	Collector current	amperes
Is	Substrate current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Power	DC power dissipation	watts
BetaDc	DC current gain	
BetaAc	AC current gain	
fTreal	Unity current gain frequency, full formula	hertz
fTappr	Unity current gain frequency, approximate formula gm/(2*PI*C)	hertz
Gm	Forward transconductance (dIce/dVbe)	siemens
Rpi	Input resistance 1/(dIbe/dVbe)	ohms
Rmu	Reedback resistance 1/(dIbe/dVbc)	ohms
Rx	Base resistance	ohms
Ro	Output resistance 1/(dIbe/dVbc - dIce/dVbc)	ohms
Rcv	Collector resistance	ohms
Cpi	Base-emitter capacitance	farads
Cmu	Base-internal collector capacitance	farads
Cbx	Base-external collector capacitance	farads
Ccs	Internal collector-substrate capacitance	farads
Cbs	Internal base-substrate capacitance	farads
Cxs	External base-substrate capacitance	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

DC Operating Point Information Model = MEXTRAM_Model (503)

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
dIc2e1_dVb2e1	(dIc2e1/dVb2e1)	siemens
Gb2e1	(dIb2e1/dVb2e1)	siemens
Gb1b2	(dIb1b2/dVb1b2)	siemens
Gb1c1	(dIb1c1/dVb1c1)	siemens
Gbc1	(dIbc1/dVbc1)	siemens
Gb2c2	(dIb2c2/dVb2c2)	siemens
Cb2e1	(dIb2e1/dVb2e1)	siemens
Cb2c2	(dIb2c2/dVb2c2)	siemens
Gb1e1	(dIb1e1/dVb1e1)	siemens
Gc1s	(dIc1s/dVc1s)	siemens
dIc2e1_dVb2c2	(dIc2e1/dVb2c2)	siemens
dIc2e1_dVb2c1	(dIc2e1/dVb2c1)	siemens
dIc1c2_dVb2e1	(dIc1c2/dVb2e1)	siemens
dIc1c2_dVb2c2	(dIc1c2/dVb2c2)	siemens
dIc1c2_dVb2c1	(dIc1c2/dVb2c1)	siemens
dIb2c2_dVb2e1	(dIb2c2/dVb2e1)	siemens
dIb2c2_dVb2c1	(dIb2c2/dVb2c1)	siemens
dIb1b2_dVb2e1	(dIb1b2/dVb2e1)	siemens
dIb1b2_dVb2c2	(dIb1b2/dVb2c2)	siemens
dIb1b2_dVb2c1	(dIb1b2/dVb2c1)	siemens
dIc1s_dVb1c1	(dIc1s/dVb1c1)	siemens
dIc1s_dVbc1	(dIc1s/dVbc1)	siemens
Cb1b2	(dQb1b2/dVb1b2)	farads
Cc1s	(dQc1s/dVc1s)	farads
Cb1c1	(dQb1c1/dVb1c1)	farads
Cbc1	(dQbc1/dVbc1)	farads
dQb2e1_dVb2c2	(dQb2e1/dVb2c2)	farads
dQb2e1_dVb2c1	(dQb2e1/dVb2c1)	farads
dQc2b2_dVb2e1	(dQc2b2/dVb2e1)	farads
dQb2c2_dVb2c1	(dQb2c2/dVb2c1)	farads
dQb1b2_dVb2e1	(dQb1b2/dVb2e1)	farads
dQb1e1_dVb2e1	(dQb1e1/dVb2e1)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

6. This device has no default artwork associated with it.

References

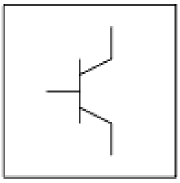
1. I. E. Getreu, *CAD of Electronic Circuits, 1; Modeling the Bipolar Transistor* , Elsevier

Scientific Publishing Company, 1978.

2. P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE* , Second Edition, McGraw-Hill, Inc., 1993.

EE_BJT2_Model (EEsof Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
Type	Model type: 1=NPN or 2=PNP	None	NPN
Nf	forward current emission coefficient	None	1.0
Ne	base emitter leakage emission coefficient	None	1.5
Nbf	forward base ideality factor	None	1.06
Vaf	forward early voltage	V	fixed at infinity †
Ise	base emitter leakage saturation current	A	0.0
Tf	ideal forward transit time (Tr and Tf, along with the depletion-layer capacitances, model base charge storage effects; Tf may be bias-dependent)	sec	0.0
Ikf	corner for forward-beta high current roll-off	A	fixed at infinity †
Xtf	coefficient of bias-dependence for Tf	None	0.0
Vtf	voltage dependence of Tf on base-collector voltage	V	fixed at infinity †
Itf	parameter for high-current effect on Tf	A	0.0
Nbr	reverse base ideality factor	None	1.04
Nr	reverse current emission coefficient	None	1.0
Nc	base collector leakage emission coefficient	None	2.0
Isc	base-collector leakage saturation current	A	0.0
Ikr	corner for reverse-beta high-current roll-off	A	fixed at infinity †
Var	reverse early voltage	V	fixed at infinity †
Tr	ideal reverse transit time (Tr and Tf, along with the depletion-layer capacitances, model base charge storage effects)	sec	0.0
Isf	forward saturation current	A	9.53e-15

Ibif	forward base saturation current	A	1.48e-16
Isr	reverse saturation current	A	1.01e-14
Ibir	reverse base saturation current	A	6.71e-16
Tamb	ambient temperature of measurement and model parameter extraction	°C	25
Cje	base-emitter zero-bias depletion capacitance (Cje, Vje, and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	F	0.0
Vje	base-emitter junction built-in potential (Cje, Vje, and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	V	0.75
Mje	base-emitter junction exponential factor (Cje, Vje, and Mje determine nonlinear depletion-layer capacitance for base-emitter junction)	None	fixed at 1/3
Cjc	base-collector zero-bias depletion capacitance (Cjc, Vjc, and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	F	0.0
Vjc	base-collector junction built-in potential (Cjc, Vjc, and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	V	0.75
Mjc	base-collector junction exponential factor (Cjc, Vjc, and Mjc determine nonlinear depletion-layer capacitance for base-collector junction)	None	fixed at 1/3
Rb	Zero-bias base resistance	Ohm	1e-4
Re	emitter resistance	Ohm	1e-4
Rc	collector resistance	Ohm	1e-4
Fc	forward-bias depletion capacitance coefficient	None	0.5
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvbe	base emitter reverse breakdown voltage (warning)	V	None
wBvbc	base collector reverse breakdown voltage (warning)	V	None
wVbcfwd	base collector forward bias (warning)	V	None
wIbmax	maximum base current (warning)	A	None
wIcmax	maximum collector current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None
† A value of 0.0 is interpreted as infinity			

Notes/Equations

1. This model specifies values for BJT_NPN or BJT_PNP devices.
2. EEBJT2 is the second generation BJT model designed by Agilent EEsof. The model has been created specifically for automatic parameter extraction from measured data including DC and S-parameter measurements. The goal of this model is to overcome some of the problems associated with EEBJT1 or Gummel-Poon models limited accuracy and parameter extraction difficulty with regard to silicon rf/microwave transistors. EEBJT2 is not generally equivalent or compatible with the Gummel-Poon or EEBJT1 models. EEBJT2 can provide a reasonably accurate reproduction of transistor behavior, including DC bias solution, bias-dependent S-parameters including the effects of package parasitics, and true nonlinear harmonic output power. The model is quasi-static, analytical, and isothermal. The model does not scale with area because parameters are intended to be extracted directly from measured data and not from layout considerations. Default values of some parameters are chosen from an average of the first EEBJT2 library model parameters.
3. To prevent numerical problems, the setting of some model parameters is trapped by

the simulator. The parameter values are changed internally:
- Mjc and Mje must be ≤ 0.99
- Fc must be ≤ 0.9999
- Rb, Rc, and Re must be ≥ 10^{-4}

4. The Temp parameter is only used to calculate the noise performance of this device. Temperature scaling of model parameters is not performed for this device.
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent (Data Access Component)* (ccsim) in *Introduction to Circuit Components* (ccsim)). Note that model parameters that are explicitly specified take precedence over those via AllParams.
6. This device has no default artwork associated with it.

Equations

Base-Emitter and Base-Collector Current

The base-emitter current in the BJT has been changed significantly from the Gummel-Poon and other earlier models. These models assume that the non-leakage base-emitter current is related to the collector-emitter current by a simple constant, known as beta. Observation of base-emitter current in both silicon and AlGaAs devices has shown that this assumption is incorrect. Difficulties with this method of modeling base current have been observed for many years. A large, very bias-dependent base resistance in the modified Gummel-Poon model in Berkeley SPICE has been used to attempt to correct the problem with the base-emitter current expressions. This base resistance value and its variation is often extracted from DC data only, with the result that the behavior of the device over frequency is often poorly modeled. This problem is then *solved* by assigning some fraction of the base-collector capacitance to either side of the base in a distributed manner.

Agilent EEsof's experience with EEBJT2 has shown that properly modeled base-emitter current and conductance renders both the large bias-dependent base resistance and distributed base-collector capacitance unnecessary and greatly improves both the DC and AC accuracy of the resulting model.
EE_BJT2 models the base-emitter current with two non-ideal exponential expressions, one for the bulk recombination current (usually dominant in silicon devices), and one for other recombination currents (usually attributed to surface leakage).

$$Ibe = \left(Ibif\left(exp\left(\frac{Vbe}{(NbfV_T)}\right) - 1.0\right)\right) + \left(Ise\left(exp\left(\frac{Vbe}{(Ne \times V_T)}\right) - 1.0\right)\right)$$

where

$$V_T = \frac{k \times Tamb}{q}$$

where

k is Boltzmann's constant, and q is deviceary charge.

Note that Nbf is not necessarily 1.0, which is effectively the case in the Gummel-Poon model.

The base-collector current is similarly modeled:

$$Ibc = \left(Ibir\left(exp(\frac{Vbc}{(Nbr V_T)}) - 1.0\right)\right) + \left(Isc\left(exp(\frac{Vbc}{(Nc \times V_T)}) - 1.0\right)\right)$$

Virtually all silicon rf/microwave transistors are vertical planar devices, so the second current term containing Isc and Nc is usually negligible.

The total base current Ib is the sum of Ibe and Ibc. Note that this method of modeling base current obsoletes the concept of a constant beta.

Collector-Emitter Current

The forward and reverse components of the collector-emitter current are modeled in a manner similar to the Gummel-Poon model, but with more flexibility. Observation of collector-emitter current behavior has shown that the forward and reverse components do not necessarily share identical saturation currents, as in the Gummel-Poon model. The basic expressions in EE_BJT2, not including high-level injection effects and Early effects, are:

$$Icf = Isf \times \left(exp(\frac{Vbe}{(Nf \times V_T)}) - 1.0\right)$$

$$Icr = Isr \times \left(exp(\frac{Vbc}{(Nr \times V_T)}) - 1.0\right)$$

where Isf and Isr are not exactly equal but are usually very close. Nf and Nr are not necessarily equal or 1.0, but are usually very close. Careful control of ambient temperature during device measurement is required for precise extraction of all of the saturation currents and emission coefficients in the model.
The effects of high-level injection and bias-dependent base charge storage are modeled via a normalized base charge, similar to the Gummel-Poon model:

$$Ice = \frac{(Icf - Icr)}{Qb}$$

where

$$Qb = \left(\frac{Q1}{2.0}\right) \times (1.0 + \sqrt{1.0 + (4.0 \times Q2)})$$

and

$$Q1 = \frac{1.0}{\left(1.0 - \left(\frac{Vbc}{Vaf}\right) - \left(\frac{Vbe}{Var}\right)\right)}$$

$$Q2 = \left(\left(\frac{Isf}{Ikf}\right) \times \left(exp(\frac{Vbe}{(Nf \times V_T)}) - 1.0\right)\right) + \left(\left(\frac{Isf}{Ikf}\right) \times \left(exp(\frac{Vbc}{(Nr \times V_T)}) - 1.0\right)\right)$$

Note
All calculations of the exponential expressions used in the model are linearized to prevent numerical overflow or underflow at large forward or reverse bias conditions, respectively.

Base-Emitter and Base-Collector Capacitances

Diffusion and depletion capacitances are modeled for both junctions of the transistor model in a manner very similar to the Gummel-Poon model.

for Vbc ≤ Fc × Vjc

$$Cbc = Cbc_{diffusion} + Cbc_{depletion}$$

where

$$Cbc_{diffusion} = \frac{Tr \times Icr}{Nr \times V_T}$$

and

$$Cbc_{depletion} = \frac{Cjc}{\left(1.0 - \left(\frac{Vbc}{Vjc}\right)\right)^{Mjc}}$$

for Vbc > Fc × Vjc

$$Cbc_{depletion} = \left(\frac{Cjc}{(1.0 - Fc)^{Mjc}}\right) \times \left(1.0 + \left(\frac{Mjc(Vbc - Fc \times Vjc)}{VJjc(1.0 - Fc)}\right)\right)$$

for Vbe ≤ Fc × Vje

$$Cbe = Cbe_{diffusion} + Cbe_{depletion}$$

where

$$Cbe_{depletion} = \frac{Cje}{\left(1.0 - \left(\frac{Vbe}{Vje}\right)\right)^{Mje}}$$

for Vbe > Fc × Vje

$$Cbe_{depletion} = \left(\frac{Cje}{(1.0 - Fc)^{Mje}}\right) \times \left(1.0 + \left(\frac{Mje(Vbe - (Fc \times Vje))}{Vje(1.0 - Fc)}\right)\right)$$

The diffusion capacitance for Cbe is somewhat differently formulated vs. that of Cbc. The transit time is not a constant for the diffusion capacitance for Cbe, but is a function of both junction voltages, formulated in a manner similar to the modified Gummel-Poon model. The total base-emitter charge is equal to the sum of the base-emitter depletion charge (which is a function of Vbe only) and the so-called transit charge (which is a function of both Vbe and Vbc).

$$Q_{transit} = Tff \times \left(\frac{Icf}{Qb}\right)$$

where

$$Tff = Tf \times \left(1.0 + Xtf\left(\frac{Icf}{Icf + Itf}\right)^{2.0} \times exp(\frac{Vbc}{1.44 \times Vtf})\right)$$

and

$$Cbe_{diffusion}(Vbe) = \frac{\partial Q_{transit}}{\partial Vbe}$$

and

$$Cbe_{diffusion}(Vbc) = \frac{\partial Q_{transit}}{\partial Vbc}$$

Noise Model

Thermal noise generated by resistors Rb, Rc, and Re is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Shot noise generated by each of the DC currents flowing from base to emitter, base to collector, and collector to emitter is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = 2qI_{DC}$$

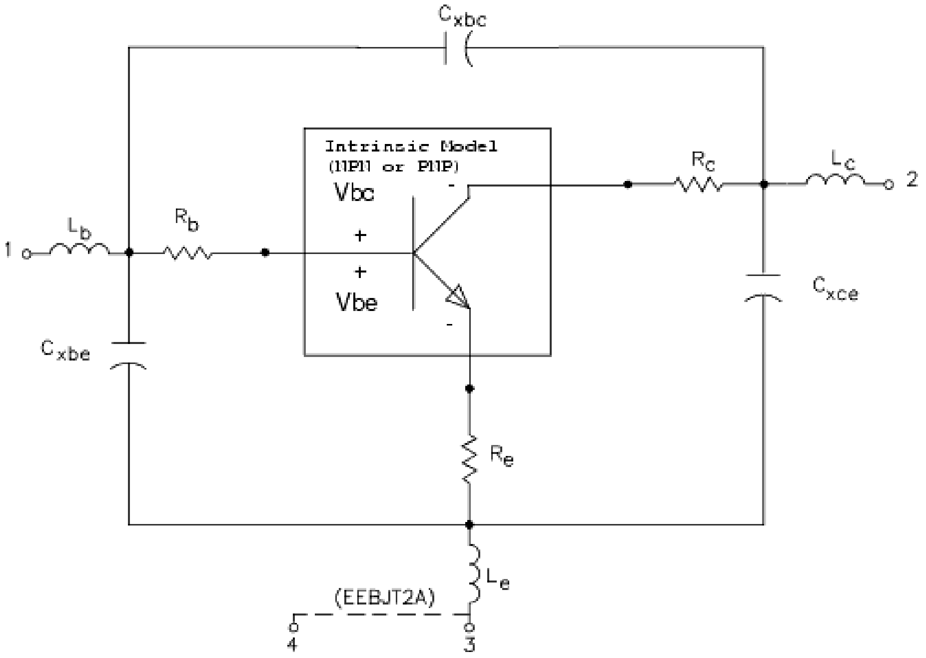
In the previous expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, and Δ*f* is the noise bandwidth.

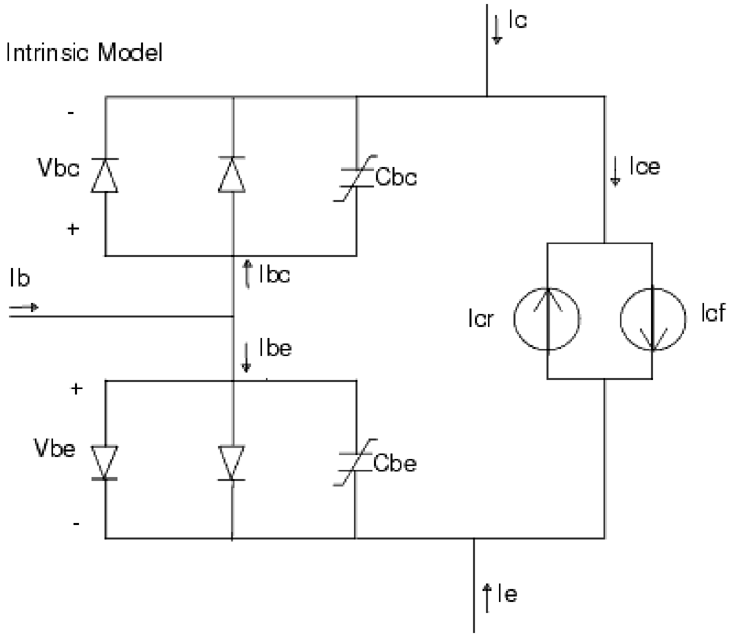
Flicker and burst noise for this device is not modeled in this version of the simulator. However, the bias-dependent noise sources I_NoiseBD and V_NoiseBD can be connected external to the device to model flicker or burst noise.

References

1. J. J. Ebers and J. L. Moll. "Large Signal Behaviour of Junction Transistors," Proc. I.R.E. 42, 1761 (1954).
2. H. K. Gummel and H. C. Poon. "An Integral Charge-Control Relation for Bipolar Transistors," Bell Syst. Techn. J. 49, 1 (1970).
3. SPICE2: A Computer Program to Simulate Semiconductor Circuits, University of California, Berkeley.
4. P. C. Grossman and A. Oki. "A Large Signal DC Model for GaAs/GaxAl1-xAs Heterojunction Bipolar Transistors," Proceedings of the 1989 IEEE Bipolar Circuits and Technology Meeting, pp. 258-262, September 1989.

Equivalent Circuit


Cxbc
Intrinsic Model
(NPN or PNP)
Vbc
-
+
+
Vbe
-
Rc
Lc
2
1
Lb
Rb
Cxce
Cxbe
Re
Le
(EEBJT2A)
4
3


Intrinsic Model
Ic
-
Vbc
+
Cbc
Ice
Ibc
Ib
Icr
Icf
Ibe
+
Vbe
-
Cbe
Ie

HICUM0_1_12 (HICUM Level 0, Version 1.12 Instance)

Parameters

Name	Description	Units	Default
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
dt	Temperature change for particular transistor	K	0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
ModelName [:Name] c b e s
```

The model statement starts with the required keyword model. It is followed by the modelname that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is HICUM0_1_12. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
Npn3:Q1 c b e s t
model Npn3 HICUM0_1_12 is=5e-16 vef=250
```

Notes/Equations

1. DC operating point parameters that can be sent to the dataset:

Name	Description	Units
ic	collector terminal current	A
ib	base terminal current	A
ie	emitter terminal current	A
is	substrate terminal current	A
vce	external voltage collector-emitter	V
vbe	external voltage base-emitter	V
vbei	internal voltage between nodes bi and ei	V
vsc	external substrate-collector voltage	V
temp	device temperature	K
tf	total forward transit time	s
tr	total reverse transit time	s
qf	minority charge forward component	coul
qr	minority charge reverse component	coul
qpt	modified hole charge	coul
it	transfer current	A
itf	forward transfer current	A
itr	reverse transfer current	A
iavl	avalanche generation current	A
ibici	current between bi and ci	A
ijsc	current for si-ci diode	A
gm	Gm	S
rbi	internal base resistance	Ohm
rbx	external base resistance	Ohm
rcx	external collector resistance	Ohm
re	external emittor resistance	Ohm
pwr	power dissipation	W
qjcx	charge between b and ci	coul
qbci	charge between b and ci	coul
cbe	capacitance between b and e	F
qbici	charge between bi and ci	coul
qbiei	charge between bi and ei	coul
qjs	charge between si and ci	coul
cjs	capacitance between si and ci	F
qjei	junction charge between bi and ei	coul
cjei	junction capacitance between bi and ei	F
cbici	dqjci/d_V_BCI	F

HICUM0_1_12_model (HICUM Level 0, Version 1.12 Model)

Parameters

Name	Description	Units	Default
Tnom	Parameter measurement temperature	deg C	27
is	(Modified) saturation current	A	1e-16
mcf	Non-ideality coefficient of forward collector current		1
mcr	Non-ideality coefficient of reverse collector current		1
vef	forward Early voltage (normalization volt.)	V	1e+10
iqf	forward d.c. high-injection toll-off current	A	1e+10
iqr	inverse d.c. high-injection roll-off current	A	1e+10
iqfh	high-injection correction current	A	1e+10
tfh	high-injection correction factor		1e+10
ibes	BE saturation current	A	1e-18
mbe	BE non-ideality factor		1
ires	BE recombination saturation current	A	0
mre	BE recombination non-ideality factor		2
ibcs	BC saturation current	A	0
mbc	BC non-ideality factor		1
cje0	Zero-bias BE depletion capacitance	F	1e-20
vde	BE built-in voltage	V	0.9
ze	BE exponent factor		0.5
aje	Ratio of maximum to zero-bias value		2.5
t0	low current transit time at Vbici=0	s	0
dt0h	Base width modulation contribution		0
tbvl	SCR width modulation contribution	s	0
tef0	Storage time in neutral emitter	s	0
gte	Exponent factor for emitter transit time		1
thcs	Saturation time at high current densities	s	0
ahc	Smoothing factor for current dependence		0.1
tr	Storage time at inverse operation	s	0
rci0	Low-field collector resistance under emitter	Ohm	150
vlim	Voltage dividing ohmic and satur.region	V	0.5
vpt	Punch-through voltage	V	100
vces	Saturation voltage	V	0.1
cjci0	Total zero-bias BC depletion capacitance	F	1e-20
vdci	BC built-in voltage	V	0.7
zci	BC exponent factor		0.333
vptci	Punch-through voltage of BC junction	V	100
cjcx0	Zero-bias external BC depletion capacitance	F	1e-20
vdcx	External BC built-in voltage	V	0.7
zcx	External BC exponent factor		0.333
vptcx	Punch-through voltage	V	100
fbc	Split factor = Cjci0/Cjc0		1

rbi0	Internal base resistance at zero-bias	Ohm	0
vr0e	forward Early voltage (normalization volt.)	V	2.5
vr0c	forward Early voltage (normalization volt.)	V	1e+10
fgeo	Geometry factor		0.656
rbx	External base series resistance	Ohm	0
rcx	Emitter series resistance	Ohm	0
re	External collector series resistance	Ohm	0
itss	Substrate transistor transfer saturation current	A	0
msf	Substrate transistor transfer current non-ideality factor		1
iscs	SC saturation current	A	0
msc	SC non-ideality factor		1
cjs0	Zero-bias SC depletion capacitance	F	1e-20
vds	SC built-in voltage	V	0.3
zs	External SC exponent factor		0.3
vpts	SC punch-through voltage	V	100
cbcpar	Collector-base isolation (overlap) capacitance	F	0
cbepar	Emitter-base oxide capacitance	F	0
eavl	Exponent factor		0
kavl	Prefactor		0
kf	flicker noise coefficient	M1-AF	0
af	flicker noise exponent factor		2
vgb	Bandgap-voltage	V	1.2
vge	Effective emitter bandgap-voltage	V	1.17
vgc	Effective collector bandgap-voltage	V	1.17
vgs	Effective substrate bandgap-voltage	V	1.17
f1vg	Coefficient K1 in T-dependent bandgap equation	V/K	-0.000102377
f2vg	Coefficient K2 in T-dependent bandgap equation	V/K	0.00043215
alt0	First-order TC of tf0	1/K	0
kt0	Second-order TC of tf0	1/K2	0
zetact	Exponent coefficient in transfer current temperature dependence		3
zetabet	Exponent coefficient in BE junction current temperature dependence		3.5
zetaci	TC of epi-collector diffusivity		0
alvs	Relative TC of satur.drift velocity	1/K	0
alces	Relative TC of vces	1/K	0
zetarbi	TC of internal base resistance		0
zetarbx	TC of external base resistance		0
zetarcx	TC of external collector resistance		0
zetare	TC of emitter resistances		0
alkav	TC of avalanche prefactor	1/K	0
aleav	TC of avalanche exponential factor	1/K	0
flsh	Flag for self-heating calculation		0
rth	Thermal resistance	K/W	0
cth	Thermal capacitance	Ws/K	0
npn	model type flag for npn		1
pnp	model type flag for pnp		0
version	model version. Not used! Introduced for Spectre compatibility		1.12

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model ModelName [:Name] c b e s
```

The model statement starts with the required keyword model. It is followed by the modelname that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is HICUM0_1_12. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
Npn3:Ql c b e s t
model Npn3 HICUM0_1_12 is=5e-16 vef=250
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's HICUM, A Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html .
2. The thermal pin can be optionally specified externally. Therefore the instance can be defined either as a 4-pin device (collector, base, emitter, substrate) or a 5-pin device (collector, base, emitter, substrate, thermal).

HICUM0_1_2 (HICUM Level 0, Version 1.2)

Parameters

Name (Alias)	**Description**	**Units**	**Default**
Temp	Device operating temperature	°C	25
Trise (Dtemp)	Temperature rise over ambient	°C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
dt	Temperature change for particular transistor	K	0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

ModelName [:Name] c b e s

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM0_1_2*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table- these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model  Npn3  HICUM0_1_2 \
 is=8e-15 t0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's HICUM, A Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html .
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
ic	collector terminal current	A
ib	base terminal current	A
ie	emitter terminal current	A
is	substrate terminal current	A
vce	external voltage collector-emitter	V
vbe	external voltage base-emitter	V
vbei	internal voltage between nodes bi and ei	V
vsc	external substrate-collector voltage	V
temp	device temperature	K
tf	total forward transit time	s
tr	total reverse transit time	s
qf	minority charge forward component	coul
qr	minority charge reverse component	coul
qpt	modified hole charge	coul
it	transfer current	A
itf	forward transfer current	A
itr	reverse transfer current	A
iavl	avalanche generation current	A
ibici	current between bi and ci	A
ijsc	current for si-ci diode	A
gm	gm	S
rbi	internal base resistance	Ohm
rbx	external base resistance	Ohm
rcx	external collector resistance	Ohm
re	external emitter resistance	Ohm
pwr	power dissipation	W
qjcx	charge between b and ci	coul
qbci	charge between b and ci	coul
cbe	capacitance between b and e	F
qbici	charge between bi and ci	coul
qbiei	charge between bi and ei	coul
qjs	charge between si and ci	coul
cjs	capacitance between si and ci	F
qjei	junction charge between bi and ei	coul
cjei	junction capacitance between bi and ei	F
cbici	dqjci/d_V_BCI	F

HICUM0_1_2 model (HICUM Level 0, Version 1.2)

Parameters

Name (Alias)	Description	Units	Default
Gender	+1=N-type, -1=P-type		1(n),-1(p)
Tnom	Parameter measurement temperature	°C	27
Secured	Secured model parameters		0
is	(Modified) saturation current	A	1e-016
mcf	Non-ideal coefficient of forward collector current		1
mcr	Non-ideal coefficient of reverse collector current		1
vef	forward Early voltage (normalization volt.)	V	1e+030
ver	reverse Early voltage (normalization volt.)	V	1e+030
iqf	forward d.c. high-injection toll-off current	A	1e+030
fiqf	flag for turning on base related critical current		0
iqr	inverse d.c. high-injection roll-off current	A	1e+030
iqfh	high-injection correction current	A	1e+030
tfh	high-injection correction factor		0
ahq	Smoothing factor for the d.c. injection width		0
ibes	BE saturation current	A	1e-018
mbe	BE non-ideal factor		1
ires	BE recombination saturation current	A	0
mre	BE recombination non-ideal factor		2
ibcs	BC saturation current	A	0
mbc	BC non-ideal factor		1
cje0	Zero-bias BE depletion capacitance	F	1e-020
vde	BE built-in voltage	V	0.9
ze	BE exponent factor		0.5
aje	Ratio of maximum to zero-bias value		2.5
vdedc	BE charge built-in voltage for d.c. transfer current	V	0.9
zedc	charge BE exponent factor for d.c. transfer current		0.5
ajedc	BE capacitance ratio Ratio maximum to zero-bias value for d.c. transfer current		2.5
t0	low current transit time at Vbici=0	s	0
dt0h			0
tbvlSCR	width modulation contribution	s	0
tef0	Storage time in neutral emitter	s	0
gte	Exponent factor for emmiter transit time		1
thcs	Saturation time at high current densities	s	0
ahc	Smoothing facor for current dependence		0.1
tr	Storage time at inverse operation	s	0
rci0	Low-field collector resistance under emitter	Ohm	150
vlim	Voltage dividing ohmic and satur.region	V	0.5
vpt	Punch-through voltage	V	100
vces	Saturation voltage	V	0.1
cjci0	Total zero-bias BC depletion capacitance	F	1e-020

vdci	BC built-in voltage	V	0.7
zci	BC exponent factor		0.333
vptci	Punch-through voltage of BC junction	V	100
cjcx0	Zero-bias external BC depletion capacitance	F	1e-020
vdcx	External BC built-in voltage	V	0.7
zcx	External BC exponent factor		0.333
vptcx	Punch-through voltage	V	100
fbc	Split factor = Cjci0/Cjc0		1
rbi0	Internal base resistance at zero-bias	Ohm	0
vr0e	forward Early voltage (normalization volt.)	V	2.5
vr0c	forward Early voltage (normalization volt.)	V	1e+030
fgeo	Geometry factor		0.656
rbx	External base series resistance	Ohm	0
rcx	Emitter series resistance	Ohm	0
re	External collector series resistance	Ohm	0
itss	Substrate transistor transfer saturation current	A	0
msf	Substrate transistor transfer current non-ideal factor		1
iscs	SC saturation current	A	0
msc	SC non-ideal factor		1
cjs0	Zero-bias SC depletion capacitance	F	1e-020
vds	SC built-in voltage	V	0.3
zs	External SC exponent factor		0.3
vpts	SC punch-through voltage	V	100
cbcpar	Collector-base isolation (overlap) capacitance	F	0
cbepar	Emitter-base oxide capacitance	F	0
eavl	Exponent factor		0
kavl	Prefactor		0
kf	flicker noise coefficient	M^(1-AF)	0
af	flicker noise exponent factor		2
vgb	Bandgap-voltage	V	1.2
vge	Effective emitter bandgap-voltage	V	1.17
vgc	Effective collector bandgap-voltage	V	1.17
vgs	Effective substrate bandgap-voltage	V	1.17
f1vg	Coefficient K1 in T-dependent bandgap equation	V/K	-0.000102377
f2vg	Coefficient K2 in T-dependent bandgap equation	V/K	0.00043215
alt0	Frist-order TC of tf0	1/K	0
kt0	Second-order TC of tf0	1/K^2	0
zetact	Exponent coefficient in transfer current temperature dependence		3
zetabet	Exponent coefficient in BE junction current temperature dependence		3.5
zetaci	TC of epi-collector diffusivity		0
alvs	Relative TC of satur.drift velocity	1/K	0
alces	Relative TC of vces	1/K	0
zetarbi	TC of internal base resistance		0
zetarbx	TC of external base resistance		0
zetarcx	TC of external collector resistance		0
zetare	TC of emitter resistances		0

zetaiqf	TC of iqf		0
alkav	TC of avalanche prefactor	1/K	0
aleav	TC of avalanche exponential factor	1/K	0
zetarth	Exponent factor for temperature dependent thermal resistance		0
flsh	Flag for self-heating calculation		0
rth	Thermal resistance	K/W	0
cth	Thermal capacitance	Ws/K	0
npn	model type flag for npn		1
pnp	model type flag for pnp		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

model modelname HICUM0_1_2 [parm=value]*

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM0_1_2*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, sub-circuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in *Using Circuit Simulators* (cktsim).

Example:

```
model  Npn3  HICUM0_1_2 \
is=8e-15 t0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's HICUM, A Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html

HICUM0 (HICUM Level 0 Model Instance)

Parameters

Name	Description	Units	Default
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
dt	Temperature change for particular transistor	K	0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
ModelName [:Name] c b e s
```

The model statement starts with the required keyword *ModelName*. It is followed by the *[:name]* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM* 0. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn3  HICUM0 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: "http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html" .
2. DC Operating Point Information lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
ic	collector terminal current	A
ib	base terminal current	A
ie	emitter terminal current	A
is	substrate terminal current	A
vce	external voltage collector-emitter	V
vbe	external voltage base-emitter	V
vbei	internal voltage between nodes bi and ei	V
vsc	external substrate-collector voltage	V
temp	device temperature	K
tf	total forward transit time	s
tr	total reverse transit time	s
qf	minority charge forward component	coul
qr	minority charge reverse component	coul
qpt	modified hole charge	coul
it	transfer current	A
itf	forward transfer current	A
itr	reverse transfer current	A
iavl	avalanche generation current	A
ibici	current between bi and ci	A
ijsc	current for si-ci diode	A
gm	gm	S
rbi	internal base resistance	Ohm
rbx	external base resistance	Ohm
rcx	external collector resistance	Ohm
re	external emittor resistance	Ohm
pwr	power dissipation	W
qjcx	charge between b and ci	coul
qbci	charge between b and ci	coul
cbe	capacitance between b and e	F
qbici	charge between bi and ci	coul
qbiei	charge between bi and ei	coul
qjs	charge between si and ci	coul
cjs	capacitance between si and ci	F
qjei	junction charge between bi and ei	coul
cjei	junction capacitance between bi and ei	F
cbici	dqjci/d_V_BCI	F

HICUM0_model (HICUM Level 0 Model)

Parameters

Name	Description	Units	Default
Tnom	Parameter measurement temperature	°C	27
Secured	Secured model parameters	0	
is	(Modified) saturation current	A	1e-016
mcf	Non-ideality coefficient of forward collector current		1
mcr	Non-ideality coefficient of reverse collector current		1
vef	forward Early voltage (normalization volt.)	V	1e+006
iqf	forward d.c. high-injection toll-off current	A	1e+006
iqr	inverse d.c. high-injection toll-off current	A	1e+006
iqfh	high-injection correction current	A	1e+006
tfh	high-injection correction factor		1e+006
ibes	BE saturation current	A	1e-018
mbe	BE non-ideality factor		1
ires	BE recombination saturation current	A	0
mre	BE recombination non-ideality factor		2
ibcs	BC saturation current	A	0
mbc	BC non-ideality factor		1
cje0	Zero-bias BE depletion capacitance	F	1e-020
vde	BE built-in voltage	V	0.9
ze	BE exponent factor		0.5
aje	Ratio of maximum to zero-bias value		2.5
t0	low current transit time at Vbici=0	s	0
dt0h			0
tbvl	SCR width modulation contribution	s	0
tef0	Storage time in neutral emitter	s	0
gte	Exponent factor for emitter transit time		1
thcs	Saturation time at high current densities	s	0
ahc	Smoothing factor for current dependence		0.1
tr	Storage time at inverse operation	s	0
rci0	Low-field collector resistance under emitter	Ohm	150
vlim	Voltage dividing ohmic and satur.region	V	0.5
vpt	Punch-through voltage	V	100
vces	Saturation voltage	V	0.1
cjci0	Total zero-bias BC depletion capacitance	F	1e-020
vdci	BC built-in voltage	V	0.7
zci	BC exponent factor		0.333
vptci	Punch-through voltage of BC junction	V	100
cjcx0	Zero-bias external BC depletion capacitance	F	1e-020
vdcx	External BC built-in voltage	V	0.7

zcx	External BC exponent factor		0.333
vptcx	Punch-through voltage	V	100
fbc	Split factor = Cjci0/Cjc0		1
rbi0	Internal base resistance at zero-bias	Ohm	0
vr0e	forward Early voltage (normalization volt.)	V	2.5
vr0c	forward Early voltage (normalization volt.)	V	1e+006
fgeo	Geometry factor		0.656
rbx	External base series resistance	Ohm	0
rcx	Emitter series resistance	Ohm	0
re	External collector series resistance	Ohm	0
iscs	SC saturation current	A	0
msc	SC non-ideality factor		1
cjs0	Zero-bias SC depletion capacitance	F	1e-020
vds	SC built-in voltage	V	0.3
zs	External SC exponent factor		0.3
vpts	SC punch-through voltage	V	100
cbcpar	Collector-base isolation (overlap) capacitance	F	0
cbepar	Emitter-base oxide capacitance	F	0
eavl	Exponent factor		0
kavl	Prefactor		0
kf	flicker noise coefficient	$M^{(1-AF)}$	0
af	flicker noise exponent factor		2
vgb	Bandgap-voltage	V	1.2
vge	Effective emitter bandgap-voltage	V	1.17
vgc	Effective collector bandgap-voltage	V	1.17
vgs	Effective substrate bandgap-voltage	V	1.17
f1vg	Coefficient K1 in T-dependent bandgap equation	V/K	0.000102377
f2vg	Coefficient K2 in T-dependent bandgap equation	V/K	0.00043215
alt0	First-order TC of tf0	1/K	0
kt0	Second-order TC of tf0	$1/K^2$	0
zetact	Exponent coefficient in transfer current temperature dependence		3
zetabet	Exponent coefficient in BE junction current temperature dependence		3.5
zetaci	TC of epi-collector diffusivity		0
alvs	Relative TC of satur.drift velocity	1/K	0
alces	Relative TC of vces	1/K	0
zetarbi	TC of internal base resistance		0
zetarbx	TC of external base resistance		0
zetarcx	TC of external collector resistance		0
zetare	TC of emitter resistances		0
alkav	TC of avalanche prefactor	1/K	0
aleav	TC of avalanche exponential factor	1/K	0
rth	Thermal resistance	K/W	0
cth	Thermal capacitance	Ws/K	0
npn	model type flag for npn		1
pnp	model type flag for pnp		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname HICUM0 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM0* . The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.
Example:

```
model  Npn3  HICUM0 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: "http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html" .

HICUM2_21 (HICUM Bipolar Junction Transistor Version 2.21)

Parameters

Name	**Description**	**Units**	**Default**
Temp	Device operating temperature	°C	25
Trise	Temperature rise over ambient	°C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
Flsh (Selfheating)	flag for turning on (1 = main currents, 2 = all currents) or off (0) self-heating effects		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
ModelName [:Name] c b e s
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_21*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn3  HICUM2_21 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: "http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html" .
2. The following table lists the DC operating point parameters that can be sent to the

dataset.

DC Operating Point Information

Name	Description	Units
IC	Collector terminal current	A
IB	Base terminal current	A
IE	Emitter terminal current	A
IS	Substrate terminal current	A
Power	Total dissipated power	W
Temp	intrinsic device temperature	°C
VBE	External BE voltage	V
VBC	External BC voltage	V
VCE	External CE voltage	V
VSC	External SC voltage	V
BETADC	Common emitter forward current gain	
GM	Transconductance	A/V
GMAVL	Transconductance for avalanche current	A/V
GMS	Transconductance of the parasitic substrate PNP	A/V
RPIi	Intrinsic input resistance	Ohm
RPIx	Extrinsic input resistance	Ohm
RMUi	Intrinsic feedback resistance	Ohm
RMUx	Extrinsic feedback resistance	Ohm
RMUs	Intrinsic substrate feedback resistance	Ohm
RO	Output resistance	Ohm
ROs	Output resistance for the parasitic substrate PNP	Ohm
CPIi	Total intrinsic BE capacitance	F
CPIx	Total extrinsic BE capacitance	F
CMUi	Total intrinsic BC capacitance	F
CMUx	Total extrinsic BC capacitance	F
CCS	CS junction capacitance	F
RBI	Internal base resistance as calculated in the model	Ohm
CRBI	Shunt capacitance across RBI as calculated in the model	F
TF	Total forward transit time as calculated in the model	S
FT	Transit frequency	Hz
VEF	Effective forward Early voltage	V
VER	Effective inverse Early voltage	V

HICUM2_21_model (HICUM Bipolar Junction Transistor Version 2.21 Model)

Parameters

Name	Description	Units	Default
Tnom	Parameter measurement temperature	°C	27
Trise (Dt)	Temperature rise over ambient	°C	0
Secured	Secured model parameters		0
C10	GICCR constant (C10=IS*QP0)	AC	2e-030
Qp0	Zero-bias hole charge	C	2e-014
Ich	High-current correction for 2D and 3D effects	A	0
Hfe	Emitter minority charge weighting factor in HBTs		1
Hfc	Collector minority charge weighting factor in HBTs		1
Hjei	B-E depletion charge weighting factor in HBTs		1
Hjci	B-C depletion charge weighting factor in HBTs		1
Ibeis	Internal B-E saturation current	A	1e-018
Mbei	Internal B-E current ideality factor		1
Ireis	Internal B-E recombination saturation current	A	0
Mrei	Internal B-E recombination current ideality factor		2
Ibeps	Peripheral B-E saturation current	A	0
Mbep	Peripheral B-E current ideality factor		1
Ireps	Peripheral B-E recombination saturation current	A	0
Mrep	Peripheral B-E recombination current ideality factor		2
Mcf	Non-ideality factor for III-V HBTs		1
Tbhrec	Base current recombination time constant at B-C barrier for high forward injection	s	0
Ibcis	Internal B-C saturation current	A	1e-016
Mbci	Internal B-C current ideality factor		1
Ibcxs	External B-C saturation current	A	0
Mbcx	External B-C current ideality factor		1
Ibets	B-E tunneling saturation current	A	0
Abet	Exponent factor for tunneling current		40
Tunode	Specifies the base node connection for the tunneling current		1
Favl	Avalanche current factor	V^{-1}	0
Qavl	Exponent factor for avalanche current	C	0
Alfav	Relative temperature coefficient for Favl	K^{-1}	0
Alqav	Relative temperature coefficient for QAVL	K^{-1}	0
Rbi0	Zero bias internal base resistance	Ohms	0
Rbx	External base series resistance	Ohms	0
Fgeo (Fge0)	Factor for geometry dependence of emitter current crowding		0.6557

Fdqr0 (Fdqro)	Correction factor for modulation by B-E and B-C space charge layer		0
Fcrbi	Ratio of HF shunt to total internal capacitance (lateral NQS effect)		0
Fqi	Ratio of internal to total minority charge		1
Re	Emitter series resistance	Ohms	0
Rcx	External collector series resistance	Ohms	0
Itss	Substrate transistor transfer saturation current	A	0
Msf	Forward ideality factor of substrate transfer current		1
Iscs	C-S diode saturation current	A	0
Msc	Ideality factor of C-S diode current		1
Tsf	Transit time for forward operation of substrate transistor	s	0
Rsu	Substrate series resistance	Ohms	0
Csu	Substrate shunt capacitance	F	0
Cjei0 (Cjeio)	Internal B-E zero-bias depletion capacitance	F	1e-020
Vdei	Internal B-E built-in potential	V	0.9
Zei	Internal B-E grading coefficient		0.5
Ajei (Aljei)	Ratio of maximum to zero-bias value of internal B-E capacitance		2.5
Cjep0 (Cjepo)	Peripheral B-E zero-bias depletion capacitance	F	1e-020
Vdep	Peripheral B-E built-in potential	V	0.9
Zep	Peripheral B-E grading coefficient		0.5
Ajep (Aljep)	Ratio of maximum to zero-bias value of peripheral B-E capacitance		2.5
Cjci0 (Cjcio)	Internal B-C zero-bias depletion capacitance	F	1e-020
Vdci	Internal B-C built-in potential	V	0.7
Zci	Internal B-C grading coefficient		0.4
Vptci	Internal B-C punch-through voltage	V	100
Cjcx0 (Cjcxo)	External B-C zero-bias depletion capacitance	F	1e-020
Vdcx	External B-C built-in potential	V	0.7
Zcx	External B-C grading coefficient		0.4
Vptcx	External B-C punch-through voltage	V	100
Fbcpar (Fbc)	Partitioning factor of parasitic B-C cap		0
Fbepar	Partitioning factor of parasitic B-E cap		1
Cjs0 (Cjso)	C-S zero-bias depletion capacitance	F	0
Vds	C-S built-in potential	V	0.6
Zs	C-S grading coefficient		0.5
Vpts	C-S punch-through voltage	V	100
T0	Low current forward transit time at VBC=0V	s	0
Dt0h	Time constant for base and B-C space charge layer width modulation	s	0
Tbvl	Time constant for modelling carrier jam at low VCE	s	0
Tef0 (Tefo)	Neutral emitter storage time	s	0
Gtfe	Exponent factor for current dependence of neutral emitter storage time		1
Thcs	Saturation time constant at high current densities	s	0
Ahc (Alhc)	Smoothing factor for current dependence of base and collector transit time		0.1
Fthc	Partitioning factor for base and collector portion		0
Rci0	Internal collector resistance at low electric field	Ohms	150

Vlim	Voltage separating ohmic and saturation velocity regime	V	0.5
Vces	Internal C-E saturation voltage	V	0.1
Vpt	Collector punch-through voltage	V	0
Tr	Storage time for inverse operation	s	0
Cbepar	Total parasitic B-E capacitance	F	0
Cbcpar (Ccox)	Total parasitic B-C capacitance	F	0
Alqf	Factor for additional delay time of minority charge		0
Alit	Factor for additional delay time of transfer current		0
Flnqs	Flag for turning on and off of vertical NQS effect		0
Kf	Flicker noise coefficient		0
Af	Flicker noise exponent factor		2
Cfbe	Flag for determining where to tag the flicker noise source		-1
Latb	Scaling factor for collector minority charge in direction of emitter width		0
Latl	Scaling factor for collector minority charge in direction of emitter length		0
Vgb	Bandgap voltage extrapolated to 0 K	V	1.17
Alt0	First order relative temperature coefficient of parameter T0	K^{-1}	0
Kt0 (Kto)	Second order relative temperature coefficient of parameter T0	$1/K^{2}$	0
Zetaci	Temperature exponent for RCI0		0
Alvs	Relative temperature coefficient of saturation drift velocity	K^{-1}	0
Alces	Relative temperature coefficient of VCES	K^{-1}	0
Zetarbi	Temperature exponent of internal base resistance		0
Zetarbx	Temperature exponent of external base resistance		0
Zetarcx	Temperature exponent of external collector resistance		0
Zetare	Temperature exponent of emitter resistance		0
Zetacx	Temperature exponent of mobility in substrate transistor transit time		1
Vge	Effective emitter bandgap voltage	V	1.17
Vgc	Effective collector bandgap voltage	V	1.17
Vgs	Effective substrate bandgap voltage	V	1.17
F1vg	Coefficient K1 in T-dependent band-gap equation	V/K	-0.000102377
F2vg	Coefficient K2 in T-dependent band-gap equation	V/K	0.00043215
Zetact	Exponent coefficient in transfer current temperature dependence		3
Zetabet	Exponent coefficient in B-E junction current temperature dependence		3.5
Alb	Relative temperature coefficient of forward current gain for V2.1 model		0
Flsh (SelfheatingModel)	Flag for turning on and off self-heating effect		0
Rth	Thermal resistance	K/W	0
Cth	Thermal capacitance	Ws/K	0
Flcomp	Flag for compatibility with v2.1 model (0=v2.1)		0
NPN	For backward compatibility		1
PNP	For backward compatibility		0
ModelLevel	For backward compatibility		1
ApproxLevel	For backward compatibility		1

AcModel	For backward compatibility		1
wBvbc	For backward compatibility		0
wBvbe	For backward compatibility		0
wBvsub	For backward compatibility		0
wIbmax	For backward compatibility		0
wIcmax	For backward compatibility		0
wPmax	For backward compatibility		0
wVbcfwd	For backward compatibility		0
wVsubfwd	For backward compatibility		0
Imax	For backward compatibility		0
Imelt	For backward compatibility		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname HICUM2_21 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_21*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn3  HICUM2_21 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: "http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html" .

HICUM2_22 (HICUM Bipolar Junction Transistor Version 2.22)

Parameters

Name	**Description**	**Units**	**Default**
Temp	Device operating temperature	°C	25
Trise	Temperature rise over ambient	°C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
Flsh (Selfheating)	flag for turning on (1 = main currents, 2 = all currents) or off (0) self-heating effects		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
ModelName [:Name] c b e s
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_22*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model  Npn3  HICUM2_22 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html .
2. The following table lists the DC operating point parameters that can be sent to the

dataset.

DC Operating Point Information

Name	Description	Units
IC	Collector terminal current	A
IB	Base terminal current	A
IE	Emitter terminal current	A
IS	Substrate terminal current	A
Power	Total dissipated power	W
Temp	Intrinsic device temperature	°C
VBE	External BE voltage	V
VBC	External BC voltage	V
VCE	External CE voltage	V
VSC	External SC voltage	V
BETADC	Common emitter forward current gain	
GM	Transconductance	A/V
GMAVL	Transconductance for avalanche current	A/V
GMS	Transconductance of the parasitic substrate PNP	A/V
RPIi	Intrinsic input resistance	Ohm
RPIx	Extrinsic input resistance	Ohm
RMUi	Intrinsic feedback resistance	Ohm
RMUx	Extrinsic feedback resistance	Ohm
RMUs	Intrinsic substrate feedback resistance	Ohm
RO	Output resistance	Ohm
ROs	Output resistance for the parasitic substrate PNP	Ohm
CPIi	Total intrinsic BE capacitance	F
CPIx	Total extrinsic BE capacitance	F
CMUi	Total intrinsic BC capacitance	F
CMUx	Total extrinsic BC capacitance	F
CCS	CS junction capacitance	F
RBI	Internal base resistance as calculated in the model	Ohm
CRBI	Shunt capacitance across RBI as calculated in the model	F
TF	Total forward transit time as calculated in the model	S
FT	Transit frequency	Hz
VEF	Effective forward Early voltage	V
VER	Effective inverse Early voltage	V

HICUM2_22_model (HICUM Bipolar Junction Transistor Version 2.22 Model)

Parameters

Name	**Description**	**Units**	**Default**
Tnom	Parameter measurement temperature	°C	27
Trise (Dt)	Temperature rise over ambient	°C	0
Secured	Secured model parameters		0
C10	GICCR constant	A^{2s}	2e-030
Qp0	Zero-bias hole charge	Coul	2e-014
Ich	High-current correction for 2D and 3D effects	A	0
Hfe	Emitter minority charge weighting factor in HBTs		1
Hfc	Collector minority charge weighting factor in HBTs		1
Hjei	B-E depletion charge weighting factor in HBTs		1
Hjci	B-C depletion charge weighting factor in HBTs		1
Ibeis	Internal B-E saturation current	A	1e-018
Mbei	Internal B-E current ideality factor		1
Ireis	Internal B-E recombination saturation current	A	0
Mrei	Internal B-E recombination current ideality factor		2
Ibeps	Peripheral B-E saturation current	A	0
Mbep	Peripheral B-E current ideality factor		1
Ireps	Peripheral B-E recombination saturation current	A	0
Mrep	Peripheral B-E recombination current ideality factor		2
Mcf	Non-ideality factor for III-V HBTs		1
Tbhrec	Base current recombination time constant at B-C barrier for high forward injection	s	0
Ibcis	Internal B-C saturation current	A	1e-016
Mbci	Internal B-C current ideality factor		1
Ibcxs	External B-C saturation current	A	0
Mbcx	External B-C current ideality factor		1
Ibets	B-E tunneling saturation current	A	0
Abet	Exponent factor for tunneling current		40
tunode	Specifies the base node connection for the tunneling current		1
Favl	Avalanche current factor	1/V	0
Qavl	Exponent factor for avalanche current	Coul	0
Alfav	Relative TC for Favl	1/K	0
Alqav	Relative TC for Qavl	1/K	0
Rbi0	Zero bias internal base resistance	Ohm	0
Rbx	External base series resistance	Ohm	0
Fgeo (Fge0)	Factor for geometry dependence of emitter current crowding		0.6557
Fdqr0 (Fdqro)	Correction factor for modulation by B-E and B-C space charge		0

	layer		
Fcrbi	Ratio of HF shunt to total internal capacitance (lateral NQS effect)		0
Fqi	Ratio of internal to total minority charge		1
Re	Emitter series resistance	Ohm	0
Rcx	External collector series resistance	Ohm	0
Itss	Substrate transistor transfer saturation current	A	0
Msf	Forward ideality factor of substrate transfer current		1
Iscs	C-S diode saturation current	A	0
Msc	Ideality factor of C-S diode current		1
Tsf	Transit time for forward operation of substrate transistor	s	0
Rsu	Substrate series resistance	Ohm	0
Csu	Substrate shunt capacitance	F	0
Cjei0 (Cjeio)	Internal B-E zero-bias depletion capacitance	F	1e-020
Vdei	Internal B-E built-in potential	V	0.9
Zei	Internal B-E grading coefficient		0.5
Ajei (Aljei)	Ratio of maximum to zero-bias value of internal B-E capacitance		2.5
Cjep0 (Cjepo)	Peripheral B-E zero-bias depletion capacitance	F	1e-020
Vdep	Peripheral B-E built-in potential	V	0.9
Zep	Peripheral B-E grading coefficient		0.5
Ajep (Aljep)	Ratio of maximum to zero-bias value of peripheral B-E capacitance		2.5
Cjci0 (Cjcio)	Internal B-C zero-bias depletion capacitance	F	1e-020
Vdci	Internal B-C built-in potential	V	0.7
Zci	Internal B-C grading coefficient		0.4
Vptci	Internal B-C punch-through voltage	V	100
Cjcx0 (Cjcxo)	External B-C zero-bias depletion capacitance	F	1e-020
Vdcx	External B-C built-in potential	V	0.7
Zcx	External B-C grading coefficient		0.4
Vptcx	External B-C punch-through voltage	V	100
Fbcpar (Fbc)	Partitioning factor of parasitic B-C cap		0
Fbepar	Partitioning factor of parasitic B-E cap		1
Cjs0 (Cjso)	C-S zero-bias depletion capacitance	F	0
Vds	C-S built-in potential	V	0.6
Zs	C-S grading coefficient		0.5
Vpts	C-S punch-through voltage	V	100
T0	Low current forward transit time at VBC=0V	s	0
Dt0h	Time constant for base and B-C space charge layer width modulation	s	0
Tbvl	Time constant for modelling carrier jam at low VCE	s	0
Tef0 (Tefo)	Neutral emitter storage time	s	0
Gtfe	Exponent factor for current dependence of neutral emitter storage time		1
Thcs	Saturation time constant at high current densities	s	0
Ahc (Alhc)	Smoothing factor for current dependence of base and collector transit time		0.1
Fthc	Partitioning factor for base and collector portion		0
Rci0	Internal collector resistance at low electric field	Ohms	150

Vlim	Voltage separating ohmic and saturation velocity regime	V	0.5
Vces	Internal C-E saturation voltage	V	0.1
Vpt	Collector punch-through voltage	V	0
Tr	Storage time for inverse operation	s	0
Cbepar	Total parasitic B-E capacitance	F	0
Cbcpar (Ccox)	Total parasitic B-C capacitance	F	0
Alqf	Factor for additional delay time of minority charge		0
Alit	Factor for additional delay time of transfer current		0
Flnqs	Flag for turning on and off of vertical NQS effect		0
Kf	Flicker noise coefficient		0
Af	Flicker noise exponent factor		2
Cfbe	Flag for determining where to tag the flicker noise source		-1
Latb	Scaling factor for collector minority charge in direction of emitter width		0
Latl	Scaling factor for collector minority charge in direction of emitter length		0
Vgb	Bandgap voltage extrapolated to 0 K	V	1.17
Alt0	First order relative temperature coefficient of parameter T0	1/K	0
Kt0 (Kto)	Second order relative TC of parameter T0		0
Zetaci	Temperature exponent for RCI0		0
Alvs	Relative TC of saturation drift velocity	1/K	0
Alces	Relative TC of VCES	1/K	0
Zetarbi	Temperature exponent of internal base resistance		0
Zetarbx	Temperature exponent of external base resistance		0
Zetarcx	Temperature exponent of external collector resistance		0
Zetare	Temperature exponent of emitter resistance		0
Zetacx	Temperature exponent of mobility in substrate transistor transit time		1
Vge	Effective emitter bandgap voltage	V	1.17
Vgc	Effective collector bandgap voltage	V	1.17
Vgs	Effective substrate bandgap voltage	V	1.17
F1vg	Coefficient K1 in T-dependent band-gap equation		-0.000102377
F2vg	Coefficient K2 in T-dependent band-gap equation		0.00043215
Zetact	Exponent coefficient in transfer current temperature dependence		3
Zetabet	Exponent coefficient in B-E junction current temperature dependence		3.5
Alb	Relative TC of forward current gain for V2.1 model	1/K	0
Flsh (SelfheatingModel)	Flag for turning on and off self-heating effect		0
Rth	Thermal resistance	K/W	0
Cth	Thermal capacitance	J/W	0
Flcomp	Flag for compatibility with v2.1 model (0=v2.1)		0
NPN	For backward compatibility		1
PNP	For backward compatibility		0
ModelLevel	For backward compatibility		1
ApproxLevel	For backward compatibility		1
AcModel	For backward compatibility		1
wBvbc	For backward compatibility		0

wBvbe	For backward compatibility		0
wBvsub	For backward compatibility		0
wIbmax	For backward compatibility		0
wIcmax	For backward compatibility		0
wPmax	For backward compatibility		0
wVbcfwd	For backward compatibility		0
wVsubfwd	For backward compatibility		0
Imax	For backward compatibility		0
Imelt	For backward compatibility		0
Ceox	For backward compatibility		0
Krbi	For backward compatibility		1
Msr	For backward compatibility		1

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname HICUM2_22 [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_22* . The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn3  HICUM2_22 \
 Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model at: "http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html" .

HICUM2_23 (HICUM Bipolar Junction Transistor Version 2.23)

Parameters

Name	Description	Units	Default
Temp	Device operating temperature	°C	25
Trise (Dtemp)	Temperature rise over ambient	°C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
flsh (Selfheating)	Flag for turning on and off self-heating effect		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

ModelName [:Name] c b e s [t]

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_23*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model  Npn3  HICUM2_23 \
 alfav=8e-5 t0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's HICUM, A Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html .
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
IC	Collector terminal current	A
IB	Base terminal current	A
IE	Emitter terminal current	A
IS	Substrate terminal current	A
Power	Total dissipated power	W
Temp	intrinsic device temperature	°C
VBE	External BE voltage	V
VBC	External BC voltage	V
VCE	External CE voltage	V
VSC	External SC voltage	V
BETADC	Common emitter forward current gain	
GM	Transconductance	A/V
GMAVL	Transconductance for avalanche current	A/V
GMS	Transconductance of the parasitic substrate PNP	A/V
RPIi	Intrinsic input resistance	Ohm
RPIx	Extrinsic input resistance	Ohm
RMUi	Intrinsic feedback resistance	Ohm
RMUx	Extrinsic feedback resistance	Ohm
RMUs	Intrinsic substrate feedback resistance	Ohm
RO	Output resistance	Ohm
ROs	Output resistance for the parasitic substrate PNP	Ohm
CPIi	Total intrinsic BE capacitance	F
CPIx	Total extrinsic BE capacitance	F
CMUi	Total intrinsic BC capacitance	F
CMUx	Total extrinsic BC capacitance	F
CCS	CS junction capacitance	F
RBI	Internal base resistance as calculated in the model	Ohm
CRBI	Shunt capacitance across RBI as calculated in the model	F
TF	Total forward transit time as calculated in the model	S
FT	Transit frequency	Hz
VEF	Effective forward Early voltage	V
VER	Effective inverse Early voltage	V

HICUM2_23 model (HICUM Bipolar Junction Transistor Version 2.23)

Parameters

Name (Alias)	**Description**	**Units**	**Default**
Gender	+1=N-type, -1=P-type		1(n),-1(p)
Tnom	Parameter measurement temperature	°C	
Trise (dt)	Temperature rise over ambient	°C	0
Secured	Secured model parameters		0
c10	GICCR constant	A^2s	2e-030
qp0	Zero-bias hole charge	Coul	2e-014
ich	High-current correction for 2D and 3D effects	A	0
hfe	Emitter minority charge weighting factor in HBTs		1
hfc	Collector minority charge weighting factor in HBTs		1
hjei	B-E depletion charge weighting factor in HBTs		1
hjci	B-C depletion charge weighting factor in HBTs		1
ibeis	Internal B-E saturation current	A	1e-018
mbei	Internal B-E current ideal factor		1
ireis	Internal B-E recombination saturation current	A	0
mrei	Internal B-E recombination current ideal factor		2
ibeps	Peripheral B-E saturation current	A	0
mbep	Peripheral B-E current ideal factor		1
ireps	Peripheral B-E recombination saturation current	A	0
mrep	Peripheral B-E recombination current ideal factor		2
mcf	Non-ideal factor for III-V HBTs		1
tbhrec	Base current recombination time constant at B-C barrier for high forward injection	s	0
ibcis	Internal B-C saturation current	A	1e-016
mbci	Internal B-C current ideal factor		1
ibcxs	External B-C saturation current	A	0
mbcx	External B-C current ideal factor		1
ibets	B-E tunneling saturation current	A	0
abet	Exponent factor for tunneling current		40
tunode	Specifies the base node connection for the tunneling current		1
favl	Avalanche current factor	1/V	0
qavl	Exponent factor for avalanche current	Coul	0
alfav	Relative TC for FAVL	1/K	0
alqav	Relative TC for QAVL	1/K	0
rbi0	Zero bias internal base resistance	Ohm	0
rbx	External base series resistance	Ohm	0
fgeo (fge0)	Factor for geometry dependence of emitter current crowding		0.6557
fdqr0 (fdqro)	Correction factor for modulation by B-E and B-C space charge layer		0
fcrbi	Ratio of HF shunt to total internal capacitance (lateral NQS effect)		0
fqi	Ratio of internal to total minority charge		1
re	Emitter series resistance	Ohm	0

rcx	External collector series resistance	Ohm	0
itss	Substrate transistor transfer saturation current	A	0
msf	Forward ideal factor of substrate transfer current		1
iscs	C-S diode saturation current	A	0
msc	Ideal factor of C-S diode current		1
tsf	Transit time for forward operation of substrate transistor	s	0
rsu	Substrate series resistance	Ohm	0
csu	Substrate shunt capacitance	F	0
cjei0 (cjeio)	Internal B-E zero-bias depletion capacitance	F	1e-020
vdei	Internal B-E built-in potential	V	0.9
zei	Internal B-E grading coefficient		0.5
ajei (aljei)	Ratio of maximum to zero-bias value of internal B-E capacitance		2.5
cjep0 (cjepo)	Peripheral B-E zero-bias depletion capacitance	F	1e-020
vdep	Peripheral B-E built-in potential	V	0.9
zep	Peripheral B-E grading coefficient		0.5
ajep (aljep)	Ratio of maximum to zero-bias value of peripheral B-E capacitance		2.5
cjci0 (cjcio)	Internal B-C zero-bias depletion capacitance	F	1e-020
vdci	Internal B-C built-in potential	V	0.7
zci	Internal B-C grading coefficient		0.4
vptci	Internal B-C punch-through voltage	V	100
cjcx0 (cjcxo)	External B-C zero-bias depletion capacitance	F	1e-020
vdcx	External B-C built-in potential	V	0.7
zcx	External B-C grading coefficient		0.4
vptcx	External B-C punch-through voltage	V	100
fbcpar (fbc)	Partitioning factor of parasitic B-C cap		0
fbepar	Partitioning factor of parasitic B-E cap		1
cjs0 (cjso)	C-S zero-bias depletion capacitance	F	0
vds	C-S built-in potential	V	0.6
zs	C-S grading coefficient		0.5
vpts	C-S punch-through voltage	V	100
t0	Low current forward transit time at VBC=0V	s	0
dt0h	Time constant for base and B-C space charge layer width modulation	s	0
tbvl	Time constant for modeling carrier jam at low VCE	s	0
tef0 (tefo)	Neutral emitter storage time	s	0
gtfe	Exponent factor for current dependence of neutral emitter storage time		1
thcs	Saturation time constant at high current densities	s	0
ahc (alhc)	Smoothing factor for current dependence of base and collector transit time		0.1
fthc	Partitioning factor for base and collector portion		0
rci0	Internal collector resistance at low electric field	Ohm	150
vlim	Voltage separating ohmic and saturation velocity regime	V	0.5
vces	Internal C-E saturation voltage	V	0.1
vpt	Collector punch-through voltage	V	0
tr	Storage time for inverse operation	s	0
cbepar	Total parasitic B-E capacitance	F	0

cbcpar (ccox)	Total parasitic B-C capacitance	F	0
alqf	Factor for additional delay time of minority charge		0
alit	Factor for additional delay time of transfer current		0
flnqs	Flag for turning on and off of vertical NQS effect		0
kf	Flicker noise coefficient		0
af	Flicker noise exponent factor		2
cfbe	Flag for determining where to tag the flicker noise source		-1
latb	Scaling factor for collector minority charge in direction of emitter width		0
latl	Scaling factor for collector minority charge in direction of emitter length		0
vgb	Bandgap voltage extrapolated to 0 K	V	1.17
alt0	First order relative TC of parameter T0	1/K	0
kt0 (kto)	Second order relative TC of parameter T0		0
zetaci	Temperature exponent for RCI0		0
alvs	Relative TC of saturation drift velocity	1/K	0
alces	Relative TC of VCES	1/K	0
zetarbi	Temperature exponent of internal base resistance		0
zetarbx	Temperature exponent of external base resistance		0
zetarcx	Temperature exponent of external collector resistance		0
zetare	Temperature exponent of emitter resistance		0
zetacx	Temperature exponent of mobility in substrate transistor transit time		1
vge	Effective emitter bandgap voltage	V	1.17
vgc	Effective collector bandgap voltage	V	1.17
vgs	Effective substrate bandgap voltage	V	1.17
f1vg	Coefficient K1 in T-dependent band-gap equation		-0.000102377
f2vg	Coefficient K2 in T-dependent band-gap equation		0.00043215
zetact	Exponent coefficient in transfer current temperature dependence		3
zetabet	Exponent coefficient in B-E junction current temperature dependence		3.5
alb	Relative TC of forward current gain for V2.1 model	1/K	0
flsh (SelfheatingModel)	Flag for turning on and off self-heating effect		0
rth	Thermal resistance	K/W	0
cth	Thermal capacitance	J/W	0
flcomp	Flag for compatibility with v2.1 model (0=v2.1)		0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname HICUM2_23 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM2_23* . The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table- these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

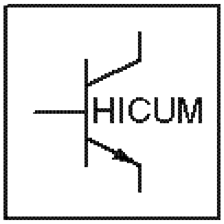
```
model  Npn3  HICUM2_23 \
 alfav=8e-5 t0=5e-12
```

Notes/Equations

1. For detailed physical and electrical effects, as well as model equations and documentation, refer to Michael Schroter's HICUM, A Scalable Physics-based Compact Bipolar Transistor Model at: http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html

HICUM_Model (Bipolar Transistor Model)

Symbol



Parameters

Name	Description	Units	Default
NPN	NPN model type: yes, no	None	yes
PNP	PNP model type: yes, no	None	no
C10	ICCR constant (=ISQp0)	$A^2 \times s$	2e-30
Qp0	zero-bias hole charge	$A^2 \times s$	2.0e-14
Ich	high-current correction for 2D/3D-ICCR	A	infinity
Hfe	GICCR weighing factor for QEf in HBTs	None	1.0
Hfc	GICCR weighing factor for Qfc (mainly for HBTs)	None	1.0
Hjei	GICCR weighing factor for Qjei in HBTs	None	1.0
Hjci	GICCR weighing factor for Qjci in HBTs	None	1.0
Mcf	GICCR weighing factor for Qjci in HBTs	None	1.0
Alit	factor for additional delay time of iT	None	0.0
Cjei0	Internal B-E zero-bias depletion capacitance	F	0.0
Vdei	Internal B-E built-in voltage	V	0.9
Zei	Internal B-E grading coefficient	None	0.5
Aljei	Ratio of maximum to zero-bias value of internal B-E capacitance	None	2.5
Cjci0	Internal B-C zero-bias depletion capacitance	F	0.0
Vdci	Internal B-C built-in voltage	V	0.7
Zci	Internal B-C grading coefficient	None	0.4
Vptci	Internal B-C punch-through voltage (=$qNCi^{w2}{}_{Ci}/(2\varepsilon)$	V	1e20
T0	Low-current forward transit time at VBC=0	sec	0.0
Dt0h	Time constant for base and B-C space charge layer width modulation	sec	0.0
Tbvl	Time constant for modeling carrier jam at low VCE	sec	0.0
Tef0	neutral emitter storage time	sec	0.0
Gtfe	exponent factor for current dependent emitter storage time	None	1.0
Thcs	saturation time constant at high current densities	sec	0.0
Alhc	smoothing factor for current dependent C and B transit time	sec	0.1
Fthc	partitioning factor for base and collector portion	None	0.0
Alqf	factor for additional delay time of Qf	None	0.0

Rci0	low-field resistance of internal collector region (including scaling)	Ohm	150.0
Vlim	Voltage separating ohmic and saturation velocity regime	V	0.5
Vpt	Collector punch-through voltage	V	3.0
Vces	internal C-E saturation voltage	V	0.1
Tr	Storage time for inverse operation	sec	0.0
Ibeis	Internal B-E saturation current	A	1e-18
Mbei	Internal B-E non-ideality factor	None	1.0
Ireis	Internal B-E recombination saturation current	A	0.0
Mrei	Internal B-E recombination current ideality factor	None	2.0
Ibcis	Internal B-C saturation current	A	1.0e-16
Mbci	Internal B-C non-ideality factor	None	1.0
Favl	Avalanche current factor	1/V	0.0
Qavl	Exponent factor for avalanche current	C	0.0
Rbi0	Zero-bias internal base resistance	Ohm	0.0
Fdqr0	correction factor for modulation by BE and BC SCR	None	0.0
Fgeo	Factor for geometry dependence of emitter current crowding (default value corresponds to long emitter stripe)	None	0.6557
Fqi	ratio of internal to total minority charge	None	1.0
Fcrbi	ration of HF shunt to total internal capacitance	None	0.0
Latb	scaling factor for QfC in bE direction	None	0.0
Latl	scaling factor for QfC in lE direction	None	0.0
Cjep0	Peripheral B-E zero-bias depletion capacitacance	F	0.0
Vdep	Peripheral B-E built-in voltage	V	0.9
Zep	Peripheral B-E grading coefficient	None	0.5
Aljep	factor for adjusting maximum value of Cjep0	None	2.5
Ibeps	Peripheral B-E saturation current	A	0.0
Mbep	Peripheral B-E current ideality factor	None	1.0
Ireps	Peripheral B-E recombination saturation current	A	0.0
Mrep	Peripheral B-E recombination current ideality factor	None	2.0
Ibets	B-E tuneling saturation current	A	0.0
Abet	Exponent factor for tuneling current	None	40.0
Cjcx0	External B-C zero-bias depletion capacitance	F	0.0
Vdcx	External B-C built-in voltage	V	0.7
Zcx	External B-C grading coefficient	None	0.4
Vptcx	External B-C punch-through voltage	V	1.0e20
Ccox	B-C overlap capacitance	F	0.0
Fbc	partitioning factor for Ccbx=Cjcx0+Ccox	None	0.0
Ibcxs	External B-C saturation current	A	0.0
Mbcx	External B-C current ideality factor	None	1.0
Ceox	B-E isolation capacitance	F	0.0
Rbx	External base series resistance	Ohm	0.0
Re	Emitter series resistance	Ohm	0.0
Rcx	External collector series resistance	Ohm	0.0
Itss	Saturation current of substrate transistor transfer current	A	0.0
Msf	Forward ideality factor of substrate transfer current	None	1.0
Msr	Reverse ideality factor of substrate transfer current	None	1.0
Iscs	Saturation current of C-S diode (latch-up modeling)	A	0.0

Msc	Ideality factor of C-S diode	None	1.0
Tsf	Transit time (forward operation) for minority charge	sec	0.0
Cjs0	C-S zero-bias depletion capacitance	F	0.0
Vds	C-S built-in voltage	V	0.6
Zs	C-S grading coefficient	None	0.5
Vpts	C-S punch-through voltage	V	1.0e20
Rsu	Substrate series resistance	Ohm	0.0
Csu	Substrate cap. given by permittivity of bulk material	F	0.0
Kf	Flicker noise factor, no unit only for Af=2	None	0.0
Af	Flicker noise exponent	None	2.0
Krbi	Factor for internal base resistance	None	1.0
Vgb	Bandgap-voltage extrapolated to 0K	V	1.17
Alb	Relative temperature coefficient of current gain	1/K	5.0e-3
Zetaci	Temperature coefficient for Rci0	None	0.0
Alvs	Relative temperature coefficient of saturation drift velocity	1/K	0.0
Alt0	First-order relative temperature coefficient of parameter T0	1/K	0.0
Kt0	Second-order relative temperature coefficient of parameter T0	$1/K^2$	0.0
Alces	Relative temperature coefficient of Vces	1/K	0.0
Zetarbi	Temperature exponent of internal base resistance	None	0.0
Zetarbx	Temperature exponent of external base resistance	None	0.0
Zetarcx	Temperature exponent of external collector resistance	None	0.0
Zetare	Temperature exponent of emitter resistance	None	0.0
Alfav	Relative temperature coefficient for avalanche breakdown Favl	1/K	0.0
Alqav	Relative temperature coefficient for avalanche breakdown Qavl		0.0
Tnom	Temperature at which parameters are specified	°C	25
Trise	Temperature rise over ambient	°C	0
Rth	Thermal resistance	K/W	0.0
Cth	Thermal capacitance	W × s/K	0.0
Imax	Explosion current	A	1e4
Imelt	Explosion current (similar to Imax; refer to note 4); defaults to Imax	A	defaults to Imax
AcModel	Selects which small signal models to use for ac and S-parameter analyses: Small signal=1, consistent with charge model=2; (refer to note 5)	None	1
SelfheatingModel	Selects which power dissipation equations to use for modeling self-heating effect: Simplified model=1, full model=2; (refer to note 6)	None	1
wVsubfwd	Substrate junction forward bias (warning)	V	None
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	None
wBvbe	Base-emitter reverse breakdown voltage (warning)	V	None
wBvbc	Base-collector reverse breakdown voltage (warning)	V	None
wVbcfwd	Base-collector forward bias (warning)	V	None
wIbmax	Maximum base current (warning)	A	None
wIcmax	Maximum collector current (warning)	A	None
wPmax	Maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname HICUM [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *HICUM*. Use either parameter NPN=yes or PNP=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

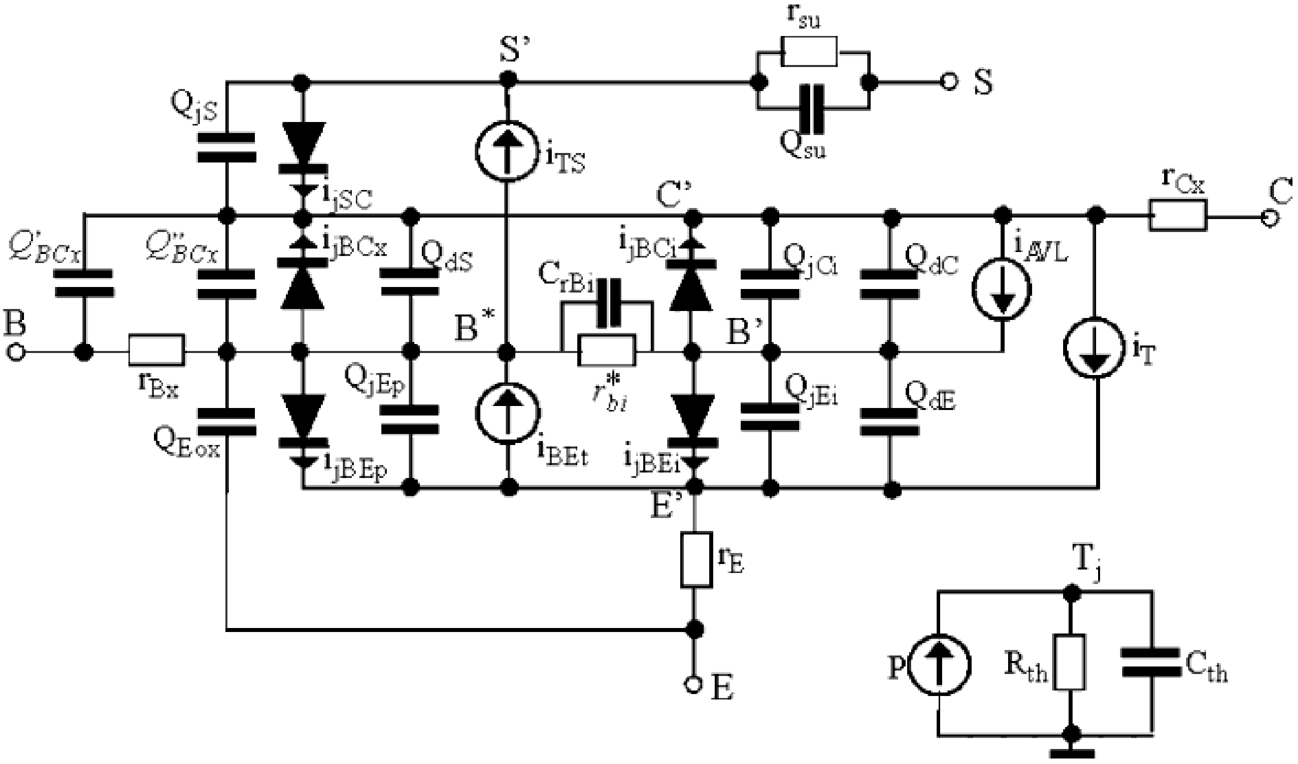
```
model  Npn3  HICUM  \
 NPN=yes Alfav=8e-5 T0=5e-12
```

Notes/Equations

1. This model (version 2.1) supplies values for a HICUM device.
2. The important physical and electrical effects taken into account by HICUM are summarized:
    - high-current effects (including quasi-saturation)
    - distributed high-frequency model for the external base-collector region
    - emitter periphery injection and associated charge storage
    - emitter current crowding (through a bias-dependent internal base resistance
    - 2- and 3-dimensional collector current spreading
    - parasitic (bias independent) capacitances between base-emitter and base-collector terminal
    - vertical non-quasi-static (NQS) effects for transfer current and minority charge
    - temperature dependence and self-heating
    - weak avalanche breakdown at the base-collector junction
    - tunneling in the base-emitter junction
    - parasitic substrate transistor
    - bandgap differences (occurring in HBTs)
    - lateral scalability
      For detailed physical and electrical effects, as well as model equations, refer to Michael Schroter's *HICUM, A* Scalable Physics-based Compact Bipolar Transistor Model *, Description of model version 2.1* , December, 2000; a pdf file is available at: "http://www.iee.et.tu-dresden.de/iee/eb/comp_mod.html" .
3. Constant transit time Tf (at dc bias) is used in harmonic balance analysis for It current delay.

4. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
5. Small-signal ac model given in the reference cited in note 1 is a derivation of the large-signal charge model. However, it is not fully compatible with the charge model with the small input. The AcModel parameter can be set to either the small-signal model (AcModel=1) or the charge model compatible model (AcModel=2) for small-signal ac and S-parameter analyses.
   The AcModel parameter has no effect on large-signal analysis.
6. Two power dissipation formulas for modeling the self-heating effect have been implemented in ADS.
   - When SelfheatingModel = 1, the simplified formula power = It × vce - Iave × vbc will be used.
   - When SelfheatingModel = 2, formula 2.1.16-1 from Schroter's document at: "http://www.iee.et.tu-dresden.de/iee/eb/comp_mod.html" will be used; the formula can be found under *General Description* > *HICUM-Equations* > section 2.1.16, equation 2.1.16-1.
     The simplified formula is implemented in Dr. Schroter's DEVICE program.
7. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams.

Equivalent Circuit

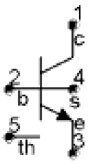

r_{su}
S'
S
Q_{jS}
i_{TS}
Q_{su}
r_{Cx}
C
C'
i_{jSC}
Q'_{BCx}
Q''_{BCx}
i_{jBCx}
Q_{dS}
i_{jBCi}
C_{rBi}
Q_{jCi}
Q_{dC}
i_{AVL}
B
B^*
B'
i_T
r_{Bx}
Q_{jEp}
r^*_{bi}
Q_{jEi}
Q_{dE}
Q_{Eox}
i_{jBEp}
i_{BEt}
i_{jBEi}
E'
r_E
E
T_j
P
R_{th}
C_{th}

(a)

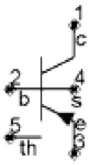
(b)

HICUM_NPN, HICUM_PNP (HICUM Bipolar Transistors, NPN, PNP)

Symbol



HICUM_NPN



HICUM_PNP

Parameters

Name	Description	Units	Default
Model	Model instance name of a HICUM_Model	None	HUCUMM1
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to *note 2*)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
Selfheating	Include selfheating effects on/off: yes, no (refer to *note 3*)	None	No
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated HICUM_Model) certain model parameters are scaled such that the device is simulated at its operating temperature.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The HICUM implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth and Cth control this: ΔT = Pdiss x Rth. To enable this, set the Selfheating flag to yes or leave it blank, and ensure that the model parameter Rth is > 0. When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using self-heating may take 50 to 100% more time than the same simulation without self-heating. Self-heating can be used with either an internal or external thermal node.
    - If the *th* (fifth) node is either connected to ground or not given in the netlist, HICUM_NPN and HICUM_PNP use an internal node to keep track of the

temperature rise of the transistor.
- If the *th* (fifth) node is either left open (unconnected) or connected to a thermal coupling network, then HICUM_NPN and HICUM_PNP use this node to keep track of the temperature rise of the transistor.

4. The following table lists the DC operating point parameters that can be sent to the dataset.

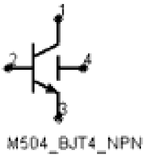
DC Operating Point Information

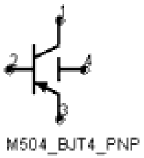
Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
Gbiei	(dIbiei/dVbiei)	siemens
Cbiei	Base-emitter capacitance	farads
Gbici	(dIbici/dVbici)	siemens
Cbici	Base-collector capacitance	farads
Gbcx	(dI/dV)	siemens
Gbep	(dI/dV)	siemens
Cbep	(dQ/dV)	farads
Gbet	(dI/dV)	siemens
Gsc	(dI/dV)	siemens
dIt_dVbi	(dIt/dVbi)	siemens
dIt_dVci	(dIt/dVci)	siemens
dIt_dVei	(dIt/dVei)	siemens
Sfbav	(dI/dV)	siemens
Sfcav	(dI/dV)	siemens
Cjs	Substrate-collector capacitance	farads
C1bcx	Base-collector capacitance	farads
C2bcx	Base-collector capacitance	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

5. This device has no default artwork associated with it.

M504_BJT4_NPN, M504_BJT4_PNP (Mextram 504 Nonlinear Bipolar Transistors with Substrate Terminal, NPN, PNP)

Symbol





Parameters

Name	Description	Units	Default
Model	name of MEXTRAM_504_Model	None	BJTM1
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
Selfheating	include selfheating effects: no, yes	None	no
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device; if different than the temperature at which the model parameters are valid or extracted (specified by Tnom of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the model to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The fourth terminal (substrate) is available for connection to an external circuit.
4. The MEXTRAM 504 implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. Model parameters Rth and Cth control this: ΔT = Pdiss x Rth. To enable this, set the Selfheating flag to yes, and ensure that the model parameter Rth is > 0. When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using self-heating may take 50 to 100% more time than the same simulation without self-heating.
   Self-heating can be used with either an internal or external thermal node.
    - M504_BJT_NPN, M504_BJT_PNP, M504_BJT4_NPN, and M504_BJT4_PNP use an

internal node to keep track of the temperature rise of the transistor.
- M504_BJT5_NPN and M504_BJT5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.

5. The following table, lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

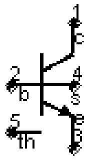
Name	**Description**	**Units**
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
In	Main current from C2-E1	amperes
Ic1c2	Epilayer current from C1-C2	amperes
Ib1b2	Pinched-base current from B1-B2	amperes
Ib1	Ideal forward base current from B2-E1	amperes
SIb1	Ideal sidewall base current from B1-E1	amperes
Ib2	Nonideal forward base current from B2-E1	amperes
Ib3	Nonideal reverse base current from B1-C1	amperes
Iavl	Avalanche current from C2-B2	amperes
Iex	Extrinsic reverse base current from B1-C1	amperes
XIex	Extrinsic reverse base current from B-C1	amperes
Isub	Substrate current from B1-S	amperes
XIsub	Substrate current from B-S	amperes
Isf	Substrate failure current from S-C1	amperes
Ire	Emitter current from E1-E	amperes
Irbc	Base current from B-B1	amperes
Ircc	Collector current from C-C1	amperes
Vc	External collector voltage	volts
Vc1	Internal collector1 voltage	volts
Vc2	Internal collector2 voltage	volts
Vb	External base voltage	volts
Vb1	Internal base1 voltage	volts
Vb2	Internal base2 voltage	volts
Ve	External emitter voltage	volts
Ve1	External emitter1 voltage	volts
Vs	Substrate voltage	volts
gx	Forward transconductance (dIn/dVb2e2)	siemens
gy	Reverse transconductance (dIn/dVb2c2)	siemens
gz	Reverse transconductance (dIn/dVb2c1)	siemens
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	siemens
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	siemens
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	siemens
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	siemens
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	siemens

gmuy	Avalanche current conductance (-dIavl/dVb2c2)	siemens
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	siemens
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	siemens
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	siemens
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	siemens
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	siemens
rbv	Base resistance (1/(dIb1b2/dVb1b2))	ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	siemens
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	siemens
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	siemens
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	siemens
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	siemens
gsf	Substrate failure conductance (dIsf/dVsc1)	siemens
Qe	Emitter or emitter neutral charge	coulombs
Qte	Base-emitter depletion charge	coulombs
SQte	Sidewall base-emitter depletion charge	coulombs
Qbe	Base-emitter diffusion charge	coulombs
Qbc	Base-collector diffusion charge	coulombs
Qtc	Base-collector depletion charge	coulombs
Qepi	Epilayer diffusion charge	coulombs
Qb1b2	AC current crowding charge	coulombs
Qtex	Extrinsic base-collector depletion charge	coulombs
XQtex	Extrinsic base-collector depletion charge	coulombs
Qex	Extrinsic base-collector diffusion charge	coulombs
XQex	Extrinsic base-collector diffusion charge	coulombs
Qts	Collector-substrate depletion charge	coulombs
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	farads
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	farads
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	farads
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	farads
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	farads
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	farads
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	farads
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	farads
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	farads
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	farads
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	farads
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	farads
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	farads
Cts	Substrate-collector capacitance (dQts/dVsc1)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

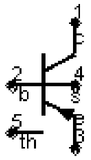
6. This device has no default artwork associated with it.
7. This model was developed by NXP Semiconductors. Documentation is available on their website: http://www.nxp.com/models/bi_models/mextram/index.html

M504_BJT5_NPN, M504_BJT5_PNP (Mextram 504 Nonlinear Bipolar Transistors with Substrate and Thermal Terminals, NPN, PNP)

Symbol



M504_BJT5_NPN



M504_BJT5_PNP

Parameters

Name	Description	Units	Default
Model	name of MEXTRAM_504_Model	None	BJTM1
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
Selfheating	include selfheating effects: no, yes	None	no
_M	number of devices in parallel	None	1

Notes/Equations/References

1. The Temp parameter specifies the physical (operating) temperature of the device; if different than the temperature at which the model parameters are valid or extracted (specified by Tnom of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the model to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The fourth terminal (substrate) is available for connection to an external circuit.
4. The MEXTRAM 504 implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth and Cth control this: $\Delta T = Pdiss \times Rth$. To enable this, set the Selfheating flag to yes, and ensure that the model parameter Rth is > 0. When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using self-heating may take 50 to 100% more time than the same simulation without self-heating. Self-heating can be used with either an internal or external thermal node.

   - M504_BJT_NPN, M504_BJT_PNP, M504_BJT4_NPN, and M504_BJT4_PNP use an internal node to keep track of the temperature rise of the transistor.
   - M504_BJT5_NPN and M504_BJT5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.
5. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
In	Main current from C2-E1	amperes
Ic1c2	Epilayer current from C1-C2	amperes
Ib1b2	Pinched-base current from B1-B2	amperes
Ib1	Ideal forward base current from B2-E1	amperes
SIb1	Ideal sidewall base current from B1-E1	amperes
Ib2	Nonideal forward base current from B2-E1	amperes
Ib3	Nonideal reverse base current from B1-C1	amperes
Iavl	Avalanche current from C2-B2	amperes
Iex	Extrinsic reverse base current from B1-C1	amperes
XIex	Extrinsic reverse base current from B-C1	amperes
Isub	Substrate current from B1-S	amperes
XIsub	Substrate current from B-S	amperes
Isf	Substrate failure current from S-C1	amperes
Ire	Emitter current from E1-E	amperes
Irbc	Base current from B-B1	amperes
Ircc	Collector current from C-C1	amperes
Vc	External collector voltage	volts
Vc1	Internal collector1 voltage	volts
Vc2	Internal collector2 voltage	volts
Vb	External base voltage	volts
Vb1	Internal base1 voltage	volts
Vb2	Internal base2 voltage	volts
Ve	External emitter voltage	volts
Ve1	External emitter1 voltage	volts
Vs	Substrate voltage	volts
gx	Forward transconductance (dIn/dVb2e2)	siemens
gy	Reverse transconductance (dIn/dVb2c2)	siemens
gz	Reverse transconductance (dIn/dVb2c1)	siemens
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	siemens
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	siemens
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	siemens

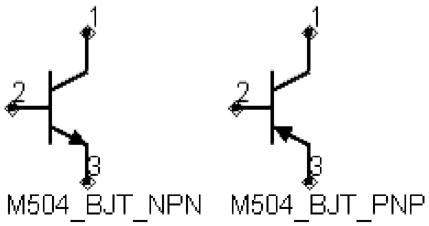
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	siemens
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	siemens
gmuy	Avalanche current conductance (-dIavl/dVb2c2)	siemens
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	siemens
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	siemens
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	siemens
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	siemens
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	siemens
rbv	Base resistance (1/(dIb1b2/dVb1b2))	ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	siemens
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	siemens
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	siemens
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	siemens
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	siemens
gsf	Substrate failure conductance (dIsf/dVsc1)	siemens
Qe	Emitter or emitter neutral charge	coulombs
Qte	Base-emitter depletion charge	coulombs
SQte	Sidewall base-emitter depletion charge	coulombs
Qbe	Base-emitter diffusion charge	coulombs
Qbc	Base-collector diffusion charge	coulombs
Qtc	Base-collector depletion charge	coulombs
Qepi	Epilayer diffusion charge	coulombs
Qb1b2	AC current crowding charge	coulombs
Qtex	Extrinsic base-collector depletion charge	coulombs
XQtex	Extrinsic base-collector depletion charge	coulombs
Qex	Extrinsic base-collector diffusion charge	coulombs
XQex	Extrinsic base-collector diffusion charge	coulombs
Qts	Collector-substrate depletion charge	coulombs
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	farads
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	farads
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	farads
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	farads
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	farads
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	farads
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	farads
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	farads
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	farads
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	farads
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	farads
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	farads
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	farads
Cts	Substrate-collector capacitance (dQts/dVsc1)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

6. This device has no default artwork associated with it.
7. This model was developed by NXP Semiconductors. Documentation is available on

their website:
http://www.nxp.com/models/bi_models/mextram/index.html

M504_BJT_NPN, M504_BJT_PNP (Mextram 504 Nonlinear Bipolar Transistors)

Symbol



Parameters

Name	Description	Units	Default
Model	name of MEXTRAM_504_Model	None	BJTM1
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to *note 2*)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
Selfheating	include selfheating effects: no, yes	None	no
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device; if different than the temperature at which the model parameters are valid or extracted (specified by Tnom of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the model to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The MEXTRAM 504 implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth and Cth control this: ΔT = Pdiss x Rth. To enable this, set the *Selfheating* flag to yes, and ensure that the model parameter Rth is > 0. When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using self-heating may take 50 to 100% more time than the same simulation without self-heating. Self-heating can be used with either an internal or external thermal node.
    - M504_BJT_NPN, M504_BJT_PNP, M504_BJT4_NPN, and M504_BJT4_PNP use an

internal node to keep track of the temperature rise of the transistor.
- M504_BJT5_NPN and M504_BJT5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.

4. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

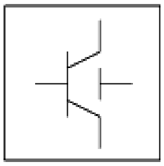
Name	**Description**	**Units**
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
In	Main current from C2-E1	amperes
Ic1c2	Epilayer current from C1-C2	amperes
Ib1b2	Pinched-base current from B1-B2	amperes
Ib1	Ideal forward base current from B2-E1	amperes
SIb1	Ideal sidewall base current from B1-E1	amperes
Ib2	Nonideal forward base current from B2-E1	amperes
Ib3	Nonideal reverse base current from B1-C1	amperes
Iavl	Avalanche current from C2-B2	amperes
Iex	Extrinsic reverse base current from B1-C1	amperes
XIex	Extrinsic reverse base current from B-C1	amperes
Isub	Substrate current from B1-S	amperes
XIsub	Substrate current from B-S	amperes
Isf	Substrate failure current from S-C1	amperes
Ire	Emitter current from E1-E	amperes
Irbc	Base current from B-B1	amperes
Ircc	Collector current from C-C1	amperes
Vc	External collector voltage	volts
Vc1	Internal collector1 voltage	volts
Vc2	Internal collector2 voltage	volts
Vb	External base voltage	volts
Vb1	Internal base1 voltage	volts
Vb2	Internal base2 voltage	volts
Ve	External emitter voltage	volts
Ve1	External emitter1 voltage	volts
Vs	Substrate voltage	volts
gx	Forward transconductance (dIn/dVb2e2)	siemens
gy	Reverse transconductance (dIn/dVb2c2)	siemens
gz	Reverse transconductance (dIn/dVb2c1)	siemens
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	siemens
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	siemens
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	siemens
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	siemens
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	siemens

gmuy	Avalanche current conductance (-dIavl/dVb2c2)	siemens
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	siemens
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	siemens
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	siemens
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	siemens
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	siemens
rbv	Base resistance (1/(dIb1b2/dVb1b2))	ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	siemens
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	siemens
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	siemens
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	siemens
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	siemens
gsf	Substrate failure conductance (dIsf/dVsc1)	siemens
Qe	Emitter or emitter neutral charge	coulombs
Qte	Base-emitter depletion charge	coulombs
SQte	Sidewall base-emitter depletion charge	coulombs
Qbe	Base-emitter diffusion charge	coulombs
Qbc	Base-collector diffusion charge	coulombs
Qtc	Base-collector depletion charge	coulombs
Qepi	Epilayer diffusion charge	coulombs
Qb1b2	AC current crowding charge	coulombs
Qtex	Extrinsic base-collector depletion charge	coulombs
XQtex	Extrinsic base-collector depletion charge	coulombs
Qex	Extrinsic base-collector diffusion charge	coulombs
XQex	Extrinsic base-collector diffusion charge	coulombs
Qts	Collector-substrate depletion charge	coulombs
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	farads
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	farads
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	farads
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	farads
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	farads
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	farads
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	farads
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	farads
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	farads
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	farads
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	farads
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	farads
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	farads
Cts	Substrate-collector capacitance (dQts/dVsc1)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

5. This device has no default artwork associated with it.
6. This model was developed by NXP Semiconductors. Documentation is available on their website: http://www.nxp.com/models/bi_models/mextram/index.html

MEXTRAM_504_Model (MEXTRAM 504 Model)

Symbol



Parameters

Name	Description	Units	Default
NPN	NPN model type: yes or no	None	yes
PNP	PNP model type: yes or no	None	no
Tref (Tnom)	Reference temperature	°C	25
Dta (Trise)	Difference between the device and ambient temperature	°C	0.0
Exmod	flag for extended modeling of reverse current gain	None	yes
Exphi	flag for distributed high-frequency effects in transient	None	yes
Exavl	flag for extended modeling of avalanche currents	None	no
Is	collector-emitter saturation current	A	22.0e-18
Ik	high-injection knee current	A	0.1
Ver	Reverse Early voltage	V	2.5
Vef	Forward Early voltage	V	44.0
Bf	Ideal forward current gain	None	215.0
Ibf	Saturation current of the non-ideal forward base current	A	2.7e-15
Mlf	Non-ideality factor of the forward base current	None	2.0
Xibi	Fraction of Ideal Base Current that belongs to the Sidewall	None	0.0
Bri	Ideal reverse current gain	None	7.0
Ibr	Saturation current of the non-ideal reverse base current	None	1.0e-15
Vlr	Cross-over voltage of the non-ideal reverse base current	V	0.2
Xext	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c2	None	0.63
Wavl	Epilayer thickness used in weak-avalanche model		1.1e-6
Vavl	Voltage determining curvature of avalanche current		3.0
Sfh	Current spreading factor of avalanche model (when EXAVL=1)	None	0.3
Re	Emitter resistance	Ohm	5.0
Rbc	Constant part of the base resistance	Ohm	23
Rbv	Zero-bias value of the variable part of the base resistance	Ohm	18
Rcc	constant part of collector resistance	Ohm	12
Rcv	Resistance of the un-modulated epilayer	Ohm	150
Scrcv	Space charge resistance of the epilayer	Ohm	1250
Ihc	Critial Current for Velocity Saturation in the Epilayer	A	4.e-3
Axi	Smoothness parameter for the onset of quasi-saturation	None	0.3

Cje	Zero-bias Emitter-Base Depletion Capacitance	F	73.0e-15
Vde	base-emitter diffusion voltage	V	0.95
Pe	base-emitter grading coefficient	None	0.4
Xcje	fraction of base-emitter capacitance that belongs to sidewall	None	0.4
Cbeo (Cbe0)	Fixed capacitance between external base and emitter nodes	F	0.0
Cjc	Zero-bias Collector-Base Depletion Capacitance		78.0e-15
Vdc	base-collector diffusion voltage	V	0.68
Pc	Collector-Base Grading Coefficient	None	0.5
Xp	constant part of Cjc	None	0.35
Mc	collector current modulation coefficient	None	0.5
Xcjc	fraction of base-collector depletion capacitance under emitter area	None	32e-3
Cbco (Cbc0)	Fixed capacitance between external base and collector nodes	None	0.0
Mtau	Non-ideality factor of the emitter stored charge	None	1.0
Taue (Te)	Minimum transit time of stored emitter charge		2.0e-12
Taub (Tb)	Transit time of stored base charge		4.2e-12
Tepi	Transit time of stored epilayer charge		41e-12
Taur (Tr)	Transit time of reverse extrinsic stored base charge		520e-12
Deg	Bandgap difference over the base		0.0
Xrec	Pre-factor of the recombination part of Ib1	None	0.0
Aqbo (Aqb0)	Temperature coefficient of the zero-bias base charge	None	0.3
Ae	Temperature coefficient of the resistivity of the emitter	None	0.0
Ab	Temperature coefficient of the resistivity of the base	None	1.0
Aepi	Temperature coefficient of the resistivity of the epilayer	None	2.5
Aex	Temperature coefficient of the resistivity of the extrinsic base	None	0.62
Ac	Temperature coefficient of the resistivity of the buried layer	None	2.0
dVgbf	Band-gap voltage difference of the forward current gain	V	0.05
dVgbr	Band-gap voltage difference of the reverse current gain	V	0.045
Vgb	Band-gap voltage of the base	V	1.17
Vgc	Band-gap voltage of the collector	V	1.18
Vgj	Band-gap voltage recombination emitter-base junction	V	1.15
dVgte	Band-gap voltage difference of emitter stored charge	V	0.05
Af	Exponent of the flicker-noise	None	2.0
Kf	Flicker-noise coefficient of the ideal base current	None	2e-11
Kfn	Flicker-noise coefficient of the non-ideal base current	None	2e-11
Iss	Base-substrate saturation current	A	48e-18
Iks	Base-substrate high injection knee current	A	250e-6
Cjs	Zero-bias collector-substrate depletion capacitance	F	315e-15
Vds	Collector-substrate diffusion voltage	V	0.62
Ps	Collector-substrate grading coefficient	None	0.34
Vgs	Band-gap voltage of the substrate	V	1.20
As	For a closed buried layer As=Ac and for an open buried layer As=Aepi	None	1.58
Rth	Thermal resistance	None	300
Cth	Thermal capacitance	None	3e-9
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvbe	base-emitter reverse breakdown voltage (warning)	V	None
wBvbc	base-collector reverse breakdown voltage (warning)	V	None

wVbcfwd	base-collector forward bias (warning)	V	None
wIbmax	maximum base current (warning)	A	None
wIcmax	maximum collector current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MextramBJT504 [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *MextramBJT504*. Use either parameter NPN=yes or PNP=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn5 MextramBJT504 \
 NPN=yes Cjc=8e-14 Aepi=2  Vdc=0.6
```

Notes/Equations

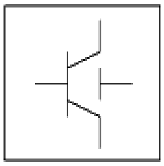
1. This model supplies values for M504_BJT_NPN, M504_BJT_PNP, M504_BJT4_NPN, M504_BJT4_PNP, M504_BJT5_NPN, and M504_BJT5_PNP devices.
2. The MEXTRAM 504 implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth and Cth control this: ΔT = Pdiss x Rth. To enable this, set the Selfheating flag to yes, and ensure that the model parameter Rth is > 0. When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using self-heating may take 50 to 100% more time than the same simulation without self-heating. Self-heating can be used with either an internal or external thermal node.
   - M504_BJT_NPN, M504_BJT_PNP, M504_BJT4_NPN, and M504_BJT4_PNP use an internal node to keep track of the temperature rise of the transistor.
   - M504_BJT5_NPN and M504_BJT5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.
3. This model was developed by NXP Semiconductors. Documentation is available on their website:

   http://www.nxp.com/models/bi_models/mextram/index.html

4. ADS implements the complete MEXTRAM 504 model, as per the NXP document NL_UR 2000/811, issued April 2001. Differences between the ADS documentation and the NXP documentation are:
   - in equations (4.96) and (4.102), Rcvt is used (not Rcv).
   - resistances are limited to a lower value of $l0^{-4}\Omega$ (not $l0^{-6}\Omega$)

MEXTRAM_Model (MEXTRAM Model)

Symbol



Parameters

Name	Description	Units	Default
NPN	NPN model type: yes or no	None	yes
PNP	PNP model type: yes or no	None	no
Release	Selection of MEXTRAM Release 503, 504, 505	None	503
Exmod	flag for extended modeling of reverse current gain	None	yes
Exphi	flag for distributed high-frequency effects in transient	None	yes
Exavl	flag for extended modeling of avalanche currents	None	yes
Is	collector-emitter saturation current	A/m^2	5.0e-17
Bf	ideal forward current gain	None	140.0
Xibi	fraction of ideal base current that belongs to sidewall	None	0.0
Ibf	saturation current of non-ideal forward base current	A/m^2	2.0e-14
Vlf	cross-over voltage of non-ideal forward base current	V	0.5
Ik	high-injection knee current	A/m^2	1.5e-2
Bri	ideal reverse current gain	None	16.0
Ibr	saturation current of non-ideal reverse base current	A/m^2	8.0e-15
Vlr	cross-over voltage of non-ideal reverse base current	V	0.5
Xext	part of IEX, QEX, QTEX and ISUB that depends on base-collector voltage VBC1	None	0.5
Qb0	base charge at zero bias	None	1.2e-12
Eta	factor of built-in field of base (= η)	None	4.0
Avl	weak avalanche parameter	None	50.0
Efi	electric field intercept (with Exavl=1)	None	0.7
Ihc	critical current for hot carriers	A/m^2	3.0e-3
Rcc	constant part of collector resistance	$Ohms/m^2$	25.0
Rcv	resistance of unmodulated epilayer	$Ohms/m^2$	750.0
Scrcv	space charge resistance of epilayer	$Ohms/m^2$	1000.0
Sfh	current spreading factor epilayer	None	0.6
Rbc	constant part of base resistance	$Ohms/m^2$	50.0
Rbv	variable part of base resistance at zero bias	$Ohms/m^2$	100.0
Re	emitter series resistance	$Ohms/m^2$	2.0

		2	
Taune	minimum delay time of neutral and emitter charge	sec	3.0e-10
Mtau	non-ideality factor of the neutral and emitter charge		1.18
Cje	B-E Zero-bias Junction Capacitance	F/m^2	2.5e-13
Vde	base-emitter diffusion voltage	V	0.9
Pe	base-emitter grading coefficient	None	0.33
Xcje	fraction of base-emitter capacitance that belongs to sidewall	None	0.5
Cjc	base-emitter Zero-bias Junction capacitance	F/m^2	1.3e-13
Vdc	base-collector diffusion voltage	V	0.6
Pc	base-collector grading coefficient variable part	None	0.4
Xp	constant part of Cjc	None	0.2
Mc	collector current modulation coefficient	None	0.5
Xcjc	fraction of base-collector depletion capacitance under emitter area	None	0.1
Tref (Tnom)	reference temperature	°C	25
Dta (Trise)	difference of device temperature to ambient temperature (TDevice=TAmbient+Dta)	°C	0.0
Vge	emitter bandgap voltage	eV	1.01
Vgb	base bandgap voltage	eV	1.18
Vgc	collector bandgap voltage	eV	1.205
Vgj	Recombination E-B Junction Band-Gap Voltage	eV	1.1
Vi	ionization voltage base dope	V	0.04
Na	maximum base dope concentration	cm^{-3}	3.0e+17
Er	temperature coefficient of Vlf and Vlr	None	2.0e-3
Ab	temperature coefficient resistivity base	None	1.35
Aepi	temperature coefficient resistivity of the epilayer	None	2.15
Aex	temperature coefficient resistivity of the extrinsic base	None	1.0
Ac	temperature coefficient resistivity of the buried layer	None	0.4
Kf	flicker noise coefficient ideal base current	None	2.0e-16
Kfn	flicker noise coefficient non-ideal base current	None	2.0e-16
Af	flicker noise exponent	None	1.0
Iss	base-substrate saturation current	A/m^2	6.0e-16
Iks	knee substrate current	A/m^2	5.0e-6
Cjs	C-S Zero-bias Junction Capacitance	F/m^2	1.0e-12
Vds	collector-substrate diffusion voltage	V	0.5
Ps	collector-substrate grading coefficient	None	0.33
Vgs	substrate bandgap voltage	V	1.15
As	for closed buried or an open buried layer	None	2.15
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvbe	base-emitter reverse breakdown voltage (warning)	V	None
wBvbc	base-collector reverse breakdown voltage (warning)	V	None
wVbcfwd	base-collector forward bias (warning)	V	None
wIbmax	maximum base current (warning)	A	None
wIcmax	maximum collector current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MextramBJT [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *MextramBJT*. Use either parameter NPN=yes or PNP=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Npn4 MextramBJT  \
 NPN=yes Ibf=3e- Qb0=1e-13
```

Notes/Equations

1. This model (version 503) supplies values for BJT_NPN, BJT_PNP, BJT4_NPN, and BJT4_PNP devices.
2. For the MEXTRAM bipolar transistor model, model equations are explicit functions of internal branch voltages; therefore, no internal quantities are solved iteratively. Transistor parameters are discussed where relevant; most parameters can be extracted from capacitance, DC, and f_T measurements, and are process and transistor layout (geometry) dependent. Initial/predictive parameter sets can be calculated from process and layout data. This model does not contain extensive geometrical or process scaling rules (only multiplication factors to put transistors in parallel). The extended modeling of reverse behavior, the increase of the avalanche current when the current density in the epilayer exceeds the doping level, and the distributed high-frequency effect are optional and can be switched on by setting flags. Besides the NPN transistor a PNP model description is available, both with and without substrate (discrete transistors) modeling.
3. The Philips model uses the MULT parameter as a scaling factor. In ADS, MULT is implemented as AREA, which has the same mathematical effect. Because the Philips model uses MULT as the multiplier/scaling, the values are in measurements such as Amps. However, in ADS, units of area are m^2, so they are listed accordingly. This accounts for differences in reporting of some units in the Phillips documentation.
4. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified

via AllParams.

Survey of Modeled Effects

- Temperature effects
- Charge storage effects
- Substrate effects and parasitic PNP
- High-injection effects
- Built-in electric field in base region
- Bias-dependent Early effect
- Low-level non-ideal base currents
- Hard and quasi-saturation
- Weak avalanche
- Hot carrier effects in the collector epilayer
- Explicit modeling of inactive regions
- Split base-collector depletion capacitance
    - Current crowding and conductivity modulation for base resistance
    - First-order approximation of distributed high-frequency effects in the intrinsic base (high-frequency current crowding and excess phase-shift).

Active Transistor

Main Current

In the MEXTRAM model the Moll-Ross relation is used to take into account the depletion and diffusion charges:

$$I_n = \frac{(I_f - I_r)}{1 + (Qt_e + Qt_c + Qb_e + Qb_c)/Qb0}$$ **(2-1)**

$$Qb_e = f_1(n_o)$$ **(2-2)**

$$Qb_c = f_2(n_b)$$ **(2-3)**

The depletion charges are represented by Qt_e and Qt_c. The calculation of the diffusion charges Qb_e and Qb_c is based directly on the solution of the differential equation for the majority carriers in the neutral base region and relates the charges to the injected minority carrier concentrations at the emitter (no) and collector edges (nb). These concentrations, in turn, depend on the internal junction voltages Vb_2e_1 and Vb_2c by considering the P-N product at both junctions. In this way high injection, bias-dependent current gain, a current- dependent transit time, and the effect of the built-in electric field are included. The ideal forward and reverse current are given by:

$$I_f - I_r = Is \times (\exp(Vb_2e_1/V_t) - \exp(Vb_2c_2/V_t))$$ **(2-4)**

where V_t is the thermal voltage.

The parameters are:

Is = extracted from Gummel plot at low V_{be}

Qb0 = integral of base charge extracted from reverse Early effect
Xcjc = fraction of Cj_c underneath emitter; obtained from forward Early effect

Ik = from gain fall-off: only one knee current
Eta = built-in field in the base due to the doping profile. This parameter is normally between 3 and 6. It is difficult to obtain from direct measurements, and has a weak influence on calculated currents and charges.

Ideal Forward Base Current

The ideal forward base current is defined in the usual way. The total base current has a bottom and a sidewall contribution. The separation is given by the factor XIb1. This factor can be determined by analyzing the maximum current gain of transistors with different geometries.

$$Ib_1 = (1 - Xibi) \times \frac{Is}{Bf}(\exp(Vb_2e_1/V_t) - 1)$$ **(2-5)**

The parameters are:
Bf = ideal forward current gain
Xibi = fraction of ideal base current that belongs to the sidewall

Non-Ideal Forward Base Current

The non-ideal base current originates from the recombination in the depleted base-emitter region:

$$Ib_2 = Ibf \times \frac{\exp(Vb_2e_1/V_t) - 1}{\exp(Vb_2e_1/(2 \times V_t)) + \exp(Vlf/(2 \times V_t))}$$ **(2-6)**

Formulation of the non-ideal base current differs from the Gummel-Poon model. The MEXTRAM formulation is less flexible than the Gummel-Poon model. The formulation is the same when in the MEXTRAM model Vl_f is small (<0.4V), and when in the Gummel-Poon model parameter n_e=2. The parameters are:

Vlf = crossover voltage of the non-ideal forward base current
Ibf = saturation current of the non-ideal forward base current

Base-Emitter Depletion Charge

The base-emitter depletion charge is modeled in the classical way using a grading coefficient. The depletion charge is partitioned in a bottom and a sidewall component by the parameter Xcje.

$$Ct_e = (1 - Xcje) \times \frac{Cje}{1 - (Vb_2e_1/Vde)^{Pe}}$$ **(2-7)**

The capacitance becomes infinity at Vb_2e_1 = Vde. Therefore in the model the integral of equation is slightly modified and consequently Ct_e. The capacitance now has a maximum at the base-emitter diffusion voltage Vde and is symmetrical around the diffusion voltage. The maximum capacitance is determined by the value of K and the grading coefficient Pe. The value of K is a model constant and is taken equal to 0.01. When Pe=0.4, the maximum is approximately three times the capacitance at zero bias. The parameters are:
Cjc = zone bias base-emitter depletion capacitance
Vde = base-emitter diffusion voltage
Pe = base-emitter grading coefficient

Base-Collector Depletion Charge

The base-collector depletion capacitance underneath the emitter Qtc, takes into account the finite thickness of the epilayer and current modulation:

$$Ct_c = Xcjc \times Cjc \times \left(\frac{(1 - Xp) \times f(Vc_1c_2)}{1 - ((Vb_2 \times c_2)/(Vdc))^{Pc}} + Xp \right)$$

(2-8)

$$f(Vc_1 \times c_2) = \left(1 - \frac{Vc_1c_2}{Vc_1c_2 + Ihc \times Rcv} \right)^{Mc}$$

(2-9)

The function $f(Vc_1c_2)$ equals one when $Ic_1c_2 = Vc_1c_2 = 0$, and becomes zero when the current density in the epilayer exceeds the doping level (Vc_1c_2 > Ihc × Rcv). The parameters are:
Cjc = zero bias base-collector depletion capacitance
Xcjc = part of Cjc underneath emitter
Vdc = base-collector diffusion voltage
Pc = base-collector grading coefficient
Xp = depletion layer thickness at zero bias divided by epilayer thickness
Mc = collector current modulation coefficient ($0.3 < mc < 0.5$)
Cjc, Pc and Xp is obtained from CV measurements; Vdc must be extracted from the quasi-saturation regime; Xcjc is obtained from the forward Early-effect.

Neutral Base and Emitter Diffusion Charge

The neutral base-emitter diffusion charge (Q_n) is given by:

$$Q_n = Qn_0 \times \left(\exp\left(\frac{Vb_2e_1}{Mtau \times V_t} \right) - 1 \right)$$

(2-10)

The charge Qn0 is calculated from the transit time Taune and Mtau. The parameters (extracted from the maximum value of the cut-off frequency, f_T) are:

Taune = minimum delay time of neutral and emitter charge
Mtau = non-ideality factor of the neutral and emitter charge; in most cases Mtau=1

Base-Charge Partitioning

Distributed high-frequency effects are modeled, in first order approximation, both in lateral direction (current crowding) and in vertical direction (excess phase-shift). The distributed effects are an optional feature of the MEXTRAM model, and can be switched on and off by flag Exphi (on: Exphi - 1; off: Exphi = 0). In vertical direction (excess phase-shift), base charge partitioning is used; for simplicity, it is implemented for forward base charge (Qb_e) and low-level injection only. No additional parameters.

$$Q'b_e = (1 - q_c(Eta)) \times Qb_e \quad \textbf{(2-11)}$$

$$Q'b_c = Qb_c + q_c(Eta) \times Qb_e \quad \textbf{(2-12)}$$

Modeling of Epilayer Current Charges

The epilayer resistance depends on the supplied collector voltage and current, imposed primarily by base-emitter voltage. The effective resistance of the epilayer is strongly voltage- and current-dependent because:

- In the forward mode of operation, the internal base charge junction voltage (Vb_2c_2) may become forward-biased at high collector currents (quasi-saturation). When this happens, the region in the collector near the base is injected by carriers from the base, causing the region to become low resistive.
- In the reverse mode of operation, both the external and internal base charge junction voltages are forward biased, flooding the whole epitaxial layer with carriers, which causes it to become low resistive.
- The current flow in the highly-resistive region is ohmic if the carrier density (n) is low (!ccnld-3-20-365.gif!), and space-charge-limited if the carrier density exceeds the doping level (!ccnld-3-20-366.gif!).
- Current spreading in the epilayer reduces the resistance and is of special importance if the carrier density exceeds N_{epi}. In the latter case, the carriers move with the saturated drift velocity, V_{sat} (hot-carrier current-flow).

  A compact modal formulation of quasi-saturation is given by Kull et al [1]. The Kull model is valid only if the collector current density is below the critical current density (J_{hc}) for hot carriers:

  $$J_{hc} = q \times N_{epi} \times v_{sat} \quad \textbf{(2-13)}$$

  The Kull formulation has served as a basis for the epilayer model in MEXTRAM.

Collector Resistance Model

The Kull model is based on charge neutrality ($p + N_{epi} \approx n$) and gives the current through the epilayer (Ic_1c_2) as a function of the internal and external b.c. junction voltage. These voltages are given by the solution vector of the circuit simulator. The final equations of the Kull formulation [1] are:

$$Ic_1c_2 = \frac{E_c + Vb_2c_2 - Vb_2c_1}{Rcv} \quad \textbf{(2-14)}$$

$$E_c = V_t \times \left[K_0 - K_w - \ln\left(\frac{K_0 + 1}{K_w + 1}\right)\right]$$

(2-15)

$$K_0 = \sqrt{1 + 4 \times \exp[(Vb_2c_2 - Vd_c)/V_t]}$$

(2-16)

$$K_w = \sqrt{1 + 4 \times \exp[(Vb_2c_1 - Vd_c)/V_t]}$$

(2-17)

$$V_t = k \times \frac{T}{q}$$

(2-18)

Voltage source (E_c) takes into account the decrease in resistance due to carriers injected from the base into the collector epilayer. If both junctions are reverse biased (Vb2c1 - Vdc and Vb_2c_2 - Vd_c are negative), E_c is zero and we have a simple constant resistance (Rcv).

Because of this, this model does not take into account the hot-carrier behavior (carriers moving with the saturated drift-velocity) in the lightly-doped collector epilayer. The model is valid if the transistor operates in the reverse mode (reverse-biased b.e. junction, forward-biased b.c. junction). Then the entire epilayer is filled with carriers and a space-charge region does not exist. The derivation of the MEXTRAM epilayer resistance model is published in de Graaff and Kloosterman [2]. In the end, the following equations are found:

$$\frac{X_i}{W_{epi}} = \frac{E_c}{Ic_1c_2 \times Rcv}$$

(2-19)

$$I_{low} = \frac{Ihc \times Vc_1c_2}{Vc_1c_2 + Ihc \times Rcv \times (1 - X_i/W_{epi})}$$

(2-20)

$$Ic_1c_2 = (I_{low} + S_f) \times \frac{Vc_1c_2 - I_{low} \times Rcv \times (1 - X_i/W_{epi})}{Scrcv \times (1 - X_i/W_{epi})^2}$$

(2-21)

Where Xi/Wepi is the thickness of the injected region of the epilayer. Substitution of equations (2-19) and (2-20) into equation (2-21) gives a cubic equation. The epilayer current (Ic1c2) is calculated by solving the cubic equation. The complex calculation can be done with real variables. Summarizing, the epilayer resistance model takes into account:

- Ohmic current flow at low current densities
- Decrease in resistance due to carriers injected from the base if only the internal base-collector junction is forward biased (quasi-saturation), and if both the internal and external base-collector junctions are forward biased (reverse mode of operation)
- Space charge limited current flow at high current densities
- Current spreading in the epilayer

  The model parameters are:

$$Ihc = q \times N_{epi} \times A_{em} \times v_{sat} \times \frac{1 + Sf_l}{\alpha_{cf}}$$

(2-22)

$$Rcv = \frac{W_{epi}}{q \times N_{epi} \times \mu \times A_{em}} \times \frac{\alpha_{cf}}{1 + Sf_l}$$

(2-23)

$$Scrcv = \frac{W^2_{epi}}{2 \times \varepsilon \times v_{sat} \times A_{em}} \times \frac{\alpha_{cf}}{1 + Sf_h}$$ **(2-24)**

$$Vdc = V_t \times \ln\left\{(N_{epi}/n_i)^2\right\}$$ **(2-25)**

$$Sfh = \frac{2}{3} \times \tan(\alpha_h) \times W_{epi} \times \left(\frac{1}{H_e} + \frac{1}{L_e}\right)$$ **(2-26)**

where:

$$A_{em} = H_e \times L_e$$ **(2-27)**,

$$Sf_l = \tan(\alpha_h) \times W_{epi} \times \left(\frac{1}{H_e} + \frac{1}{L_e}\right)$$ **(2-28)**,

αl = the spreading angle at low current levels (Ic_1c_2 < Ihc)

αh = the spreading angle at high current levels Ic_1c_2 > Ihc)

αcf = the fraction of Ic_1c_2 flowing through the emitter floor area

L_e = the length of the emitter stripe.

The turnover from equations (2-20) and (2-21) in the forward mode to equation (2-14) in the reverse mode does not give discontinuities in the first and second derivative. The third derivative is discontinuous. Parameter Sfh depends on transistor geometry and the decrease in gain and cutoff frequency will be affected by this parameter. SF1 is included in Rcv and Ihc, and not needed as a separate parameter. In most cases, Vdc is calculated directly from the doping level. Rcv, Ihc, and Scrcv are extracted from the quasi-saturation regime at low values of Vce.

Diffusion Charge of the Epilayer

The diffusion charge of the epilayer can be easily derived by applying the Moll-Ross relation to the base + collector region (from node e_1 to node c_1):

$$I_n = Ic_1c_2 = \frac{Is \times \{\exp(Vb_2e_1/V_t) - \exp(Vb_2c_1/V_t)\}}{1 + \dfrac{Q_{te} + Q_{tc} + Q_{be} + Q_{bc} + Q_{epi}}{Qb0}}$$ **(2-29)**

Subtracting equation (2-1), the expression for Q_{epi} becomes:

$$Q_{epi} = Is \times Qb0 \times \frac{\exp(Vb_2c_1/V_t) - \exp(Vb_2c_1/V_t)}{Ic_1c_2}$$ **(2-30)**

In the transition from forward to reverse mode, Ic_1c_2 passes zero and numerical problems can be expected. Substitution of equation (2-14) into equation (2-29) leads in the case where $Vb_2c_2 \approx Vb_2c_1$ to the following expression for Q_{epi}:

$$p_0 = \frac{2 \times \exp\{(Vb_2c_2 - Vdc)/V_t\}}{1 + K_0} \quad (2\text{-}31)$$

$$p_w = \frac{2 \times \exp\{(Vb_2c_1 - Vdc)/V_t\}}{1 + K_w} \quad (2\text{-}32)$$

$$Q_{epi} = Is \times Qb0 \times Rcv \times \exp(Vdc/V_t) \times \frac{p_0 + p_w}{2 \times V_t} \quad (2\text{-}33)$$

Avalanche Multiplication Model

Due to the high-electric field in the space-charge region, avalanche currents are generated; this generation strongly depends on the maximum electric field. The maximum electric field may reside at the base charge junction or at the buried layer. The generation of avalanche current in Kloosterman and de Graaff [3] is only a function of the electric field at the internal base charge junction. Therefore, the validity of this model is restricted to low current levels (Ic_1c_2<Ihc).

Current spreading in the collector region changes the electric-field distribution and decreases the maximum electric field. Because the generation of avalanche current is sensitive with respect to the maximum electric-field, it is difficult to set up an accurate and still simple model for high collector current densities. Because this operating area (high voltages, high current levels) is not of practical interest (due to power dissipation) and, more importantly, the convergency behavior of the model degrades, we must carefully consider the extension of the avalanche model to the high current regime.
At low current densities (Ic_1c_2<Ihc), the model is essentially the same as in Kloosterman

and de Graaff [3]. As an optional feature, the model is extended to current levels exceeding Ihc (negative output resistance: snap-back behavior). Due to negative output resistance, serious convergency problems are imaginable. Without this feature, output resistance can be very small, but is always positive.
The generation of avalanche current is based on Chynoweth's empirical law for the ionization coefficient [4]:

$$P_n = \alpha_n \times \exp\left(\frac{-b_n}{|E|}\right) \quad (2\text{-}34)$$

Because only weak avalanche multiplication is considered, the generated avalanche current is proportional with the main current (I_n):

$$I_g = I_n \times \int_{x=0}^{x=X_d} \alpha_n \times \exp\left(\frac{-b_n}{|E(x)|}\right) \times dx \quad (2\text{-}35)$$

X_d = the boundary of the space-charge region.

To calculate the avalanche current, we must evaluate the integral of equation (2-34) in the space-charge region. This integral is determined by the maximum electric field. We make a suitable approximation around the maximum electric field:

$$E(x) = E_m \times \left(1 - \frac{x}{\lambda}\right) \cong \frac{E_m}{1 + x/\lambda}$$

l = the point where the extrapolated electric-field is zero.
Then the generated avalanche current becomes:

$$\frac{I_g}{I_n} = \frac{\alpha_n}{b_n} \times E_m \times \lambda \times \left\{ \exp\left(\frac{-b_n}{E_m}\right) - \exp\left(\frac{-b_n}{E_m} \times \left(1 + \frac{X_d}{\lambda}\right)\right) \right\}$$

The maximum electric field (E_m), the depletion layer thickness (X_d), and the intersection point (l) are calculated using the charge model of Q_{tc} and the collector resistance model.

The model parameters are:

$$Avl = b_n \times \sqrt{\frac{2 \times \varepsilon \times Vdc}{q \times N_{epi}}}$$

$$F_i = 2 \times \frac{1 + 2 \times Sf_l}{1 + 2 \times Sfh} \times \frac{2 + Sf_l + 2 \times Sfh}{2 + 3 \times Sf_l}(-1)$$

Avl = obtained from the decrease of I_b at high V_{cb} and low I_c values

Sfh = equation (2-26)

Sf_l = equation (2-27)

Efi = used in extended avalanche model only
Sfh and Efi are extracted from the output characteristics at high V_{ce} and high I_c. Because most devices are heated due to power dissipation in this operation regime, parameter extraction is cumbersome. Calculating Efi and Sfh is often a good alternative.

Extrinsic Regions

Reverse Base Current

The reverse base current is affected by high injection and partitioned over the two external base-collector branches:

$$ah_b = 2 \times \left(\frac{1 - \exp(-Eta)}{Eta}\right)$$

$$al_b = \exp(-Eta)$$

$$g_1 = \frac{4 \times Is \times ah_b^{\;2} \times \exp\left(\frac{Vb_1c_1}{V_t}\right)}{I_k \times al_b^{\;2}}$$

$$n_{b_{ex}} = al_b \times \frac{g_1}{2 \times (1 + \sqrt{1 + g_1})}$$

$$I_{ex} = \frac{(1 - Xext)}{Bri} \times \left(\frac{al_b + n_{b_{ex}}}{ah_b + n_{b_{ex}}} \times \frac{Ik}{ah_b} \times n_{b_{ex}} - Is\right)$$

The current XI_{ex} is calculated in a similar way using the voltage Vbc1. Because the time to evaluate the extrinsic regions is doubled due to this partitioning, it is an optional feature.
The parameters are:
Bri = ideal reverse current gain
Xext = partitioning factor

Non-Ideal Reverse Base Current

The non-ideal reverse base current (Ib3) is modeled in the same way as the forward non-ideal base current. The parameters are:
Ibr = saturation current of the non-ideal reverse base current
Vlr = crossover voltage of the non-ideal reverse base current

Extrinsic Base-Collector Depletion Capacitance

The base-collector depletion capacitance of the extrinsic region is divided over the external-base node b_1 (part: Q_{tex}). The model formulation is obtained by omitting the current modulation term in the formulation of Q_{tc}, equation (2-8).

$$Ctc_{ex} = (1 - Xext) \times (1 - Xcjc) \times Cjc \times \left(\frac{1 - Xp}{1 - (Vb_1c_1/\mathrm{Vdc})^{Pc}} + Xp\right)$$

$$Xctc_{ex} = Xext \times (1 - Xcjc) \times Cjc \times \left(\frac{1 - Xp}{1 - (Vb_1c_1/(Vdc))^{Pc}} + Xp\right)$$

Parameter Xext is partitioning factor for the extrinsic region.
This partitioning factor is important for the output conductance (Y12) at high frequencies.

Diffusion Charge of the Extrinsic Region

Diffusion Charge of the Extrinsic Region

These charges are formulated in the same way as Qb_c and Q_{epi}, now using voltages Vc_1b_1 and Vbc_1, and the appropriate area (1 - Xcjc)/Xcjc.

Parasitic PNP

The substrate current of the PNP takes into account high injection. The parameters are:
Iss = substrate saturation current
Iks = knee in the substrate current; when the value of *Iks* is low, the reverse current gain increases at medium reverse current levels
When the collector-substrate junction becomes forward biased, only a signal current (Is_f) is present in the model.

$$Is_f = Iss \times (\exp((Vsc_1)/(Vt)) - 1)$$

No additional parameters.

Collector-Substrate Depletion Capacitance

The collector-substrate charge (Qt_s) is modeled in the usual way:

$$Ct_s = \frac{Cjs}{1 - (Vsc_1/(Vds))^{Ps}}$$

Parameters Cjs, Vds, and P *s* are obtained from collector-substrate CV measurement.

Base-Emitter Sidewall

Base-emitter sidewall base current Sib_1:

$$Sib_1 = Xibi \times \frac{Is}{Bf} \times (\exp(Vb_1e_1/V_t) - 1)$$

Parameter *Xibi* obtained from geometrical scaling of the current gain.
Base-emitter sidewall depletion capacitance SQt_e:

$$SCt_e = \frac{Xcje \times Cje}{1 - (Vb_1e_1/\mathrm{Vde})^{Pe}}$$

Parameter Xcje obtained from geometrical scaling of the capacitances.

Variable Base Resistance

The base resistance is divided in a variable part (R_{bv}) and a constant part (R_{bc}). The variable part is modulated by the base width variation (depletion charges at the junctions Q_{te} and Q_{tc}) and at high current densities it decreases because of the diffusion charges Q_{be} and Q_{bc}. The parameter Rbv is the resistance at zero base-emitter and base-collector

voltage. The resistance model also considers DC current crowding. The resistance decreases at high base currents when V_{b1b2} is positive, and it increases when V_{b1b2} is negative (reversal of the base e current).
Charge modulation:

$$R_b = \frac{Rbv}{1 + (Qt_e + Qt_c + Qb_e + Qb_c)/(Qb0)}$$

DC current crowding:

$$Ib_1b_2 = \frac{2 \times V_t}{3 \times R_b} \times (\exp(Vb_1b_2/V_t) - 1) + \frac{Vb_1b_2}{3 \times R_b}$$

Ac current crowding is an optional feature of the model (Exphi=1):

$$Qb_1b_2 = Vb_1b_2 \times (Ct_e + Cb_e + C_n)/5$$

Constant Series Resistances

The model contains three constant series resistors at the base, emitter, and collector terminals (Rbc, Re, Rcc). (Substrate resistance is not incorporated in the model.)

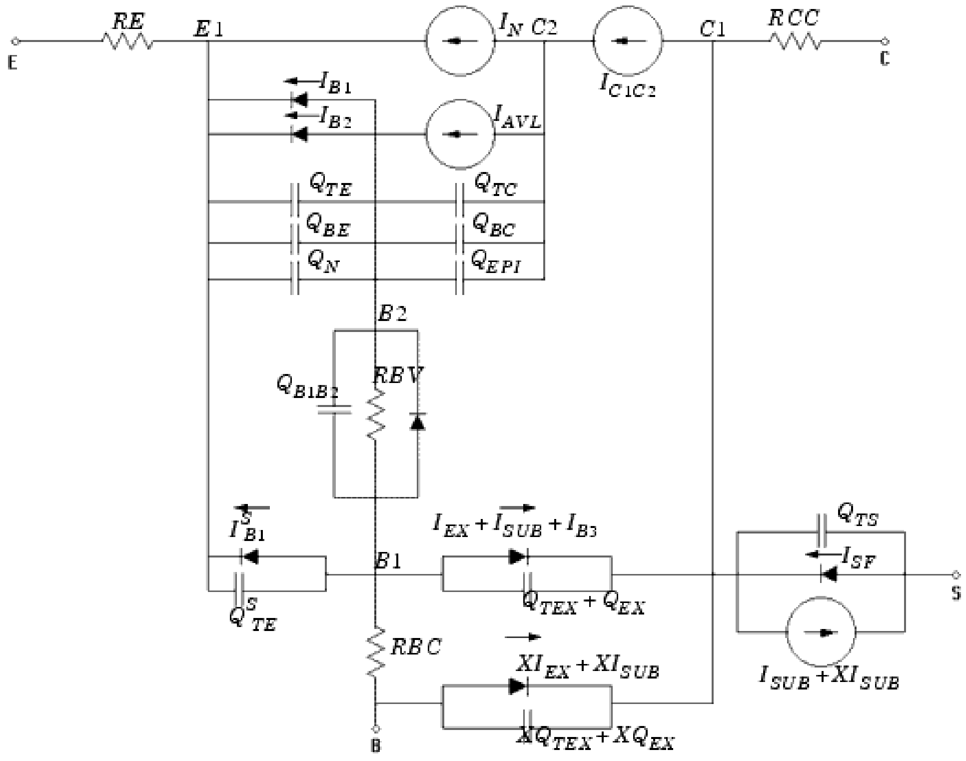
Temperature Scaling Rules

Temperature scaling rules are applied to these parameters.
Resistances: Rbc, Rbv, Re, and Rcc
Capacitances: Cje, Vde, Cjc, Vdc, Xp, Cjs, Vds, Qbo, Qn_0, and Mtau
Saturation Currents: Is and Iss
Gain Modeling: Bf, Ibf, Vif, Bri, Ibr, Vlr, Ik, and Iks
Avalanche: Avl
These parameters are used in the temperature scaling rules:
Bandgap Voltages: Vge, Vgb, Vgc, Vgs, and Vgj
Mobility Exponents: Ab, Aepi, Aex, Ac, and As
Qb0: Vi and Na
Vlf and Vlr: Er

Noise Model

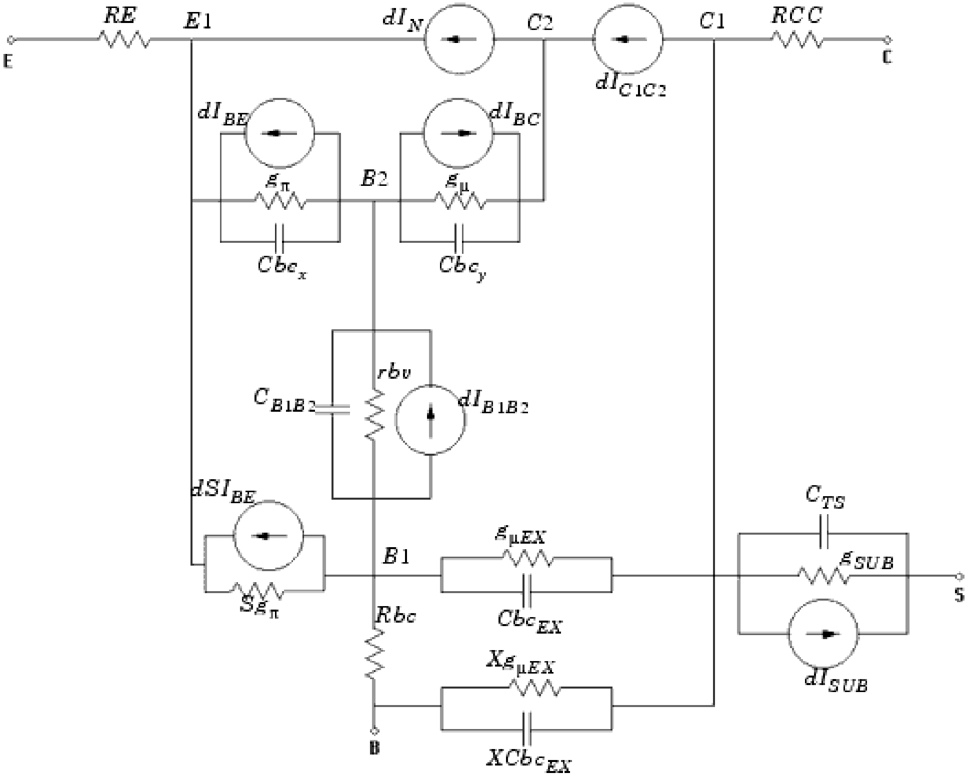
Thermal Noise: Resistances Rbc, Rbv, Re, and Rcc
Shot Noise: I_n, Ib1, Sib1, Ib_2, Ib_3, I_{ex}, and XI_{ex}
1/F noise: Ib_1, SIb_1, Ib_2, and Ib_3
1/F noise parameters: Kf, Kfn, and Af

Equivalent Circuits



mextramv.tif

Equivalent Circuit for Vertical NPN Transistor



Small Signal Equivalent Circuit for Vertical NPN Transistor

References

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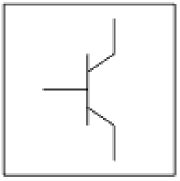
2. H.C. de Graaff and W.J. Kloosterman: "Modeling of the collector Epilayer of a Bipolar Transistor in the Mextram Model." IEEE Transaction on Electron devices, Vol. ED-42, p. 274, February 1995.
3. W.J. Kloosterman, H.C. de Graaff: "Avalanche Multiplication in a Compact Bipolar Transistor Model for Circuit Simulation." IEEE Transactions on Electron Devices, Vol. 36, No. 7, 1989.
4. A.G. Chynoweth: "Ionization rates for electron and holes in silicon." Phys. Rev., Vol. 109, p. 37, 1958.

STBJT_Model (ST Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

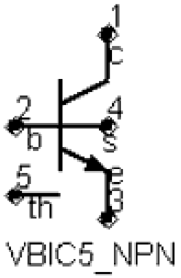
Name	Description	Units	Default
Type	Model type: 1=NPN; 2=PNP	None	1
Tmeas (Tnom)	measurement temperature	°C	25
Is	forward transport saturation current	A	1.0e-16
Isn	reverse transport saturation current; defaults to Is	A	defaults to Is
Bf	ideal forward current gain	None	100.0
Nf	forward current emission coefficient	None	1.0
Br	ideal reverse current gain	None	1.0
Nr	reverse emission coefficient	None	1.0
Isf	ideal B-E junction saturation current; defaults to Is/Bf	A	defaults to Is/Bf
Nbf	ideal B-E junction emission coefficient; defaults to Nf	None	defaults to Nf
Isr	ideal B-C junction saturation current; defaults to Isn/Br	A	defaults to Isn/Br
Nbr	ideal B-C junction emission coefficient; defaults to Nr	None	defaults to Nr
Ise	B-E recombination saturation current	A	0.0
Ne	B-E recombination emission coefficient	None	2.0
Isc [†, ††]	B-C recombination saturation current	A	0.0
Nc	B-C recombination emission coefficient	None	1.5
Vaf	forward early voltage	V	fixed at infinity†††
Var	reverse early voltage	V	fixed at infinity†††
Enp	base push out exponent	None	2.0
Rp	BPO fitting parameter	None	1.0e-3
Rw	ratio of collector width to the base	None	0
Vij	modified B-C potential	V	0.8
Vrp	voltage drop across vertical Rc	V	1.0e-9
Bvc	junction breakdown of C-B junction	V	fixed at infinity†††
Mf	exponent of B-C multiplication factor	None	0.0
Fa	Bvcbo/Bvc	None	0.95

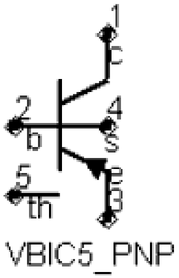
Avc	fitting parameter	None	1.0
Bve	junction breakdown of the E-B junction	V	fixed at infinity†††
Mr	exponent of the E-B multiplication factor	None	0.0
Fb	Bvebo/Bve	Hz	0.95
Ave	fitting parameter	None	1.0
Rb	zero-bias base resistance	Ohm	0.0
Irb	current when base resistance falls halfway to its minimum value	A	fixed at infinity†††
Rbm	minimum base resistance at high current (0 means Rb)	Ohm	0.0
Re	emitter resistance	Ohm	0.0
Rc	collector resistance under the emitter	Ohm	0.0
Rcs	collector resistance in saturation	Ohm	0.0
Cje	B-E zero-bias depletion capacitance	F	0.0
Vje	B-E junction built-in potential	V	0.75
Mje	B-E grading coefficient	None	0.33
Fc	Forward-bias Depletion Cap. Coefficient	None	0.5
Cjc	B-C zero-bias depletion gap	F	0.0
Vjc	B-C junction built-in potential	V	0.75
Mjc	junction grading coefficient	None	0.33
Xjbc	fraction of Cjc connected to B int node	None	1.0
Cjs	zero-bias collector substrate (ground) cap	F	0.0
Vjs	C-S (B-S) built-in potential	V	0.75
Mjs	C-S (B-S) grading coefficient	None	0.33
Xjbs	fraction of B-S cap connected to B int node	None	1.0
Vert	1=vertical structures; 0=else	None	0
Subsn	1=N substrate; 0=else	None	0
Tf	ideal forward transit time	sec	0.0
Xtf	coefficient of bias dependence for TF	None	0.0
Vtf	voltage dependence of Tf on B-C voltage	V	fixed at infinity†††
Itf	parameter for Tf high currents roll off	A	fixed at infinity†††
Ptf	excess phase	deg	0.0
Tfcc	Tf BPO model: 1=Spice, 0=else	None	0
Tr	ideal reverse transit time	sec	0.0
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Eg	bandgap voltage at 0K	V	1.11
Xti	temperature exponent	None	3.0
Xtb	temperature exponent for gain currents	None	0.0
Trb1	linear temperature coefficient for Rb	1/°C	0.0
Trb2	quadratic temperature coefficient for Rb	$1/(°C)^2$	0.0
Trbm1	linear temperature coefficient for Rbm	1/°C	0.0
Trbm2	quadratic temperature coefficient for Rbm	$1/(°C)^2$	0.0
Tre1	linear temperature coefficient for Re	1/°C	0.0

Tre2	quadratic temperature coefficient for Re	$1/(°\mathrm{C})^2$	0.0
Trc1	linear temperature coefficient for Rc	1/°C	0.0
Trc2	quadratic temperature coefficient for Rc	$1/(°\mathrm{C})^2$	0.0
Trcs1	linear temperature coefficient for Rcs	1/°C	0.0
Trcs2	quadratic temperature coefficient for Rcs	$1/(°\mathrm{C})^2$	0.0
Ikf†††	forward Ik	A	fixed at infinity†††
Ikr†††	reverse Ik	A	fixed at infinity†††
Gmin	minimum conductance	None	1e-12
All Params	Data Access Component (DAC) Based Parameters	None	None
† This parameter value varies with temperature based on model Tnom and device Temp.†† This parameter value scales with Area specified with the BJT or BJT4 model.††† A value of 0.0 is interpreted as infinity.			

VBIC5_NPN, VBIC5_PNP (VBIC Nonlinear Bipolar Transistors with Thermal Terminal, NPN, PNP)

Symbol





Parameters

Name	Description	Units	Default
Model	name of a VBIC_Model	None	VCICM1
Scale	scaling factor	None	1.0
Region	dc operating region: 0=off, 1=on, 2=rev, 3=sat	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated VBIC_Model) certain model parameters are scaled such that the device is simulated at its operating temperature.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The VBIC implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth, Cth, and Selft control this: ΔT = Pdiss x Rth. (Refer to VBIC_Model *note 5* (ccnld).) When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using

self-heating may take 50 to 100% more time than the same simulation without self-heating.

Self-heating can be used with either an internal or external thermal node.

- VBIC_NPN and VBIC_PNP use an internal node to keep track of the temperature rise of the transistor.
- VBIC5_NPN and VBIC5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.

4. The following table lists the DC operating point parameters that can be sent to the dataset.

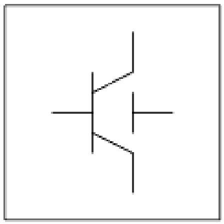
DC Operating Point Information

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gbe	Transconductance gbe	siemens
Cbe	Base-emitter capacitance cbe	farads
Gbc	Transconductance gbc	siemens
Cbc	Base-collector capacitance cbc	farads
Gbex	Transconductance gbex	siemens
Cbex	Base-emitter capacitance cbex	farads
Gbep	Transconductance gbep	siemens
Cbep	Base-emitter capacitance cbep	farads
Gbcp	Transconductance gbcp	siemens
Cbcp	Base-collector capacitance cbcp	farads
dIcc_dVbei	(dIcc/dVbei)	siemens
dIcc_dVbci	(dIcc/dVbci)	siemens
dIccp_dVbep	(dIccp/dVbep)	siemens
dIccp_dVbcp	(dIccp/dVbcp)	siemens
dIccp_dVbci	(dIccp/dVbci)	siemens
dIbc_dVbei	(dIbc/dVbei)	siemens
Grbi	Base conductance grbi	siemens
dIrbi_dVbei	(dIrbi/dVbei)	siemens
dIrbi_dVbci	(dIrbi/dVbci)	siemens
Grbp	Base conductance grbp	siemens
dIrbp_dVbep	(dIrbp/dVbep)	siemens
dIrbp_dVbci	(dIrbp/dVbci)	siemens
Grci	Collector conductance grci	siemens
dIrci_dVbci	(dIrci/dVbci)	siemens
dQbe_dVbci	(dQbe/dVbci)	farads
dQbep_dVbci	(dQbep/dVbci)	farads
dQbcx_dVbci	(dQbcx/dVbci)	farads
dQbcx_dVrci	(dQbcx/dVrci)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

5. This device has no default artwork associated with it.

VBIC_Model (VBIC Model)

Symbol



Parameters

Name	Definition	Units	Default
NPN	N-channel model type: yes, no	None	yes
PNP	P-channel model type: yes, no	None	no
Tnom	nominal ambient temperature	°C	25
Trise	temperature rise above ambient	°C	0
Rcx †, ††	extrinsic collector resistance	Ohm	0.0
Rci †, ††	intrinsic collector resistance	Ohm	0.0
Vo †	epi drift saturation voltage	V	0.0
Gamm †	epi doping parameter	None	0.0
Hrcf	high-current RC factor	None	1.0
Rbx †, ††	extrinsic base resistance	Ohm	0.0
Rbi †, ††	intrinsic base resistance	Ohm	0.0
Re †, ††	emitter resistance	Ohm	0.0
Rs †, ††	substrate resistance	Ohm	0.0
Rbp †, ††	parasitic base resistance	Ohm	0.0
Is †, †††	transport saturation current	A	1.0e-16
Nf †	forward emission coefficient	None	1.0
Nr †	reverse emission coefficient	None	1.0
Fc	forward bias junction capacitance threshold	None	0.9
Cbeo †††	base-emitter small signal capacitance	F	0.0
Cje †, †††	base-emitter zero-bias junction capacitance	F	0.0
Pe †	base-emitter grading coefficient	None	0.75
Me	base-emitter junction exponent	None	0.33
Aje	base-emitter capacitance smoothing factor	None	-0.5

Cbco †††	base-collector small signal capacitance	F	0.0
Cjc †, †††	base-collector zero-bias junction capacitance	F	0.0
Qco †††	collector charge at zero bias	C	0.0
Cjep †, †††	base-emitter zero-bias extrinsic capacitance	F	0.0
Pc †	base-collector grading coefficient	None	0.75
Mc	base-collector junction exponent	None	0.33
Ajc	base-collector capacitance smoothing factor	None	-0.5
Cjcp †, †††	base-collector zero-bias extrinsic capacitance	F	0.0
Ps †	collector-substrate grading coefficient	None	0.75
Ms	collector-substrate junction exponent	None	0.33
Ajs	collector-substrate capacitance smoothing factor	None	-0.5
Ibei †, †††	ideal base-emitter saturation current		1.0e-18
Wbe	portion of Ibei from Vbei, 1-Wbe from Vbex	None	1.0
Nei	ideal base-emitter emission coefficient	None	1.0
Iben †, †††	non-ideal base-emitter saturation current		0.0
Nen	non-ideal base-emitter emission coefficient	None	2.0
Ibci †, †††	ideal base-collector saturation current		1.0e-16
Nci	ideal base-collector emission coefficient	None	1.0
Ibcn †, †††	non-ideal base-collector saturation current		0.0
Ncn	non-ideal base-collector emission coefficient	None	2.0
Isp †, †††	parasitic transport saturation current		0.0
Wsp	portion of Iccp from Vbep, 1-Wsp from Vbci	None	1.0
Nfp	parasitic forward emission coefficient	None	1.0
Ibeip †, †††	ideal parasitic base-emitter saturation current		0.0
Ibenp †, †††	non-ideal parasitic base-emitter saturation current		0.0
Ibcip †, †††	ideal parasitic base-collector saturation current		0.0
Ncip	ideal parasitic base-collector emission coefficient	None	1.0
Ibcnp †, †††	non-ideal parasitic base-collector saturation current		0.0
Avc1	base-collector weak avalanche parameter 1	None	0.0
Avc2 †	base-collector weak avalanche parameter 2	None	0.0
Ncnp	non-ideal parasitic base-collector emission coefficient	None	2.0
Vef	forward Early voltage (0=infinity)	V	infinity
Ver	reverse Early voltage (0=infinity)	V	infinity
Ikf †††	forward knee current (0=infinity)	A	infinity
Ikr †††	reverse knee current	A	0.0
Ikp †††	parasitic knee current	A	0.0
Tf	forward transit time		0.0
Qtf	variation of Tf with base-width modulation	None	0.0
Xtf	coefficient of Tf bias dependence	None	0.0
Vtf	coefficient of Tf dependence on Vbc	None	0.0
Itf	coefficient of Tf dependence on Icc	None	0.0

Tr	ideal reverse transit time		0.0
Td	forward excess-phase delay time		0.0
Kfn	flicker noise coefficient	None	0.0
Afn	flicker noise exponent	None	1.0
Bfn	flicker noise frequency exponent	None	1.0
Xre	temperature exponent of emitter resistance	None	0.0
Xrb	temperature exponent of base resistance	None	0.0
Xrc	temperature exponent of collector resistance	None	0.0
Xrs	temperature exponent of substrate resistance	None	0.0
Xvo	temperature exponent of Vo	None	0.0
Ea	activation energy for Is	eV	1.12
Eaie	activation energy for Ibei	eV	1.12
Eaic	activation energy for Ibci/Ibeip	eV	1.12
Eais	activation energy for Ibcip	eV	1.12
Eane	activation energy for Iben	eV	1.12
Eanc	activation energy for Ibcn/Ibenp	eV	1.12
Eans	activation energy for Ibcnp	eV	1.12
Xis	temperature exponent of Is	None	3.0
Xii	temperature exponent of Ibei/Ibci/Ibeip/Ibcip	None	3.0
Xin	temperature exponent of Iben/Ibcn/Ibenp/Ibcnp	None	3.0
Tnf	temperature coefficient of Nf	None	0.0
Tavc	temperature coefficient of Avc	None	0.0
Rth ††	thermal resistance	Ohm	0.0
Cth †††	thermal capacitance	F	0.0
Imax	explosion current	A	1.0
Imelt	explosion current, similar to Imax; defaults to Imax (refer to note 4).	A	defaults to Imax
Selft	flag denoting self-heating: yes, no; (refer to note 5).	None	None
Dtmax	maximum expected device temperature	°C	500
wVsubfwd (Vsubfwd)	substrate junction forward bias (warning)	V	None
wBvsub (Bvsub)	substrate junction reverse breakdown voltage (warning)	V	None
wBvbe (Bvbe)	base-emitter reverse breakdown voltage (warning)	V	None
wBvbc (Bvbc)	base-collector reverse breakdown voltage (warning)	V	None
wVbcfwd (Vbcfwd)	base-collector forward bias (warning)	V	None
wIbmax	maximum base current (warning)	A	None
wIcmax	maximum collector current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	name of DataAccessComponent for file-based model parameter values	None	None

† This parameter value varies with temperature based on model Tnom and device Temp.†† This parameter value scales inversely with the device parameter Scale.††† This parameter value scales directly with the device parameter Scale

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname VBIC [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by transistor components to refer to the model. The third parameter indicates the type of model; for this model it is *VBIC* . Use either parameter NPN=yes or PNP=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model  Npn2 VBIC \
 NPN=yes Gamm=8e-10  Cje=1e-13
```

Notes/Equations

1. This model (version 1.1.4) supplies values for a VBIC device.
2. The VBIC vertical BJT model was developed specifically as a replacement for the SPICE Gummel-Poon model by representatives of the IC and CAD industries.

   VBIC includes improved modeling of the Early effect (output conductance), substrate current, quasi-saturation, and behavior over temperature-information necessary for accurate modeling of current state-of-the-art devices. However, it has additionally been defined so that, with default parameters, the model will simplify to be as similar as possible to the Gummel-Poon model.

   Advantages of VBIC over the Gummel-Poon model include:

   - An Early effect model based on the junction depletion charges
   - A modified Kull model for quasi-saturation valid into the Kirk regime (the high-injection effect at the collector)
   - Inclusion of the parasitic substrate transistor
   - An improved single-piece junction capacitance model for all 3 junction capacitances
   - Improved static temperature scaling
   - First-order modeling of distributed base and emitter AC and DC crowding
   - Overall improved high-level diffusion capacitance modeling (including quasi-saturation charge)
   - Inclusion of parasitic overlap capacitances; inclusion of the onset of weak

avalanche current for the base-collector junction.
  - High-order continuity (infinite) in equations. A noise model similar to that of the Gummel-Poon model, with shot, thermal, and 1/f components
3. More information about this model is available at: http://www.designers-guide.com/VBIC/references.html
4. Imax and Imelt Parameters

   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.

   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.

   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
5. If the Selft parameter is not set, the value of Rth will determine whether self-heating is taken into account or not, as in previous versions (Rth>0 implies self-heating is on). If Selft is set, then it will take priority in determining whether self-heating is on or off.

   Note
   When inserting a new component, the Selft default value is blank.
6. Rth and Cth Parameters

   The Rth parameter's units is shown as Ohms. Strictly speaking it should be power/temp, such as W/degK. The units of Ohms is acceptable given the following explanation.

   In terms of an electrical analogue of the thermal equations it is acceptable to use the electrical units for the thermal circuit.

   The thermal circuit (electrical model) consists of a current source, a resistance and a capacitance (all in parallel), and using electrical units is a convenience. The relation to the actual units comes from the way that electrical model is constructed.

   The reality is that the value of the *current* source is the power dissipated in the device and the node *voltage* represents the temperature (rise). The *current* in Rth thus represents power and therefore the true unit of Rth (in thermal equations) is degK/W (or degC/W). Similarly, the true unit of the Cth *capacitance* is J/degC (or J/degK), and not F.
7. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim)). Note that model parameters that are explicitly specified take precedence over those via AllParams.

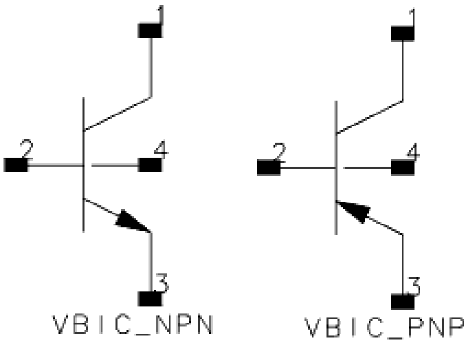
References

1. C. McAndrew, AT&T/Motorola; J. Seitchik, Texas Instruments; D. Bowers, Analog Devices; M. Dunn, Hewlett-Packard; M. Foisy, Motorola; I. Getreu, Analogy; M. McSwain, MetaSoftware; S. Moinian, AT&T Bell Laboratories; J. Parker, National Semiconductor; P. van Wijnen, Intel/Philips; L. Wagner, IBM, *VBIC95: An Improved Vertical, IC Bipolar Transistor Model*.

2. W. J. Kloosterman and H. C. de Graaff. "Avalanche Multiplication in a Compact Bipolar Transistor Model for Circuit Simulation," *IEEE 1988 BCTM*.
3. McAndrew and Nagel. "Spice Early Model," *IEEE 1994 BCTM*.
4. J. Berkner, SMI System Microelectronic Innovation GmbH, Frankfurt/Oder, Germany. *A Survey of DC Methods for Determining the Series Resistance of Bipolar Transistors Including the New Delta ISub Method*.

VBIC_NPN, VBIC_PNP (VBIC Nonlinear Bipolar Transistors, NPN, PNP)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a VBIC_Model	None	VBICM1
Scale	scaling factor	None	1.0
Region	dc operating region: 0=off, 1=on, 2=rev, 3=sat	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated VBIC_Model) certain model parameters are scaled such that the device is simulated at its operating temperature.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The VBIC implements self-heating. As the transistor dissipates power, it causes its temperature to rise above ambient. The model parameters Rth, Cth, and Selft control this: ΔT = Pdiss x Rth. (Refer to VBIC_Model *note 5* (ccnld).) When self-heating is enabled, it may be necessary to increase the maximum number of iterations due to the additional unknown (temperature rise) that must be solved for. Simulation using

self-heating may take 50 to 100% more time than the same simulation without self-heating.

Self-heating can be used with either an internal or external thermal node.

- VBIC_NPN and VBIC_PNP use an internal node to keep track of the temperature rise of the transistor.
- VBIC5_NPN and VBIC5_PNP make this thermal node externally available as the fifth terminal. This node can then be used for additional thermal modeling.

4. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Ic	Collector current	amperes
Ib	Base current	amperes
Ie	Emitter current	amperes
Is	Substrate current	amperes
Power	DC power dissipated	watts
Gbe	Transconductance gbe	siemens
Cbe	Base-emitter capacitance cbe	farads
Gbc	Transconductance gbc	siemens
Cbc	Base-collector capacitance cbc	farads
Gbex	Transconductance gbex	siemens
Cbex	Base-emitter capacitance cbex	farads
Gbep	Transconductance gbep	siemens
Cbep	Base-emitter capacitance cbep	farads
Gbcp	Transconductance gbcp	siemens
Cbcp	Base-collector capacitance cbcp	farads
dIcc_dVbei	(dIcc/dVbei)	siemens
dIcc_dVbci	(dIcc/dVbci)	siemens
dIccp_dVbep	(dIccp/dVbep)	siemens
dIccp_dVbcp	(dIccp/dVbcp)	siemens
dIccp_dVbci	(dIccp/dVbci)	siemens
dIbc_dVbei	(dIbc/dVbei)	siemens
Grbi	Base conductance grbi	siemens
dIrbi_dVbei	(dIrbi/dVbei)	siemens
dIrbi_dVbci	(dIrbi/dVbci)	siemens
Grbp	Base conductance grbp	siemens
dIrbp_dVbep	(dIrbp/dVbep)	siemens
dIrbp_dVbci	(dIrbp/dVbci)	siemens
Grci	Collector conductance grci	siemens
dIrci_dVbci	(dIrci/dVbci)	siemens
dQbe_dVbci	(dQbe/dVbci)	farads
dQbep_dVbci	(dQbep/dVbci)	farads
dQbcx_dVbci	(dQbcx/dVbci)	farads
dQbcx_dVrci	(dQbcx/dVrci)	farads
Vbe	Base-emitter voltage	volts
Vbc	Base-collector voltage	volts
Vce	Collector-emitter voltage	volts

5. This device has no default artwork associated with it.

Devices and Models, Diode

- *ADSDiode (ADS Root Diode)* (ccnld)
- *ADS Diode Model (ADS Root Diode Model)* (ccnld)
- *dio500 (Diode Level 500)* (ccnld)
- *Diode (PN-Junction Diode)* (ccnld)
- *Diode Model (PN-Junction Diode Model)* (ccnld)
- *JUNCAP (Philips JUNCAP Device)* (ccnld)
- *Juncap Model (Philips JUNCAP Model)* (ccnld)
- *PIN diode (PIN Diode)* (ccnld)

Bin Model

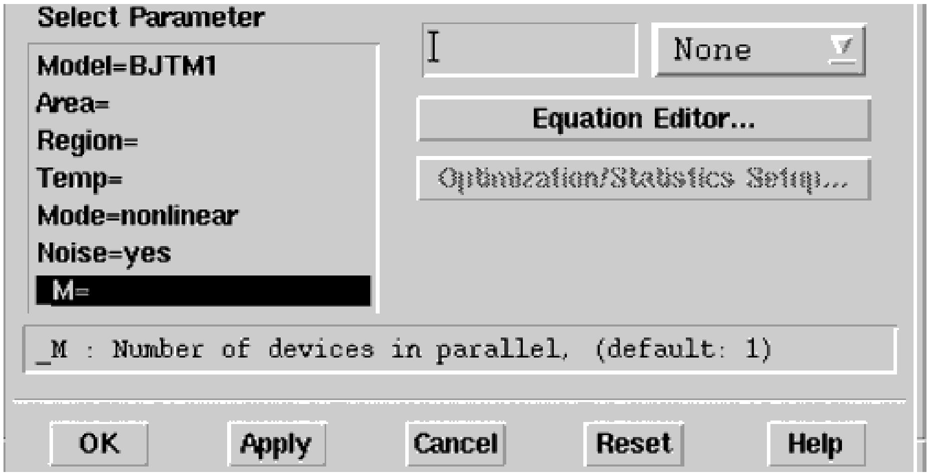
The BinModel in the Diodes library enables you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically does not work for all sizes of a device.

For information on the use of the binning feature, refer to *BinModel (Bin Model for Automatic Model Selection)* (ccsim).

Multiplicity Parameter _M

The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M* , the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

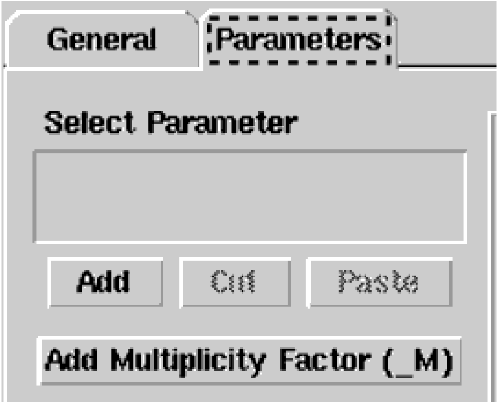
The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



Model=BJTM1
Area=
Region=
Temp=
Mode=nonlinear
Noise=yes
M=

_M : Number of devices in parallel, (default: 1)

For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, click **Add Multiplicity Factor_M**.



Netlist Syntax

Models for the ADS circuit simulator have the following syntax:

```
model modelname modeltype [param=value]*
```

where `model` is a keyword, `modelname` is the user-defined name for the model and `modeltype` is one of the predefined model types (e.g., Diode, BJT, MOSFET). After these three required fields comes zero or more `param=value` pairs. `param` is a model keyword and value is its user-assigned value. There is no required order for the `param=value` pairs. Model keywords that are not specified take on their default values. Refer to documentation for each model type to see the list of model parameters, their meanings and default values.

The model statement must be on a single line. Use the backslash "\" as a line continuation character. Instance and model parameter names are case sensitive; most (not all) model parameters have their first character capitalized and the rest are lower case. Scale factors (e.g., p=10^{-12}, n=10^{-9}, u=10^{-6}, m=10^{-3}, k=10^{+3}, M=10^{+6}) can be used with numbers for numeric values. For more information about the circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

A netlist translator is available for translating models and subcircuits from Pspice, Hspice, and Spectre syntax to the form used by the ADS Circuit Simulator. Refer to *Netlist Translator for SPICE and Spectre* (netlist) for more information.

Parameter Aliases

For compatibility with other simulators, some models accept two or more different keywords for the same parameter. For example, the Diode model accepts both model keywords Is and Js for the saturation current. In the documentation, the parameter Name column lists the aliases in parentheses after the main parameter name. The main parameter name is the one that appears in the ADS dialog box for the model.

Tnom

All nonlinear device models have a parameter that specifies the temperature at which the model parameters were extracted. Normally called Tnom, some models may use Tref, Tr, or Tmeas. The default value for Tnom is specified on the Options item in the Tnom field. If Options.Tnom is not specified it defaults to 25 °C. This is true for all nonlinear devices.

It is strongly suggested that the user explicitly set Tnom in each model and not depend on its default value. First, this provides a self-documenting model; other users of the device will not have to guess at what Tnom should be. Second, different users of the same model would get different results for the same circuit if they simulate with different values of Options.Tnom.

Temp and Trise

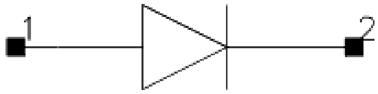
Advanced Design System enables you to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp, which defaults to 25 °C.

For compatibility with other simulators, many of the nonlinear devices enable you to specify Trise for each device instance, which specifies actual device temperature as an increase from ambient. It defaults to zero. The Trise instance value is used only if the Temp instance value is not specified. If you do not specify Trise on the instance, a default value for Trise can also be specified in the model. It defaults to zero. The following shows the logic of how the instance temperature is calculated if it is not explicitly specified.

```
if Instance.Temp is not specified
if instance.Trise is not specified
Instance.Temp = Options.Temp + Model.Trise
else
Instance.Temp = Options.Temp + Instance.Trise
```

ADSDiode (ADS_Root Diode)

Symbol



Parameters

Name	Description	Units	Default
Model	model instance name	None	ADSDIODEM1
Area	junction		1.0
_M	number of devices in parallel	None	1

Range of Usage

Area > 0

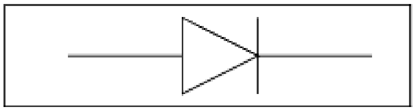
Notes/Equations

1. *DC Operating Point Information* lists the DC operating point parameters that can be sent to the dataset.

Name	Description	Units
Id	Diode current	amperes
Power	DC power dissipated	watts
Rd	Series resistance	ohms
Cd	Junction capacitance	farads
Vd	Anode-cathode voltage	volts

ADS_Diode_Model (ADS_Root Diode Model)

Symbol



Parameters

Name	Description	Units	Default
File	name of rawfile	None	None
Rs	series resistance		fixed at 0
Ls	parasitic inductance		fixed at 0
Tt	transit time	sec	0.0
All Params	Data Access Component (DAC) Based Parameters	None	None

Notes/Equations

1. This model supplies values for an ADSDiode device.
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those via AllParams.
3. Because this model is measurement-based, extrapolation warning messages may occur if the Newton iteration exceeds the measurement range. If these messages occur frequently, check that the measurement data is within the simulation range.

References

1. D. Root, "Technology independent large signal non quasi static FET model by direct construction from automatically characterized device data," in *21st EuMC* , 1991, p. 927.
2. D. E. Root, S. Fan, and J. Meyer, "Technology-independent large-signal FET models: A measurement-based approach to active device modeling," in *Proc. th ARMMS Conf., Bath, U.K.* , Sept. 1991, pp. 1-21.
3. D. E. Root, M. Pirola, S. Fan, W. J. Anklam, and A. Cognata, "Measurement-based large-signal diode modeling system for circuit and device design," *IEEE Trans. Microwave Theory Tech.* , vol. 41, pp. 2211-2217, Dec. 1993.
4. D. E. Root and B. Hughes, "Principles of nonlinear active device modeling for circuit simulation," in *32nd ARFTG Conf. Dig* ., Tempe, AZ, 1988, pp. 3-26.
5. D. E. Root, S. Fan, and J. Meyer, "Technology-independent large-signal non quasi static FET models by direct extraction from automatically characterized device data," in *21st European Microwave Conf. Proc.* , Stuttgart, Germany, 1991, pp. 927-932.

6. D. E. Root and S. Fan, "Experimental evaluation of large-signal modeling assumptions based on vector analysis of bias-dependent S-parameters data from MESFET's and HEMT's," in *IEEE MTT-S Int. Microwave Symp. Tech. Dig.* , 1992, pp. 927-932.

dio500 (Diode Level 500)

Instance Parameters

Name	Description	Default
area	Multiplication factor	1.0
mult	Alias of area factor	
m	Multiplicity factor	1.0
Mode	Simulation mode: nonlinear or linear	Nonlinear
Noise	Noise generation option: yes, no	yes

Model Parameters

Name	Description	Units	Default
is	Saturation current	A	7.13e-13
n	Junction emission coefficient		1.044
vlc	Voltage dependence at low forward currents	V	0.0
vbr	Breakdown voltage	V	7.459
emvbr	Electric field at breakdown	V/cm	1.36e+06
csrh	Shockley-Read-Hall generation	A/cm	7.44e-07
cbbt	Band to band tunneling	A/V	3.255
ctat	Trap assisted tunneling	A/cm	3.31e-06
rs	Series resistance	Ohm	0.0
tau	Transit time	s	500.0e-12
cj	Zero-bias depletion capacitance	F	7.0e-12
vd	Diffusion voltage	V	0.9
p	Grading coefficient		0.4
tref	Reference temperature. Default set by option *tnom*.	C	
tnom	Alias of *tref*	C	
tr	Alias of *tref*	C	
vg	Bandgap voltage	V	1.206
ptrs	Power for temperature dependence of *rs*		0.0
kf	Flickernoise coefficient		0.0
af	Flickernoise exponent		1.0
dta	Difference between device temperature and ambient temperature	K	0.0
trise	Alias of *dta*	K	
imax	Explosion current	A	1.0

Notes/Equations

1. The *dio500* model provides a detailed description of the diode currents in forward and reverse biased Si-diodes. Please see the following NXP pdf file for detailed

documention:
http://www.nxp.com/acrobat_download/other/models/d500.pdf

2. In extension to the modelbook description a minimum conductance *gmin* is inserted between the diode nodes to aid convergence. The value of *gmin* is set by an options statement, default is gmin = 1.0e-12 S . The *imax* parameter is used to aid convergence and to prevent numerical overflow. The junction characteristics of the diode are accurately modeled for currents up to *imax*. For currents above *imax*, the junction is modeled as a linear resistor.
3. Sample Instance Statement:

   modelName: D1 1 2 area = 2

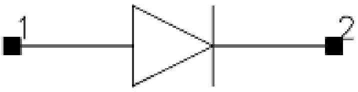
   Sample Model Statement:

   model phdiode dio500 is = model modelName dio500 is =3.5e-12 rs=26.3 n=2.7 imax=1e20 vlc=1.8 vbr=9.63 cj=2.65e-11 dta=12.88 tau=7.5e-10 tnom=25
4. This device is supported within altergroups.
5. The following table lists the DC operating point parameters that can be sent to the dataset.

Name	Description	Units
vak	Diode voltage, measured from anode to cathode (including rs)	V
id	Total resistive diode current	A
qd	Diffusion charge	Coul
qt	Depletion charge	Coul
rst	Series resistance (temperature updated)	Ohm
rl	AC linearized resistance	Ohm
cl	AC linearized capacitance	F
pwr	Power dissipation	W

Diode (PN-Junction Diode)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	DIODEM1
Area	Scaling Factor	None	1.0
Periph (Perim)	Scaling Factor that affects the sidewall	None	0
Width (W) †	Geometric width of diode junction	meter	0
Length (L) †	Geometric length of diode junction	meter	0
Scale	Scaling Factor that scales Area, Periph, Width and Length	None	1.0
Region	DC operating region, 0=off, 1=on (gives the DC simulator a good initial guess to enhance its convergence properties)	None	on
Temp	Device operating temperature	°C	25
Trise	Temperature rise over ambient	°C	0
Mode	Simulation mode: Nonlinear, Linear, Standard (refer to Note 3)	None	Nonlinear
Noise	Noise generation option; yes=1, no=0	None	yes
_M	Number of devices in parallel	None	1
† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.			

Range of Usage

Area > 0
Periph ≥ 0
Scale > 0

Notes/Equations

1. The size of the diode may be specified geometrically using the Width and Length parameters if the Area and Periph parameters are not explicitly specified. Default values for the width and length are taken from the width and length specified in the

model if they are not specified in the instance. The model parameters Shrink and Dwl are also used. Exact area and periphery calculations are described in the model Notes section.

The area must be greater than 0. The periphery can be 0, in which case the sidewall components are not simulated.

2. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated Diode_Model), certain model parameters are scaled such that the device is simulated at its operating temperature (refer to *Diode_Model (PN-Junction Diode Model)* (ccnld) to see which parameter values are scaled).
3. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
4. The table below lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Parameters

Name	**Description**	**Units**
Id	Diode current	amperes
Power	DC power dissipated	watts
Rd	Junction series resistance	ohms
Rdsw	Sidewall series resistance	ohms
Cd	Junction capacitance	farads
Cdsw	Sidewall capacitance	farads
Vd	Anode-cathode voltage	volts

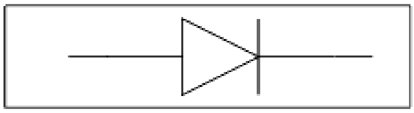
5. This device has no default artwork associated with it.

References

1. *SPICE2: A Computer Program to Simulate Semiconductor Circuits*, University of California, Berkeley.
2. P. Antognetti and G. Massobrio. S *emiconductor Device Modeling with SPICE*, Second Edition, McGraw-Hill, Inc., 1993.

Diode_Model (PN-Junction Diode Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
Level	Model level selector (1=standard, 3=Hspice geometry 11=Spectre)	None	1
Is (Js) †, ††	Saturation Current, A (with N, determines diode DC characteristics)	A	1.0e-14
Rs †††	Ohmic Resistance	Ohm	fixed at 0
Gleak †	Bottom junction leakage conductance	S	0
N	Emission Coefficient (with Is, determines diode DC characteristics)	None	1.0
Tt	Transit Time	sec	0.0
Cd †	Linear capacitance	F	0.0
Cjo †, ††	Zero-bias Junction capacitance	F	0.0
Vj (Pb) ††	Junction Potential	V	1.0
M	Grading Coefficient	None	fixed at 0.5
Fc	Forward-bias Depletion Capacitance Coefficient	None	0.5
Imax	Explosion current beyond which diode junction current is linearized	A	1.0
Imelt	Explosion current (similar to Imax; refer to Note 4); defaults to Imax	A	defaults to Imax
Isr †, ††	Recombination current	A	0.0
Nr	Emission coefficient for Isr	None	2.0
Ikf (Ik) †	High-injection knee current	A	infinity ‡
Ikr †	Reverse high injection knee current	A	0
IkModel	Model to use for Ikf/Ikr: 1=ADS/Libra/Pspice, 2=Hspice/Spectre	None	1
Bv	Reverse breakdown voltage	V	infinity ‡
Ibv †	Current at reverse breakdown voltage	A	0.001
Nbv (Nz)	Reverse breakdown ideality factor	None	1.0
Ibvl †	Low-level reverse breakdown knee current	A	0.0

Nbvl	Low-level reverse breakdown ideality factor	None	1.0
Kf	Flicker noise coefficient	None	0.0
Af	Flicker noise exponent	None	1.0
Ffe	Flicker noise frequency exponent	None	1.0
Jsw (Isw) †† ‡‡	Sidewall saturation current	None	0.0
Rsw ‡‡‡	Sidewall series resistance	Ohm	0.0
Gleaksw ‡‡	Sidewall junction leakage conductance	S	0.0
Ns	Sidewall emission coefficient	None	if (Level=11) Ns=1, else Ns=N
Ikp ‡‡	high-injection knee current for sidewall; defaults to Ikf	A	Ikf
Cjsw †† ‡‡	Sidewall zero-bias capacitance	None	0.0
Msw (Mjsw)	Sidewall grating coefficient	None	0.33
Vjsw (Pbsw) ††	Sidewall junction potential; defaults to Vj	None	1: when level=11; defaults to Vj
Fcsw	Sidewall forward-bias depletion capacitance coefficient	None	0.5; Fc: when level=11
Area	Default area for diode	None	1
Periph (Perim)	Default periphery for diode	None	0
Width	Default width for diode	meter	0
Length	Default length for diode	meter	0
Etch	Sidewall narrowing due to etching per side	meter	0
Etchl	Sidewall length reduction due to etching per side; defaults to Etch	meter	defaults to Etch
Dwl	Geometry width and length addition	meter	0
Shrink	Geometry shrink factor	None	1.0
AllowScaling	Allow scale option and instance scale parameter to affect geometry parameters: yes or no	None	no
Tnom	Nominal ambient temperature	°C	25
Trise	Temperature rise over ambient	°C	0
Tlev	Temperature equation selector (0/1/2)	None	0
Tlevc	Temperature equation selector for capacitance (0/1/2/3)	None	0
Xti	Saturation-current temperature exponent (with Eg, helps define the dependence of Is on temperature)	None	3.0
Eg	Energy gap (with Xti, helps define the dependence of Is on temperature)	eV	1.11
EgAlpha (Gap1)	Energy gap temperature coefficient alpha	eV/°C	7.02e-4
EgBeta (Gap2)	Energy gap temperature coefficient beta	K	1108
Tcjo (Cta)	Cjo linear temperature coefficient	1/°C	0
Tcjsw (Ctp)	Cjsw linear temperature coefficient	1/°C	0
Ttt1	Tt linear temperature coefficient	1/°C	0
Ttt2	Tt quadratic temperature coefficient	1/(°C)^2	0
Tm1	Mj linear temperature coefficient	1/°C	0
Tm2	Mj quadratic temperature coefficient	1/(°C)^2	0
Tvj (Pta)	Vj linear temperature coefficient	°	0

		1/ C	
Tvjsw (Ptp)	Vjsw linear temperature coefficient	1/°C	0
Trs	Rs linear temperature coefficient	1/°C	0
Trs2	Rs quadratic temperature coefficient	1/(°C)^2	0
Tgs	Gleak, Gleaksw linear temperature coefficient	1/°C	0
Tgs2	Gleak, Gleaksw quadratic temperature coefficient	1/(°C)^2	0
Tbv (Tbv1)	Bv linear temperature coefficient	1/°C	0
Tbv2	Bv quadratic temperature coefficient	1/(°C)^2	0
wBv (Bvj)	Diode reverse breakdown voltage (warning)	V	infinity ‡
wPmax	Maximum power dissipation (warning)	W	infinity ‡
AllParams	Data Access Component (DAC) Based Parameters	None	None

† Parameter value is scaled with Area specified with the Diode device. †† Value varies with temperature based on model Tnom and device Temp. ††† Parameter value is scaled with 1/Area. ‡ Value 0.0 is interpreted as infinity. ‡‡ Parameter value is scaled with the Periph specified with the Diode device. ‡‡‡ Parameter value is scaled with 1/Periph.

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname Diode [parm=value]*
```

The model statement starts with the required keyword *diode*. It is followed by the *modelname* that will be used by diode components to refer to the model. The third parameter indicates the type of model; for this model it is *Diode*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model SimpleDiode Diode \
Is=1e-9 Rs=4 Cjo=1.5e-12
```

Notes/Equations

1. This model supplies values for a Diode device.
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent (Data Access Component)* (ccsim) in *Introduction to Circuit Components* (ccsim). Note that model parameters that are explicitly specified take

precedence over those specified via AllParams.

3. **Area and Periph**

   When Level is set to 1 (standard):
   Device Area will be used if specified and > 0; otherwise the model Area will be used.

   Device Periph will be used if specified; otherwise the model Periph will be used.
   When Level is set to 3 (Hspice geometry):

   Device Width and Length will be used if specified; otherwise the model Width and Length will be used.

   If Width > 0 and Length > 0

   Area = w × l
   Periph = 2 × (w + l)
   where w = Width × Shrink + Dwl
   l = Length × Shrink + Dwl
   otherwise the Area and Periph specified in the device or model
   (follow the same logic described when Level=1)
   will be used to calculate the new area and periph.

   Area = area (from device/model) × Shrink^2
   Periph = periph (from device/model) × Shrink

   When Level is set to 11 (Spectre):

   Device Area will be used if it is specified and > 0;

   Otherwise

   if Length and Width in device or model (in this order) are specified and > 0,

   Area = Weff × Leff
   where
   Weff = Width - Etch
   Leff = Length - Etchl

   otherwise use model Area if it is specified and > 0

   otherwise, Area = 1 (default)

   Device Periph will be used if it is specified and > 0

   Otherwise,

   if Length and Width in device or model (in this order) are specified and > 0,

   Periph = 2 × (Weff + Leff)
   where
   Weff = device Width - Etch
   Leff = device Length - Etchl

   otherwise use model Periph if it is specified and > 0
   otherwise, Periph = 0 (default)

If model parameter Allowscaling is set to yes, the diode geometry parameters Periph, Width, and Length are multiplied by Scale × Scale, while Area is multiplied by Scale × Scale (for Level = 11 only).

4. **Imax and Imelt Parameters**
   Imax and Imelt specify the P-N junction explosion current ExplI which is used in the following equations. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value. If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) ExplI = Imelt; otherwise, if Imax is specified (in the model or in Options) ExplI = Imax; otherwise, ExplI = model Imelt default value (which is the same as the model Imax default value).
5. **Currents and Conductances**
   Is and Isr in the following equations have been multiplied by the effective area factor aeff.
   If vd > vmax

   idexp = [Imax + (vd - vmax) × gmax]
   gdexp = gmax

   where

$$vmax = N \times vt \times ln\left(\frac{ExplI}{Is} + 1\right)$$

$$gmax = \frac{ExplI + Is}{N \times vt}$$

   vt is thermal voltage

   If vmax ≥ vd ≥ - 10 × N × vt

$$idexp = Is\left(e^{\frac{vd}{N \times vt}} - 1\right)$$

$$gdexp = \frac{Is}{N \times vt} \times e^{\frac{vd}{N \times vt}}$$

   If vd < -10 × N × vt

$$idexp = [Is(e^{-10} - 1) + gdexp(vd + 10 \times N \times vt)]$$

$$gdexp = \frac{Is}{N \times vt} \times e^{-10}$$

   Breakdown current contribution is considered if Bv is specified and Ibv is not equal to zero.

   If -(vd + Bv) > vbmax

   ib= -{ExplI + [-(vd + Bv) - vbmax] × gbmax - ibo}
   gb = gbmax

where

$$vbmax = Nbv \times vt \times ln\left(\frac{ExplI}{Ibv}\right)$$

$$gbmax = \left(\frac{ExplI}{Nbv \times vt}\right)$$

If vbmax ≥ -(vd + Bv) > -MAXEXP × Nbv × vt

$$ib = -Ibv \times e^{-\frac{vd + Bv}{Nbv \times vt}} + ibo$$

$$gb = \frac{-ib}{Nbv \times vt}$$

Otherwise

ib = 0
gb = 0

For ibo

If Bv < MAXEXP × Nbv × vt

$$ibo = Ibv \times e^{\frac{-Bv}{Nbv \times vt}}$$

Otherwise

ibo = 0

MAXEXP is the maximum exponent supported by the machine; value range is 88 to 709.
Low level reverse breakdown current is considered if Ibvl is specified and not equal to zero.

If -(vd + Bv) > vlbmax

ilb = -{ExplI + [-(vd + Bv) - vlbmax] × glbmax - ilbo}
glb = glbmax

where

$$vlbmax = Nbvl \times vt \times ln\left(\frac{ExplI}{Ibvl}\right)$$

$$glbmax = \left(\frac{ExplI}{Nbvl \times vt}\right)$$

If vlbmax ≥ -(vd + Bv) > - MAXEXP × bvl × vt

$$ilb = -Ibvl \times e^{\frac{-(vd + Bv)}{Nbvl \times vt}} + ilbo$$

$$glb = \frac{-ilb}{Nbvl \times vt}$$

Otherwise

ilb = 0
glb = 0

For ilbo
If Bv < MAXEXP × Nbvl × vt

$$ilbo = Ibvl \times e^{\frac{-Bv}{Nbvl \times vt}}$$

Otherwise

ilbo = 0

Recombination current is considered if Isr is specified and not equal to zero.
If vd > vrmax

ir = ExplI + (vd - vrmax) × grmax
| gr = grmax

where

$$vrmax = Nr \times vt \times \ln\left(\frac{ExplI}{Isr} + 1\right)$$

$$grmax = \frac{ExplI + Isr}{Nr \times vt}$$

If vrmax ≥ vd ≥ - 10 × Nr × vt

$$ir = Isr\left(e^{\frac{Vd}{Nr \times vt}} - 1\right)$$

$$gr = \frac{Isr}{Nr \times vt} \times e^{\frac{vd}{Nr \times vt}}$$

If vd < - 10 × Nr × vt

$$ir = [Isr(e^{-10} - 1) + gr(vd + 10 \times Nr \times vt)]$$

$$gr = \frac{Isr}{Nr \times vt} \times e^{-10}$$

iexp = idexp + ib + ilb
gexp = gdexp + gb + glb

There are two ways to model high-injection effect.

When IkModel is set to ADS/Libra/Pspice and when Ikf ≠ 0 and iexp > 0.

$$idh = iexp\ \sqrt{\frac{Ikf}{Ikf + iexp}}$$

$$gdh = gexp\ \frac{1}{2}\left(1 + \frac{Ikf}{Ikf + iexp}\right)\sqrt{\frac{Ikf}{Ikf + iexp}}$$

When IkModel is set to Hspice:
If Ikf is not equal to zero and iexp > 0

$$idh = iexp\ \frac{1}{1 + \sqrt{\dfrac{iexp}{Ikf}}}$$

$$gdh = gexp\left(\frac{1}{1 + \sqrt{\dfrac{iexp}{Ikf}}}\right) \times \left(1 - \frac{\sqrt{\dfrac{iexp}{Ikf}}}{2\left(1 + \sqrt{\dfrac{iexp}{Ikf}}\right)}\right)$$

Otherwise if Ikr is not equal to zero and iexp < 0

$$idh = iexp\frac{1}{1 + \sqrt{\dfrac{-iexp}{Ikr}}}$$

$$gdh = gexp\left(\frac{1}{1 + \sqrt{\dfrac{-iexp}{Ikr}}}\right) \times \left(1 - \frac{\sqrt{\dfrac{-iexp}{Ikr}}}{2\left(1 + \sqrt{\dfrac{-iexp}{Ikr}}\right)}\right)$$

The total diode DC current and conductance

id = idh + ir
Id = id + Gleak × vd + Gmin × vd
gd = gdh + gr
Gd = gd + Gleak + Gmin

where Gmin is minimum junction conductance.

Sidewall diode:

Sidewall diode equations have been multiplied by Periph, Isw, Ibv, Ikp, Gleaksw.

If vdsw > vmaxsw

idexpsw = [ExplI + (vdsw - vmaxsw) × gmaxsw]
gdexpsw = gmaxsw

where

vdsw is sidewall diode voltage

$$vmaxsw = Ns \times vt \times \ln\left(\frac{ExplI}{Isw} + 1\right)$$

$$gmaxsw = \frac{ExplI + Isw}{Ns \times vt}$$

vt is thermal voltage

If vmaxsw ≥ vdsw ≥ - 10 × Ns × vt

$$idexpsw = Isw\left(e^{\frac{vdsw}{Ns \times vt}} - 1\right)$$

$$gdexswp = \frac{Isw}{Ns \times vt} \times e^{\frac{vdsw}{Ns \times vt}}$$

If vdsw < -10 × Ns × vt

$$idexpsw = [Isw(e^{-10} - 1) + gdexpsw(vdsw + 10 \times Ns \times vt)]$$

$$gdexpsw = \frac{Isw}{Ns \times vt} \times e^{-10}$$

Breakdown current contribution is considered if Bv is specified and Ibv ≠ 0 and Level ≠ 11.

If -(vdsw + Bv) > vbmaxsw

ibsw = -{ExplI + [-(vdsw + Bv) - vbmaxsw] × gbmaxsw - ibosw}
gbsw = gbmaxsw

where

$$vbmaxsw = Nbv \times vt \times \ln\left(\frac{ExplI}{Ibv}\right)$$

$$gbmaxsw = \left(\frac{ExplI}{Nbv \times vt}\right)$$

If vbmaxsw ≥ -(vd + Bv) > -MAXEXP × Nbv × vt

$$ibsw = -Ibv \times e^{\frac{-(vd+Bv)}{Nbv \times vt}} + ibosw$$

$$gbsw = \frac{-ibsw}{Nbv \times vt}$$

Otherwise

ibsw = 0
gbsw = 0

For ibosw

If (vd + Bv) < MAXEXP × Nbv × vt

$$ibosw = Ibv \times e^{\frac{-Bv}{Nbv \times vt}}$$

Otherwise

ibosw = 0

MAXEXP is the maximum exponent supported by the machine; value range is 88 to 709.

iexpsw = idexpsw + ibsw
gexp = gdexp + gb

There are two ways to model sidewall diode high-injection effect.

When IkModel is set to ADS/Libra/Pspice and when Ikp ≠ 0 and iexp > 0.

$$idsw = iexpsw \sqrt{\frac{Ikp}{Ikp + iexpsw}}$$

$$gdsw = gexpsw \frac{1}{2}\left(1 + \frac{Ikp}{Ikp + iexpsw}\right) \sqrt{\frac{Ikp}{Ikp + iexpsw}}$$

When IkModel is set to Hspice:

If Ikp ≠ 0 and iexp > 0

$$idsw = iexpsw \frac{1}{1 + \sqrt{\frac{iexpsw}{Ikp}}}$$

$$gdsw = gexpsw\left(\frac{1}{1+\sqrt{\frac{iexpsw}{Ikp}}}\right)\times\left(1-\frac{\sqrt{\frac{iexpsw}{Ikp}}}{2\left(1+\sqrt{\frac{iexp}{Ikp}}\right)}\right)$$

The total diode DC current and conductance

Idsw = idsw + Gleaksw × vdsw + Gmin × vdsw
Gdsw = gdsw + Gleaksw + Gmin

6. **Diode Capacitances**
   For main diode capacitance
   Diffusion capacitance

   Cdiff = Tt × gdexp

   Junction capacitance
   If vd ≤ Fc × Vj

   $$Cj = Area\times Cjo\times\left(1-\frac{vd}{Vj}\right)^{-M}$$

   If Vd > Fc × Vj

   $$Cj = Area\times\frac{Cjo}{(1-Fc)^{M}}\left[1+\left(\frac{M}{Vj\times(1-Fc)}\right)\times(vd-Fc\times Vj)\right]$$

   Total main capacitance

   Cdj = Cdiff + Cj + Cd × Area

   For sidewall capacitance
   If vdsw ≤ Fcsw × Vjsw

   $$Cjsw = Periph\times Cjsw\left(1-\frac{vdsw}{Vjsw}\right)^{-Msw}$$

   If vdsw > Fcsw × Vjsw

   $$Cjsw = Periph\frac{Cjsw}{(1-Fcsw)^{Msw}}\left[1+\left(\frac{Msw}{Vjsw\times(1-Fcsw)}\right)\times(vdsw-Fcsw\times Vjsw)\right]$$

7. **Temperature Scaling**
   Parameters Is, Jsw, Isr, Cjo, Cjsw, Vj, Vjsw, Bv, Tt, and Rs are temperature dependent.

   > **Note**
   > Expressions for the temperature dependence of the energy bandgap and the intrinsic carrier concentration are for silicon only. Depletion capacitance for non-silicon diodes may not scale properly with temperature, even if values of Eg and Xti are altered from the default values given in the parameters list.

   The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

   The energy bandgap E_G varies as:

$$E_G(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108}$$

if *Tlev* = 0, 1

$$E_G(T) = Eg - \frac{EgAlphaT^2}{T + EgBeta}$$

if *Tlev* = 2

The intrinsic carrier concentration n_i for silicon varies as:

$$n_i(T) = 1.45 \times 10^{10} \left(\frac{T}{300.15}\right)^{3/2} \exp\left(\frac{E_G(300.15)}{2k300.15/q} - \frac{E_G(T)}{2kT/q}\right)$$

The saturation currents Is, Isr, and Jsw scale as:

if Tlev = 0 or Tlev = 1

$$Is^{NEW} = Is \times \exp\left[\frac{Eg}{NkTnom/q} - \frac{Eg}{NkTemp/q} + \frac{Xti}{N}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isr^{NEW} = Isr \times \exp\left[\frac{Eg}{NrkTnom/q} - \frac{Eg}{NrkTemp/q} + \frac{Xti}{Nr}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Jsw^{NEW} = Jsw \times \exp\left[\frac{Eg}{NkTnom/q} - \frac{Eg}{NkTemp/q} + \frac{Xti}{N}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

else if Tlev = 2

$$Is^{NEW} = Is \times \exp\left[\frac{E_G(Tnom)}{NkTnom/q} - \frac{E_G(Temp)}{NkTemp/q} + \frac{Xti}{N}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isr^{NEW} = Isr \times \exp\left[\frac{E_G(Tnom)}{NrkTnom/q} - \frac{E_G(Temp)}{NrkTemp/q} + \frac{Xti}{Nr}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Jsw^{NEW} = Jsw \times \exp\left[\frac{E_G(Tnom)}{NkTnom/q} - \frac{E_G(Temp)}{NkTemp/q} + \frac{Xti}{N}\ln\left(\frac{Temp}{Tnom}\right)\right]$$

The breakdown voltage Bv scales as:

if Tlev = 0

$$Bv^{NEW} = Bv - Tbv(Temp - Tnom)$$

if Tlev = 1 or Tlev = 2

$$Bv^{NEW} = Bv - Tbv[1 - Tbv(Temp - Tnom)]$$

The breakdown current Ibv does not scale with temperature.

The transit time Tt scales as:

$$Tt^{NEW} = Tt[1 + Ttt1(Temp - Tnom) + Ttt2(Temp - Tnom)^2]$$

The series resistance Rs scales as:

$$Rs^{NEW} = Rs[1 + Trs(Temp - Tnom)]$$

The depletion capacitances Cjo and Cjsw and the junction potentials Vj and Vjsw vary as:
if Tlevc = 0

$$Vj^{NEW} = Vj\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Vjsw^{NEW} = Vjsw\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Cj^{NEW} = Cj\left(1 + M\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Vj^{NEW}}{Vj}\right]\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 + Msw\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Vjsw^{NEW}}{Vjsw}\right]\right)$$

if Tlevc = 1

$$Vj^{NEW} = Vj - Tvj(Temp - Tnom)$$

$$Vjsw^{NEW} = Vjsw - Tvjsw(Temp - Tnom)$$

$$Cj^{NEW} = Cj[1 + Tcj(Temp - Tnom)]$$

$$Cjsw^{NEW} = Cjsw[1 + Tcjsw(Temp - Tnom)]$$

if Tlevc = 2

$$Vj^{NEW} = Vj - Tvj(Temp - Tnom)$$

$$Vjsw^{NEW} = Vjsw - Tvjsw(Temp - Tnom)$$

$$Cj^{NEW} = Cj\left(\frac{Vj}{Vj^{NEW}}\right)^{M}$$

$$Cjsw^{NEW} = Cjsw\left(\frac{Vjsw}{Vjsw^{NEW}}\right)^{Msw}$$

if Tlevc = 3

if Tlev = 2

$$dVjdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2EgBeta}{Tnom + EgBeta} - Vj\right)\frac{1}{Tnom}$$

$$dVjswdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2EgBeta}{Tnom + EgBeta} - Vjsw\right)\frac{1}{Tnom}$$

if Tlev = 0 or Tlev = 1

$$dVjdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2\times 1108}{Tnom + 1108} - Vj\right)\frac{1}{Tnom}$$

$$dVjswdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2\times 1108}{Tnom + 1108} - Vjsw\right)\frac{1}{Tnom}$$

$$Vj^{NEW} = Vj + dVjdT(Temp - Tnom)$$

$$Vjsw^{NEW} = Vjsw + dVjswdT(Temp - Tnom)$$

$$Cj^{NEW} = Cj\left(1 - \frac{dVjdT(Temp - Tnom)}{2Vj}\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 - \frac{dVjswdT(Temp - Tnom)}{2Vjsw}\right)$$

The junction grading coefficient M scales as:

$$M^{NEW} = M[1 + Tm1(Temp - Tnom) + Tm2(Temp - Tnom)^2]$$

The sidewall grading coefficient Msw does not scale.

8. **Noise Model**
Thermal noise generated by resistor Rs is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{Rs}$$

Shot noise and flicker noise (Kf, Af, Ffe) generated by the DC current flow through the diode is characterized by the following spectral density:

$$\frac{<i_d^2>}{\Delta f} = 2qI_D + Kf\frac{I_D^{Af}}{f^{Ffe}}$$

In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, *Kf*, *Af*, and *Ffe* are model parameters, *f* is the simulation frequency, and Δ *f* is the noise bandwidth.

9. The sidewall model parameters model a second ideal diode that scales with the

instance parameter Periph, in parallel with the main diode that scales with the instance parameter Area. The series resistance Rs scales only with Area, not with Periph.

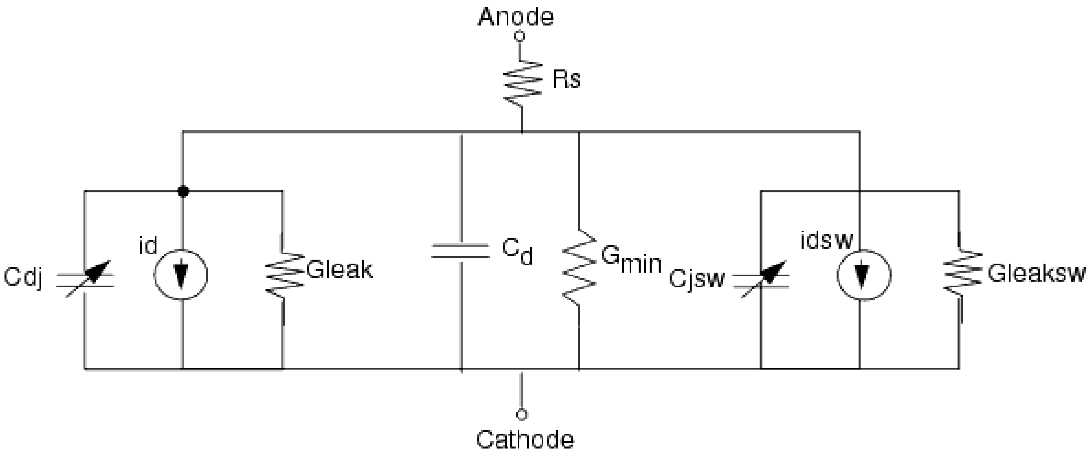
10. To model a Zener diode, the model parameters Bv and Ibv can be used. Bv should be set to the Zener reverse breakdown voltage as a positive number. Ibv is set to the breakdown current that flows at that voltage as a positive number; typically this is in the range of 1 to 10 mA. The series resistance Rs should also be set; a typical value is 1 Ohm.

References

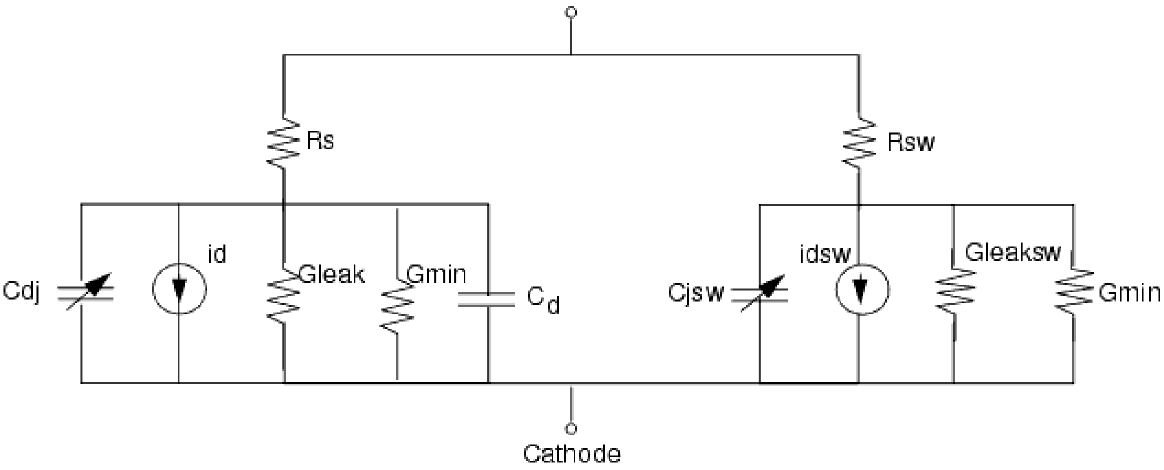
1. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE*, New York: McGraw-Hill, Second Edition 1993.

Equivalent Circuit

If Rsw is not given

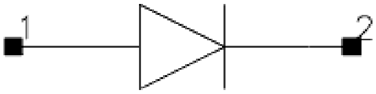


If Rsw is given



JUNCAP (Philips JUNCAP Device)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	JUNCAPM1
Ab †	diffusion area	m^2	1.0e-12
Ls †	length of sidewall of the diffusion area that is not under the gate	meter	1.0e-6
Lg †	length of sidewall of the diffusion area that is under the gate	meter	1.0e-6
Region	DC operating region; 0=off, 1=on, 2=rev, 3=sat	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to Note 1)	None	Nonlinear
Noise	noise generation option; yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.

Notes/Equations

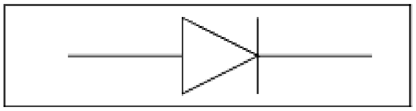
1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

Name	Description	Units
Id	Diode current	amperes
Power	DC power dissipated	watts
Rd	Series resistance	ohms
Cd	Junction capacitance	farads
Vd	Anode-cathode voltage	volts

3. Additional information about this device is available from the website: http://www.nxp.com/models/add_models/juncap/index.html
4. This device has no default artwork associated with it.

Juncap_Model (Philips JUNCAP Model)

Symbol



Parameters

Name	Description	Units	Default
Tr (Tnom)	Temperature for the Reference Transistor	°C	25
Trise	temperature rise above ambient	°C	0
Vr	Reference Voltage	V	0.0
Jsgbr	Bottom Saturation Current Density due to Electron-Hole generation	A/m^2	1.0e-3
Jsdbr	Bottom Saturation Current Density due to Diffusion from Back Contact	A/m^2	1.0e-3
Jsgsr	Sidewall Saturation Current Density due to Electron-Hole generation	A/m	1.0e-3
Jsdsr	Sidewall Saturation Current Density due to Diffusion from Back Contact	A/m	1.0e-3
Jsggr	Gate-Edge Saturation Current Density due to Electron-Hole generation	A/m	1.0e-3
Jsdgr	Gate-Edge Saturation Current Density due to Diffusion from Back Contact	A/m	1.0e-3
Cjbr	Bottom Junction Capacitance	F/m^2	1.0e-12
Cjsr	Bottom Junction Capacitance	F/m	1.0e-12
Cjgr	Bottom Junction Capacitance	F/m	1.0e-12
Vdbr	Bottom Junction Capacitance	V	1.0
Vdsr	Bottom Junction Capacitance	V	1.0
Vdgr	Bottom Junction Capacitance	V	1.0
Pb	Bottom Junction Grading Coefficient	None	0.4
Ps	Bottom Junction Grading Coefficient	None	0.4
Pg	Bottom Junction Grading Coefficient	None	0.4
Nb	Emission Coefficient of the Bottom Forward Current	None	1.0
Ns	Emission Coefficient of the Bottom Forward Current	None	1.0
Ng	Emission Coefficient of the Bottom Forward Current	None	1.0
Gmin	P-N junction parallel conductance	None	1.0e-15
Imax	Explosion current	A	1.0
All Params	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname Juncap [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by diode components to refer to the model. The third parameter indicates the type of model; for this model it is *Juncap*. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model DSpar Juncap \
Jsbgr=3e-4 Cjbr=1e-4 Tr=25
```

Notes/Equations

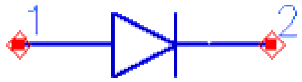
> **Note**
> Information about this model must be provided in a *model* file; refer to the Netlist Format.

1. The JUNCAP model is used to describe the behavior of diodes that are formed by the source, drain, or well-to-bulk junctions in MOS devices. The model is limited to the case of reverse biasing of these junctions. Similar to the MOS model, the current equations are formulated and ac effects are modeled via charge equations using the quasi-static approximation. In order to include the effects from differences in the sidewall, bottom and gate-edge junction profiles, these contributions are calculated separately in the JUNCAP model. Both the diffusion and the generation currents are treated in the model, each with its own temperature and voltage dependence.

   In the JUNCAP model a part of the total charge comes from the gate-edge junction very close to the surface. This charge is also included in the MOS-model charge equations, and is therefore counted twice. However, this results in only a very minor error.
2. More information about the model can be obtained from: http://www.nxp.com/models/add_models/juncap/code_history/index.html
3. Use AllParams with a *DataAccessComponent (Data Access Component)* (ccsim) to specify file-based parameters. Note that model parameters that are explicitly specified take precedence over those via AllParams.

PIN_diode (PIN Diode)

Symbol



Parameters

Name	Description	Units	Default
Area	Area scaling factor	None	1.0
Temp	Device operating temperature	°C	25.0
Trise	Temperature rise above the circuit ambient (if Temp not specified)	°C	0.0
Tnom	Temperature at which device parameters were established	°C	25.0
Noise	Noise generation option: yes, no	None	yes
Model_level	Model level selector: 1=SPICE Cj model, 2=advanced Cj model	None	1
Is †, ††	Saturation Current	A	1.0e-14
N	Emission coefficient	None	1.0
B	PI-IN emission coefficient splitting factor	None	1.0
Ikf ††	High-injection knee current (0.0 means infinity)	A	infinity
Bv †	Reverse breakdown voltage (0.0 means infinity)	V	infinity
Ibv †	Current at reverse breakdown voltage	A	0.001
Rs †, †††	Diode ohmic resistance	Ohms	0.0
Rp †, †††	Junction parallel resistance	Ohms	1.0e9
Repi †, †††	Zero-bias resistance	Ohms	1.0e3
Rlim †, †††	Minimum series resistance	Ohms	1.0e-3
W	I-region width	m	1.0e-4
Wd	Depletion area width	m	1.0e-6
Tau	Ambipolar carrier lifetime	sec	1.0e-6
Iknee	Current dependent lifetime knee current (0.0 means infinity)	A	infinity
Rho	I-region resistivity	Ohm × m	0.0
Eps	I-region dielectric constant	None	11.9
Cj †, ††	Zero-bias capacitance	F	1.0e-15
Vj †	Junction potential	V	1.0
M †	Grading coefficient	None	0.0
Fc	Forward-bias depletion capacitance coefficient	None	0.5
Eg	Energy gap	eV	1.11
Xti	Temperature exponent for Is	None	3.0
Trs	Linear relative temperature coefficient for Rs	1/°C	0.0

Trs2	Quadratic relative temperature coefficient for Rs	$1/(°C)^2$	0.0
Trp	Linear relative temperature coefficient for Rp	1/°C	0.0
Trp2	Quadratic relative temperature coefficient for Rp	$1/(°C)^2$	0.0
Trepi	Linear relative temperature coefficient for Repi	1/°C	0.0
Trepi2	Quadratic relative temperature coefficient for Repi	$1/(°C)^2$	0.0
Trlim	Linear relative temperature coefficient for Rlim	1/°C	0.0
Trlim2	Quadratic relative temperature coefficient for Rlim	$1/(°C)^2$	0.0
Tm1	Linear relative temperature coefficient for M	1/°C	0.0
Tm2	Quadratic relative temperature coefficient for M	$1/(°C)^2$	0.0
Tbv	Temperature coefficient for Bv	V/°C	0.0
Kf	Flicker noise coefficient		0.0
Af	Flicker noise exponent	None	1.0
Ffe	Flicker noise frequency exponent	None	1.0
Cpack ††	Package parasitic capacitance	F	0.0
Lbond †††	Package parasitic inductance	H	0.0
Imax	Explosion current	A	1.0
_M	Number of devices in parallel	None	1
† Parameter value varies with the temperature based on Tnom and Temp. †† Parameter value scales with Area. ††† Parameter value scales inversely with Area.			

Range of Usage

All parameters, except Trise and temperature coefficients Txxx, should be either positive or non-negative. Model_level can currently be 1 or 2. Out-of-range parameter values for Area, Temp, Tnom and W are reset to their default values. Parameters which are subject to temperature scaling are clipped at a small positive number or zero if, after scaling, their values become too small.

Notes/Equations

1. The PIN diode device does not use a *model* card. All parameters are specified on each instance of the PIN diode device.
2. For Model_level = 1 the standard SPICE diode equation is used to model the junction capacitance. Specifically, a linear extension is used for V_D > Fc × Vj.
3. For Model_level = 2 the advanced model equations of [1] are implemented. However, for Transient simulations the frequency dependence of the junction capacitance could significantly affect the robustness of the simulation, and thus is disabled. This may create some discrepancies between Harmonic Balance and Transient simulation results.
4. The device operating temperature *T* is either equal to the value of the parameter Temp, if it is specified, or defaults to the global (ambient) circuit temperature specified by the parameter Temp in the Options controller and modified by the value of Trise:
_ T = circuit_ambient_temperature_ + Trise
If Temp is not specified in the Options controller, the circuit ambient temperature

defaults to 25°C.

5. Tnom parameter, if not specified, defaults to the global value of Tnom as specified in the Options controller. If it is not specified in the Options controller, default is 25°C.
6. Imax Parameter
   Imax specifies the P-N junction explosion current. The global value of Imax given in the Options controller is not used as the default value if the PIN diode parameter Imax is not specified. The default value remains as shown in the table.
7. The parameter Rs is the series ohmic resistance of the diodes DPI and DIN shown in Equivalent Circuit. The overall PIN diode series resistance is not Rs, but rather a combination of Repi, Rlim and GRMOD, and is also affected by other parameters.
8. Implementation of the PIN_diode model is based on [1-4]

Equations - Diode Current

The PIN diode main current equation follows that of the standard PN diode but comes as a result of two diodes connected in series: DPI and DIN, in addition to being processed by the controlled sources as shown in Equivalent Circuit. The two diodes share the following parameters:

Area, Temp, Tnom, Is, Rs, Ikf, Bv, Ibv, Trs, Trs2 and Tbv.

but may have different emission coefficients as

$$N_{PI} = \frac{N}{1+B}, \quad N_{IN} = \frac{N \cdot B}{1+B}$$

if the model parameter B is different from 1.0.

The diode current is affected by the RC sub-circuit which is devised to model the impact of the charge storage in the I-region and its lifetime. The component values of the RC sub-circuit are defined as follows:

$$RP_i = 4i-3, \quad CP_i = \frac{Tau}{4i-3}, \quad RS_i = \frac{alpha}{4i-1}$$

where i = 1, 2, ... , 5,

$$alpha = \frac{W^2}{0.00048375 \cdot Tau}$$

and Tau and W are model parameters.

The main diode current IS2 is fed back to the main diode branch through a CCCS with a gain of 1.
To establish the current in the main diode branch, its voltage Vpin is sensed by a VCVS and applied (with a gain of 1) directly to the diodes DPI and DIN. The current IS1 through the two diodes excites the RC sub-circuit via a CCVS with a trans-resistance of 1.

Finally, in addition to a limiting resistance Rlim and the zero-bias resistance Repi the diode current is affected by two nonlinear resistors, marked in the equivalent circuit as GRMOD and GE.
The current i_{GE} in GE is expressed in terms of its voltage v_{GE} as:

$$i_{GE} = 0.25 \cdot \left(v_{GE} + \sqrt{(v_{GE})^2 + 4\varepsilon^2}\right)^2 / Iknee$$

where Iknee is a model parameter and $\Sigma = 10^{-12}$.

The GRMOD component is actually a voltage controlled resistance and its current i_{GRMOD} is expressed in terms of its voltage v_{GRMOD} and of the controlling voltage v_{rp1} as:

$$i_{GRMOD} = \left(\left(v_{RP1} + \sqrt{(v_{RP1})^2 + 4\varepsilon^2}\right) / (Wm)\right) \cdot v_{GRMOD}$$

where

$$Wm = \frac{10 \cdot W^2}{Tau}$$

and Tau and W are model parameters.

Equations - Diode Capacitance

The default setting of the parameter M (M = 0) makes the junction capacitance to be linear with its value specified by the parameter Cj.

For M > 0 and VD < Fc × Vj the standard SPICE nonlinear capacitance equation is used

$$C = \frac{Cj}{\left(1 - \frac{V_D}{Vj}\right)^M}$$

where VD is the voltage across the capacitance and Cj, Fc and Vj are model parameters.

The extension of this equation beyond Fc × Vj is controlled by the parameter Model_level.

For Model_level = 1 (default) and V_D > Fc × Vj the standard linear extension is used

$$C = \frac{Cj}{(1 - Fc)^M} \cdot \left[1 + \frac{M}{(1 - Fc) \cdot Vj} \cdot (V_D - Fc \cdot Vj)\right].$$

For Model_level = 2 and Fc × Vj < V_D < (2-Fc) × Vj the quadratic extension is used:

$$C = \frac{Cj}{(1 - Fc)^M} \cdot \left[1 + \frac{M}{2} \cdot \left(1 - \left(\frac{V_D - Vj}{(1 - Fc) \cdot Vj}\right)^2\right)\right]$$

which is followed by a decaying exponential extension for V_D > (2-Fc) × Vj, defined as follows.

$$C = \frac{Cj}{(1-Fc)^{M}} \cdot \exp\left(-\frac{M}{(1-Fc)\cdot Vj} \cdot (V_D - (2-Fc)\cdot Vj)\right)$$

Additionally, for Model_level = 2, a frequency dependence of Cj is incorporated into the capacitance equation using the following factor, if the model parameter Rho is specified and greater than zero. By default Rho = 0 and the frequency dependence of Cj does not take effect, i.e., the factor is set to 1.0.

$$Cj \Leftarrow Cj \cdot \frac{1+\left(\frac{f}{f_r}\right)^2}{\left(\frac{Wd}{W}\right)+\left(\frac{f}{f_r}\right)^2}$$

where f_r is the dielectric relaxation frequency

$$f_r = \frac{1}{2\pi\rho\varepsilon_r\varepsilon_0},\ \rho = Rho,\ \varepsilon_r = Eps$$

Rho, Eps, Wd and W are model parameters, and Σ0 is the permittivity of vacuum.

Other RLC Components

The parameters Rp, Repi, Rlim, Cpack and Lbond provide the component values for the respective components. Rp is the junction parallel (leakage) resistance. Repi is the zero-bias series diode resistance. Rlim establishes the minimum diode resistance. Cpack and Lbond are the package parasitic capacitance and inductance, respectively.

Temperature Scaling Relations

Temperature scaling is performed when the operating device temperature T (see Note 4) is different from Tnom. The temperature scaling relations used for the PIN diode are the same as for the PN diode with Tlev = 0 and Tlevc = 0. This includes scaling of the saturation current Is, the breakdown voltage Bv, the grading coefficient M, the junction potential Vj, the junction capacitance Cj, as well as the thermal voltage in the equation for the diode current. See *Diode_Model (PN-Junction Diode Model)* (ccnld) for more information.

Additionally, the resistances Rs, Rp, Repi and Rlim are scaled in the same way as the resistor component.

Dimensional Scaling Relations

If the parameter Area is different from 1.0 then the dimensional scaling is performed on several model parameters, as indicated in the parameter table for Area.

Noise Model

Thermal noise generated by resistors Rs, Rp, Repi and Rlim is characterized by the following spectral density:

$$\frac{\langle i^2 \rangle}{\Delta f} = \frac{4kT}{R}$$

where R=Rs, Rp, Rlim or Repi, respectively. Since the resistor Rs is included in both diodes DPI and DIN, there are correspondingly two noise sources.

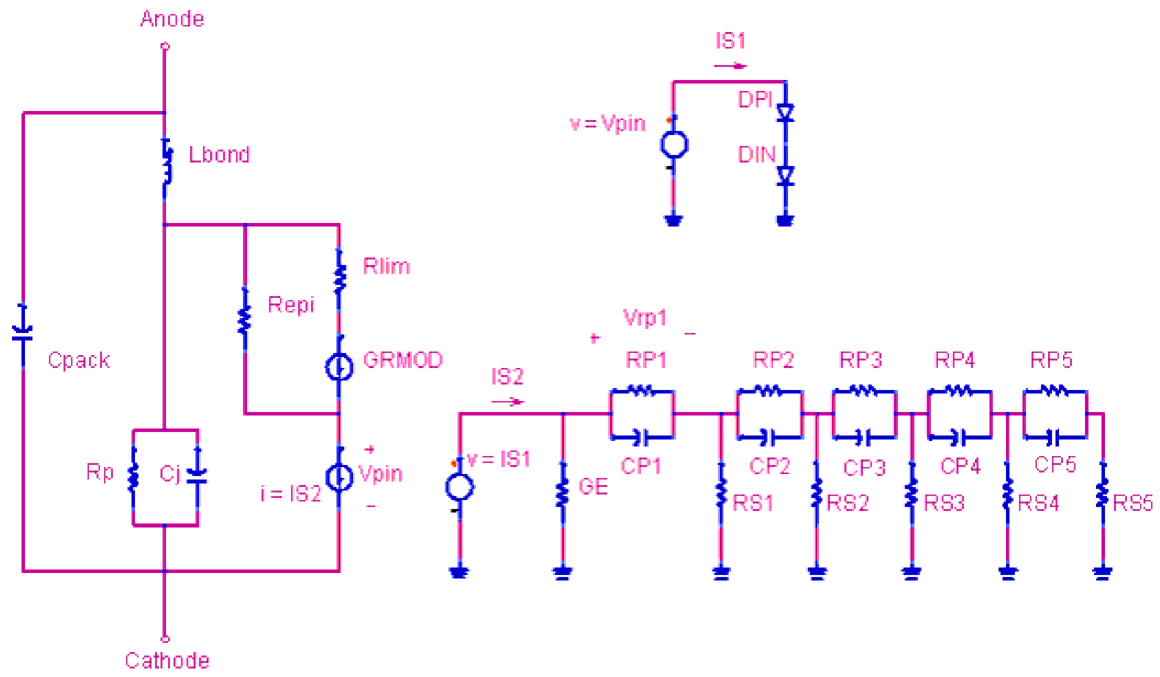
Both diodes DPI and DIN are considered noisy (if the parameter Noise is set to "YES"). Shot noise and flicker noise (Kf, Af, Ffe) generated by the DC current flowing through the diodes is characterized by the following spectral density:

$$\frac{\langle i^2 \rangle}{\Delta f} = 2qI_D + Kf \cdot \frac{{I_D}^{Af}}{f^{Ffe}}$$

In the preceding expressions, k is Boltzmann's constant, T is the operating temperature in Kelvin, q is the electron charge, Kf, Af, and Ffe are model parameters, f is the simulation frequency, and Δ f is the noise bandwidth.

The RC sub-circuit is considered noiseless.

Equivalent Circuit



References

1. J. Kyhl and M. Andersson, "An Advanced PIN-diode Model," Microwave Journal, September 2005, pp. 206-212.
2. R.H. Caverly, N.V. Drozdovski, L.M. Drozdovskaia and M.J. Quinn, "SPICE Modeling of Microwave and RF Control Diodes," Proc. 43rd IEEE Midwest Symp., August 8-11, 2000.
3. A.G.M. Strollo, "A New SPICE Model of Power P-I-N Diode Based on Asymptotic Waveform Evaluation," IEEE Transactions on Power Electronics, Vol. 12, No. 1, pp. 12-20, January 1997.

Devices and Models, GaAs

- *ADS FET (ADS Root FET)* (ccnld)
- *ADS FET Model (ADS Root Model GaAsFET Model)* (ccnld)
- *Advanced Curtice2 Model (Advanced Curtice-Quadratic GaAsFET Model)* (ccnld)
- *Angelov FET (Angelov Nonlinear GaAsFET)* (ccnld)
- *Angelov Model (Angelov (Chalmers) Nonlinear GaAsFET Model)* (ccnld)
- *Curtice2 Model (Curtice-Quadratic GaAsFET Model)* (ccnld)
- *Curtice3 Model (Curtice-Cubic GaAsFET Model)* (ccnld)
- *EE FET3 (EEsof Scalable Nonlinear GaAsFet, Second Generation)* (ccnld)
- *EE FET3 Model (EEsof Scalable Nonlinear GaAsFet Model)* (ccnld)
- *EE HEMT1 (EEsof Scalable Nonlinear HEMT)* (ccnld)
- *EE HEMT1 Model (EEsof Scalable Nonlinear HEMT Model)* (ccnld)
- *GaAsFET (Nonlinear Gallium Arsenide FET)* (ccnld)
- *Materka Model (Materka GaAsFET Model)* (ccnld)
- *Mesfet Form (Symbolic MESFET Model)* (ccnld)
- *Modified Materka Model (Modified Materka GaAsFET Model)* (ccnld)
- *Statz Model (Statz Raytheon GaAsFET Model)* (ccnld)
- *Tajima Model (Tajima GaAsFET Model)* (ccnld)
- *TOM3 (TriQuint TOM3 Scalable Nonlinear FET)* (ccnld)
- *TOM3 Model (TriQuint TOM3 Scalable Nonlinear FET Model)* (ccnld)
- *TOM4 (TriQuint TOM4 Scalable Nonlinear FET)* (ccnld)
- *TOM4 Model (TriQuint TOM4 Scalable Nonlinear FET Model)* (ccnld)
- *TOM (TriQuint Scalable Nonlinear GaAsFET)* (ccnld)
- *TOM Model (TriQuint Scalable Nonlinear GaAsFET Model)* (ccnld)
- *TriQuintMaterka (TriQuint-Materka Nonlinear FET)* (ccnld)
- *TriQuintMaterka Model (TriQuint-Materka Nonlinear FET Model)* (ccnld)

Bin Model

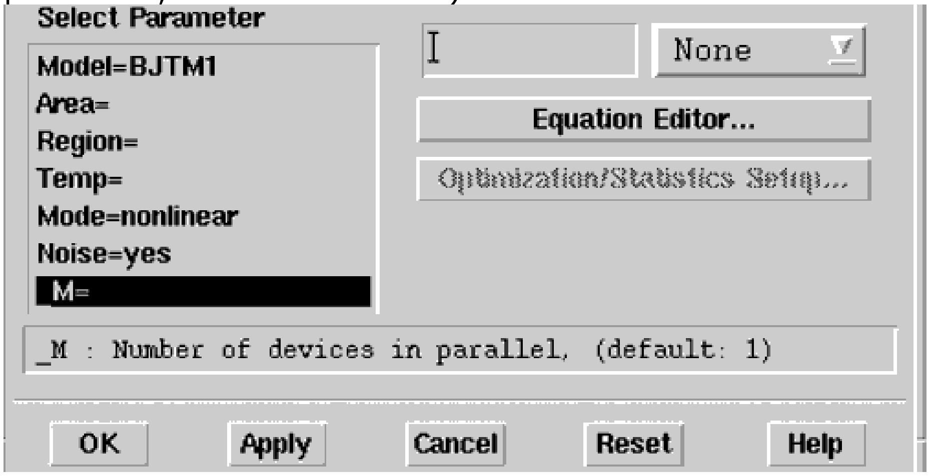
The BinModel in the GaAs library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to *BinModel* (ccsim) in *Introduction to Circuit Components*.

Multiplicity Parameter _M

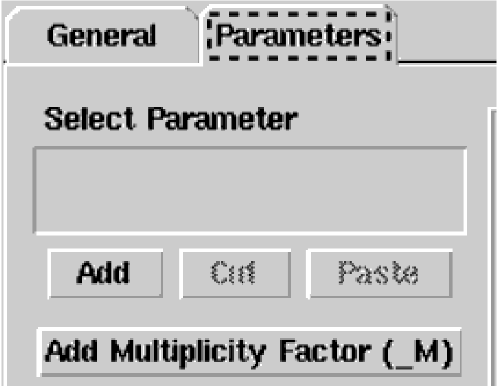
The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M* , the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



_M : Number of devices in parallel, (default: 1)

For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor_M**.



Netlist Syntax

Models for the ADS circuit simulator have the following syntax:

```
model modelname modeltype [param=value]*
```

where `model` is a keyword, `modelname` is the user-defined name for the model and `modeltype` is one of the predefined model types (e.g., Diode, BJT, MOSFET). After these three required fields comes zero or more `param=value` pairs. `param` is a model keyword and value is its user-assigned value. There is no required order for the `param=value` pairs. Model keywords that are not specified take on their default values. Refer to documentation for each model type to see the list of model parameters, their meanings and default values.

The model statement must be on a single line. Use the backslash "\" as a line continuation character. The instance and model parameter names are case sensitive. Most, but not all, model parameters have their first character capitalized and the rest are lower case. Scale factors (e.g., p=10^{-12}, n=10^{-9}, u=10^{-6}, m=10^{-3}, k=10^{+3}, M=10^{+6}) can be used with numbers for numeric values. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

A netlist translator is available for translating models and subcircuits from Pspice, Hspice, and Spectre syntax to the form used by the ADS Circuit Simulator. Refer to *Netlist Translator for SPICE and Spectre* (netlist) for more information.

Parameter Aliases

For compatibility with other simulators, some models accept two or more different keywords for the same parameter. For example, the Diode model accepts both model keywords Is and Js for the saturation current. In the documentation, the parameter Name column lists the aliases in parentheses after the main parameter name. The main parameter name is the one that appears in the ADS dialog box for the model.

Tnom

All nonlinear device models have a parameter that specifies the temperature at which the model parameters were extracted. Normally called Tnom, some models may use Tref, Tr, or Tmeas. The default value for Tnom is specified on the Options item in the Tnom field. If Options.Tnom is not specified it defaults to 25°C. This is true for all nonlinear devices.

It is strongly suggested that the user explicitly set Tnom in each model and not depend on its default value. First, this provides a self-documenting model; other users of the device will not have to guess at what Tnom should be. Second, different users of the same model would get different results for the same circuit if they simulate with different values of Options.Tnom.

Temp and Trise

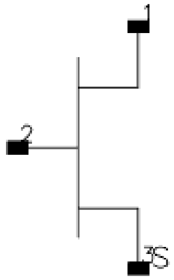
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp, which defaults to 25°C.

For compatibility with other simulators, many of the nonlinear devices allow the user to specify Trise for each device instance, which specifies actual device temperature as an increase from ambient. It defaults to zero. The Trise instance value is used only if the Temp instance value is not specified. If the user does not specify Trise on the instance, a default value for Trise can also be specified in the model. It defaults to zero. The following shows the logic of how the instance temperature is calculated if it is not explicitly specified.

```
if Instance.Temp is not specified
 if instance.Trise is not specified
   Instance.Temp = Options.Temp + Model.Trise
 else
   Instance.Temp = Options.Temp + Instance.Trise
```

ADS_FET (ADS_Root FET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of an ADS_FET model	None	ADSFETM1
Wtot	total gate width		1.0e-4
N	number of device gate fingers	None	1
_M	number of devices in parallel	None	1

Notes/Equations

1. If Wtot or N is specified as *Rawfile value* or zero, the default gate width as specified in the model file is used. For other values, these values can be used to scale the extracted model for different geometries. Scaling remains valid for ratios up to 5:1.
2. Wtot is the total gate width-not the width per finger; the parameter N is the number of fingers; therefore, the width per finger is Wtot/N.
3. Currents and capacitances scale linearly with gate width:

$$I = I_0 \times \frac{Wtot}{W_0}$$

$$C = C_0 \times \frac{Wtot}{W_0}$$

Parasitic resistances scale as:

$$Rg = R_{G0} \times \frac{Wtot}{W_0}\left(\frac{N_0}{N}\right)^2$$

$$Rd = R_{D0} \times \frac{W_0}{Wtot}$$

$$Rs = R_{S0} \times \frac{W_0}{Wtot}$$

where Wtot and N are the user-specified values and W_0 and N_0 are the extracted values given in the ADS_FET_Model. The parasitic inductances do not scale.

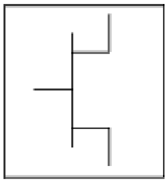
4. Care should be taken when using the transistor outside of the region at which the model measurements were taken. Extrapolation of the measured data may occur without warning during DC, harmonic balance, and time-domain analyses. This extrapolated data may produce unreliable results.
5. ADS_FET currents can be measured with the standard current measurements, except that pins must be specified by number instead of name; for example, 1=G, 2=D, 3=S.
6. The ADS_FET cannot be temperature scaled and is noiseless.
7. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Ggs	Gate conductance (dIg/dVgs)	siemens
dIg_dVds	(dIg/dVds)	siemens
dQd_dVds	(dQd/dVds)	farads
dQd_dVgs	(dQd/dVgs)	farads
dQg_dVds	(dQg/dVds)	farads
dQg_dVgs	(dQg/dVgs)	farads
Vgs	Gate-source voltage	volts
Vds	Gate-drain voltage	volts

ADS_FET_Model (ADS Root Model GaAsFET Model)

Symbol



Parameters

Name	Description	Units	Default
File	name of file containing measured data	None	None
Rs	source resistance (overrides extracted value)	Ohm	None
Rg	gate resistance (overrides extracted value)	Ohm	None
Rd	drain resistance (overrides extracted value)	Ohm	None
Ls	source inductance (overrides extracted value)	H	None
Lg	gate inductance (overrides extracted value)	H	None
Ld	drain inductance (overrides extracted value)	H	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Notes/Equations

1. This model supplies values for an ADS_FET device.
2. The default extension for the model file is.*raw*. This file should be in the same format as ADS Root model data.
3. If Rs, Rg, Rd, Ls, Lg, or Ld is specified as *rawfile value* or zero, the default parasitic value is taken from the extracted values stored in the data file named by File parameter. Generally, *rawfile value* should be used.
4. Because this model is measurement-based, extrapolation warning messages may occur if the Newton iteration exceeds the measurement range. If these messages occur frequently, check that the measurement data is within the simulation range.
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

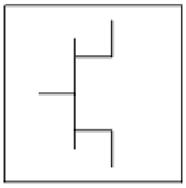
References

1. D. Root, "Technology independent large signal non quasi static FET model by direct construction from automatically characterized device data," in *21st EuMC* , 1991, p. 927.

2. D. E. Root, S. Fan, and J. Meyer, "Technology-independent large-signal FET models: A measurement-based approach to active device modeling," in *Proc. th ARMMS Conf., Bath, U.K.* , Sept. 1991, pp. 1-21.
3. D. E. Root, M. Pirola, S. Fan, W. J. Anklam, and A. Cognata, "Measurement-based large-signal diode modeling system for circuit and device design," *IEEE Trans. Microwave Theory Tech.* , vol. 41, pp. 2211-2217, Dec. 1993.
4. D. E. Root and B. Hughes, "Principles of nonlinear active device modeling for circuit simulation," in *32nd ARFTG Conf. Dig* ., Tempe, AZ, 1988, pp. 3-26.
5. D. E. Root, S. Fan, and J. Meyer, "Technology-independent large-signal non quasi static FET models by direct extraction from automatically characterized device data," in *21st European Microwave Conf. Proc.* , Stuttgart, Germany, 1991, pp. 927-932.
6. D. E. Root and S. Fan, "Experimental evaluation of large-signal modeling assumptions based on vector analysis of bias-dependent S-parameters data from MESFET's and HEMT's," in *IEEE MTT-S Int. Microwave Symp. Tech. Dig.* , 1992, pp. 927-932.

Advanced_Curtice2_Model (Advanced Curtice-Quadratic GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel model: yes or no	None	yes
PFET	P-channel model: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	1
Vto †	threshold voltage	V	−2.0
Beta † , ††	transconductance	A/V^2	1.0e-4
Lambda	channel length modulation	1/V	0.0
Alpha	hyperbolic tangent function	1/V	2.0
Tau	transit time under gate	sec	0.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Idstc	Ids temperature coefficient		0.0
Ucrit	critical field for mobility degradation	None	0
Vgexp	Vgs − Vto exponent	None	2
Gamds	effective pinch-off combined with Vds	None	-0.01
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	BETA Exponential Temperature Coefficient	%/°C	0.0
Rgs †††	gate-source resistance	Ohm	0.0
Rf †††	gate-source effective forward- bias resistance	Ohm	infinity ‡
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs † , ††	zero bias gate-source junction capacitance	F	0.0
Cgd † , ††	zero bias gate-drain junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear

Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Rgd †††	gate drain resistance	Ohm	0.0
Rd †††	drain ohmic resistance	Ohm	fixed at 0.0
Rg	gate resistance	Ohm	fixed at 0.0
Rs †††	source ohmic resistance	Ohm	fixed at 0.0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds ††	drain-source capacitance	F	0.0
Rc †††	used with Crf to model frequency dependent output conductance	Ohm	infinity ‡
Crf ††	used with Rc to model frequency dependent output conductance	F	0.0
Gsfwd	0=none, 1=linear, 2=diode	None	linear
Gsrev	0=none, 1=linear, 2=diode	None	None
Gdfwd	0=none, 1=linear, 2=diode	None	None
Gdrev	0=none, 1=linear, 2=diode	None	linear
R1 †††	approximate breakdown resistance	Ohm	infinity ‡
R2 †††	resistance relating breakdown voltage to channel current	Ohm	infinity ‡
Vbi †	built-in gate potential	V	0.85
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with Vds < 0)	V	1e100
Vjr	breakdown junction potential	V	0.025
Is † , ††	gate junction saturation current (diode model)	A	1.0e-14
Ir	gate reverse saturation current	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 2)	A	defaults to Imax
Xti	temperature exponent for saturation current	None	3.0
Eg	energy gap for temperature effect on Is	eV	1.11
N	gate junction emission coefficient (diode model)	None	1
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate-drain noise correlation coefficient	None	0.9
Taumdl	use second order Bessel polynomial to model tau effect in transient simulation: yes or no	None	no
wVgfwd	gate junction forward bias warning	V	
wBvgs	gate-source reverse breakdown voltage warning	V	
wBvgd	gate-drain reverse breakdown voltage warning	V	
wBvds	drain-source breakdown voltage warning	V	
wIdsmax	maximum drain-source current warning	A	
wPmax	maximum power dissipation warning	W	
AllParams	DataAccessComponent for file-based model parameter values	None	None
† Parameter value varies with temperature based on model Tnom and device Temp. †† Parameter value			

scales with Area. [†††] Parameter value scales inversely with Area. [‡] A value of 0.0 is interpreted as infinity.

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
3. The P, R, and C parameters model drain and gate noise sources.

$$\frac{\langle i_d^2\rangle}{\Delta f} = 4kTg_m P(1+f_{NC}/f)$$

$$\frac{\langle i_g^2\rangle}{\Delta f} = 4kT C_{gs}^2 \omega^2 R/g_m$$

$$\frac{\langle i_g, i_d^*\rangle}{\Delta f} = 4kTj\, C_{gs}\, \omega\sqrt{PR}\, C$$

4. Drain-Source Current
   Drain current in the Advanced Curtice quadratic model is based on the modification of the drain current equation in the Curtice quadratic model.
   The quadratic dependence of the drain current with respect to the gate voltage is calculated with the following expression in the region $V_{ds} \geq 0.0V$.

$$I_{ds} = Beta_{NEW} \times (V_{gs} - Vto_{NEW})^{Vgexp} \times (1+Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$$

where:

$$Vto_{NEW} = Vto + Gainds \times Vds$$

$$Beta_{NEW} = Beta/(1 + Ucrit \times (Vgs - Vto_{NEW}))$$

Assuming symmetry, in the reverse region, the drain and source swap roles and the expression becomes:

$$I_{ds} = Beta_{NEW} \times (V_{gd} - Vto_{NEW})^{Vgexp} \times (1-Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$$

where:

$I_{ds} = Beta_{NEW} \times (V_{gd} - Vto_{NEW})^{Vgexp} \times (1+Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$.

where:

$Vto_{NEW} = Vto + Gainds \times Vds$

$Beta_{NEW} = Beta/(1 + Ucrit \times (Vgd - Vto_{NEW}))$

The drain current is set to zero in either case if the junction voltage (V_{gs} or V_{gd}) drops below the threshold voltage Vto.
If Ucrit is not equal to 0, the temperature coefficients Vtotc and Betatc are disabled.

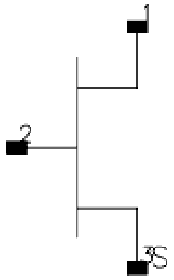
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

References

1. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Angelov_FET (Angelov Nonlinear GaAsFET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of an Angelov_Model	None	ANGELOVM1
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient	None	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 1)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

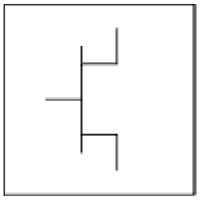
DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Ggs	Gate-source conductance	siemens
Ggd	Gate-drain conductance	siemens
Cgs	Gate-source capacitance	farads
Cgd	Gate-drain capacitance	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts

3. This device has no default artwork associated with it.

Angelov_Model (Angelov (Chalmers) Nonlinear GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
Idsmod	Ids model flag: 0=original, 1=symmetric	None	0
Igmod	Igs/Igd model flag	None	0
Capmod	Capacitance model selector: 0=linear, 1=bias-dependent capacitances, 2=charge	None	2
Ipk0 †	Current for maximum transconductance	A	0.05
Vpks	Gate voltage for maximum transconductance	V	-0.2
Dvpks	Delta gate voltage at peak Gm	V	0.2
P1 †	Polynomial coefficient for channel current	None	1.0
P2	Polynomial coefficient for channel current	None	0.0
P3	Polynomial coefficient for channel current	None	0.0
Alphar	Saturation parameter	None	0.1
Alphas	Saturation parameter	None	1.0
Vkn ††	Knee voltage	V	0.8
Lambda	Channel length modulation parameter	None	0.0
Lambda1 ††	Channel length modulation parameter	None	0.0
Lvg ††	Coefficient for Lambda parameter	None	0.0
B1	Unsaturated coefficient for P1	None	0.0
B2	Unsaturated coefficient for P2	None	3.0
Lsb0 †	Soft breakdown model parameter	None	0.0
Vtr	Threshold voltage for breakdown	V	20.0
Vsb2	Surface breakdown model parameter	None	0.0

Cds	Drain-source capacitance	F	0.0
Cgspi	Gate-source pinch-off capacitance	F	0.0
Cgs0 †	Gate-source capacitance	F	0.0
Cgdpi	Gate-drain pinch-off capacitance	F	0.0
Cgd0 †	Gate-drain capacitance	F	0.0
Cgdpe	External gate-drain capacitance	F	0.0
P10	Polynomial coefficient for capacitance	None	0.0
P11	Polynomial coefficient for capacitance	None	1.0
P20	Polynomial coefficient for capacitance	None	0.0
P21	Polynomial coefficient for capacitance	None	0.2
P30	Polynomial coefficient for capacitance	None	0.0
P31	Polynomial coefficient for capacitance	None	0.2
P40	Polynomial coefficient for capacitance	None	0.0
P41	Polynomial coefficient for capacitance	None	1.0
P111	Polynomial coefficient for capacitance	None	0.0
Ij	Gate fwd saturation current	A	0.5e-3
Pg	Gate current parameter	None	15.0
Ne	Ideality factor	None	1.4
Vjg	Gate current parameter	V	0.7
Rg	Gate resistance	Ohm	0.0
Rd	Drain resistance	Ohm	0.0
Ri	Gate-source resistance	Ohm	0.0
Rs	Source resistance	Ohm	0.0
Rgd	Gate-drain resistance	Ohm	0.0
Lg	Gate inductance	H	0.0
Ld	Drain inductance	H	0.0
Ls	Source inductance	H	0.0
Tau	Internal time delay	sec	0.0
Rcmin	Minimum value of Rc resistance	Ohm	1.0e3
Rc†	R for frequency dependent output conductance	Ohm	10.0e3
Crf†	C for frequency dependent output conductance	F	0.0
Rcin	R for frequency dependent input conductance	Ohm	100.0e3
Crfin	C for frequency dependent input conductance	F	0.0
Rth	Thermal resistance	Ohm	0.0
Cth	Thermal capacitance	F	0.0
Tcipk0	Temperature coefficient of Ipk0 parameter	None	0.0
Tcp1	Temperature coefficient of P1 parameter	None	0.0
Tccgs0	Temperature coefficient of Cgs0 parameter	None	0.0
Tccgd0	Temperature coefficient of Cgd0 parameter	None	0.0
Tclsb0	Temperature coefficient of Lsb0 parameter	None	0.0
Tcrc	Temperature coefficient of Rc parameter	None	0.0
Tccrf	Temperature coefficient of Crf parameter	None	0.0
Tnom	Parameter measurement temperature	°C	25

(Tamb)			
Selft	Flag denoting self-heating	None	no
Noimod	Noise model selector	None	0
NoiseR	Gate noise coefficient	None	0.5
NoiseP	Drain noise coefficient	None	1.0
NoiseC	Gate-drain noise correlation coefficient	None	0.9
Fnc	Flicker-noise corner frequency	Hz	0.0
Kf	Flicker noise coefficient	None	0.0
Af	Flicker noise exponent	None	1.0
Ffe	Flicker noise frequency exponent	None	1.0
Tg	Gate equivalent temperature	°C	25
Td	Drain equivalent temperature coefficient	°C	25
Td1	Drain equivalent temperature coefficient		0.1
Tmn	Noise fitting coefficient	None	1.0
Klf	Flicker noise coefficient	None	0.0
Fgr	Generation-recombination frequency corner	Hz	0.0
Np	Flicker noise frequency exponent	None	1.0
Lw	effective gate noise width	mm	0.1
AllParams	DataAccessComponent for file-based model parameter values	None	None

† This parameter varies with temperature. †† This parameter is only used with Idsmod=1

Notes/Equations

1. This model supplies values for an Angelov device.
   This model is based on the original Angelov (Chalmers) model described in [1] and [2], but includes the latest developments made by Prof. Itcho Angelov that have not been published.
2. The original Angelov model is not symmetrical (which corresponds to setting Idsmod=0). ADS implementation of the Angelov model is enhanced by providing a symmetrical Ids equation which corresponds to setting Idsmod=1. It should be used when simulating switches or resistive mixers. Part of this work was published in [6].
3. The published Angelov model is capacitance based (which corresponds to setting Capmod=1). In general, the bias-dependent capacitor models are known to be less robust, which sometimes leads to non-convergence problems. Charge-based models are normally more robust. ADS implementation of the Angelov model is enhanced by providing a charge-based model, which corresponds to setting Capmod=2. Both of the models have been created by Prof. Angelov.
4. If Rcmin is specified, the resistance Rc will be calculated based on the following nonlinear equation:

   $$Rc = Rcmin + \frac{Rc}{(1 + \tanh(\psi))}$$

5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

Ids Equations

$$P1m = P1 \times (1 + B1/\cosh^2(B2 \times Vds))$$

$$Vpkm = VPKS - DVPKS + DVPKS$$

$$\times \tanh(ALPHAS \times Vds) - VSB2 \times (Vdg - VTR)^2$$

$$\psi = P1m \times (Vgs - Vpkm) + P2 \times (Vgs - Vpkm)^2 + P3 \times (Vgs - Vpkm)^3$$

$$\alpha = ALPHAR + ALPHAS \times (1 + \tanh(\psi))$$

For the original model (Idsmod=0)

$$Ids = IPK0 \times (1 + \tanh(\psi)) \times \tanh(\alpha \times Vds)$$

$$\times (\ 1 + LAMBDA \times Vds + LSB0 \times \exp(Vdg - VTR))$$

For the symmetric model (Idsmod=1)

$$\psi_n = P1m \times (Vgd - Vpkm) + P2 \times (Vgd - Vpkm)^2 + P3 \times (Vgd - Vpkm)^3$$

$$\alpha_n = ALPHAR + ALPHAS \times (1 + \tanh(\psi_n))$$

$$\lambda_n = LAMBDA + LVG \times (1 + \tanh(\psi_n))$$

$$\lambda_p = LAMBDA + LVG \times (1 + \tanh(\psi))$$

$$\lambda_{n1} = LAMBDA1 + LVG \times (1 + \tanh(\psi_n))$$

$$\lambda_{p1} = LAMBDA1 + LVG \times (1 + \tanh(\psi))$$

$$Idsp = IPK0 \times (1 + \tanh(\psi)) \times (1 + \tanh(\alpha \times Vds))$$

$$\times \left(1 + \lambda_p \times \mathrm{Vds} + \lambda_{p1} \times \exp\left(\frac{Vds}{Vkn} - 1\right)\right)$$

$$Idsn = IPK0 \times (1 + \tanh(\psi_n)) \times (1 - \tanh(\alpha_n \times Vds))$$

$$\times \left(\ 1 - \lambda_n \times Vds - \lambda_{n1} \times \exp\left(\frac{Vds}{Vkn} - 1\right)\right)$$

$$Ids = 0.5 \times (Idsp - Idsn)$$

Igs, Igd Equations

For Igmod = 0

$$Igs = IJ \times (\exp(PG \times \tanh(2 \times (Vgsc - VJG))) - \exp(PG \times \tanh(-2 \times VJG)))$$

$$Igd = IJ \times (\exp(PG \times \tanh(2 \times (Vgdc - VJG))) - \exp(PG \times \tanh(-2 \times VJG)))$$

For Igmod = 1

$$Igs = IJ \times (\exp(PG \times \tanh(Vgsc - VJG)) - \exp(-PG \times VJG))$$

$$Igd = IJ \times (\exp(PG \times \tanh(Vgdc - VJG)) - \exp(-PG \times VJG))$$

If *PG* is not specified (left blank), but *NE* is specified then:

$$PG = 1/(2 \times NE \times Vt)$$

where *Vt* = *K* × *Temp* / *q*

If both *PG* and *NE* are not specified then the default value for *NE* is used.

(*Vgsc* and *Vgdc* are the voltages directly across each current source in the *Equivalent Circuit* diagram).

Charge Equations

For Capmod = 0 (linear capacitance)

Cgs = CGSPI

Cgd = CGDPI

For Capmod = 1

$$Cgs = CGSPI + CGS0 \times (1 + \tanh(Phi1))(1 + \tanh(Phi2))$$

$$Cgd = CGDPI + CGD0 \times ((1 - P111 + \tanh(Phi3))(1 + \tanh(Phi4)) + 2 \times P111)$$

$$Phi1 = P10 + P11 \times Vgsc + P111 \times Vds$$

$$Phi2 = P20 + P21 \times Vds$$

$$Phi3 = P30 - P31 \times Vds$$

$$Phi4 = P40 + P41 \times Vgdc - P111 \times Vds$$

For Capmod = 2

$$Lc1 = 1n(\cosh(Phi1))$$

$$Lc10 = 1n(\cosh(P10 + P111 \times Vds))$$

$$Qgs = CGSPI \times Vgsc + CGS0$$

$$\times ((Phi1 + Lc1 - Qgs0) \times (1 - P111 + \tanh(Phi2))/P11 + 2 \times P111 \times Vgsc)$$

$$Qgs0 = P10 + P111 \times Vds + Lc10$$

$$Lc4 = 1n(\cosh(Phi4))$$

$$Lc40 = 1n(\cosh(P40 - P111 \times Vds))$$

$$Qgd = CGDPI \times Vgdc + CGD0$$

$$\times ((Phi4 + Lc4 - Qgd0) \times (1 - P111 + \tanh(Phi3))/P41 + 2 \times P111 \times Vgdc)$$

$$Qgd0 = P40 - P111 \times Vds + Lc40$$

$$Phi1 = P10 + P11 \times Vgsc + P111 \times Vds$$

$$Phi2 = P20 + P21 \times Vds$$

$$Phi3 = P30 - P31 \times Vds$$

$$Phi4 = P40 + P41 \times Vgdc - P111 \times Vds$$

Temperature Equations

$$Ipk0 = IPK0 \times (1 + TCIPK0 \times (Temp - Tnom))$$
$$P1 = P1 \times (1 + TCP1 \times (Temp - Tnom))$$
$$Lsb0 = LSB0 \times (1 + TCLSB0 \times (Temp - Tnom))$$
$$Cgs0 = CGS0 \times (1 + TCGS0 \times (Temp - Tnom))$$
$$Cgd0 = CGD0 \times (1 + TCGD0 \times (Temp - Tnom))$$
$$Rc = RC \times (1 + TCRC \times (Temp - Tnom))$$
$$Crf = CRF \times (1 + TCCRF \times (Temp - Tnom))$$

Ids Noise

Noimod = 0 (default value)

$$I_{dtn} = |I_{DS}| + |I_{GD}|$$

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTLw\sqrt{\frac{T'_D}{T}} I_{dtn} + Td1 \cdot I_{dtn}^2$$

$$T'_D = Td[1 + Tmn(1 + \tanh(\Psi)) \cdot |\tanh(\alpha V_{DS})| \cdot (1 + Lambda \cdot V_{DS})]$$

where Ψ
and α
are functions calculated for the Ids equation.
Noimod=1
Parameters NoiseP, NoiseR and NoiseC model the drain and gate noise sources, and their correlation.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ NoiseP$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^2\ \omega^2\ NoiseR/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = jNoiseC4kT\ C_{gs}\ \omega\sqrt{NoiseP \cdot NoiseR}$$

Noimod=2 (supported for linear noise only)

If TMN is specified, Td (drain equivalent temperature) and Tg (gate equivalent temperature) are bias dependent:

$$Td = TD \times (1 + TMN \times (1 + \tanh[\psi]) \times ABS(\tanh[\alpha \times Vds] \times (1 + Lambda \times Vds)))$$

$$Tg = Temp \times (1 + (1 + \tanh[\psi]) \times ABS(\tanh[\alpha \times Vds] \times (1 + Lambda \times Vds)))$$

(ψ and α are functions calculated for the Ids equation)

Ids Flicker Noise Equations

NoiMod=0 (default value)

$$\frac{\langle i_{fl}^{2} \rangle}{\Delta f} = 4kTLw\sqrt{\frac{T'_{D}}{T}I_{dtn} + Td1 \cdot I_{dtn}^{2}}\left[\frac{Klf}{f^{Np}} + \frac{Klf}{1 + f^{2}/(Fgr^{2})}\right]$$

NoiMod=1 or NoiMod=2

$$\frac{\langle i_{fl}^{2} \rangle}{\Delta f} = \frac{4kTg_{m}P \cdot Fnc}{f} + \frac{KfI_{DS}^{Af}}{f^{Ffe}}$$

Igs, Igd Shot Noise and Flicker Noise Equations

$$\frac{\langle i_{gs}^{2} \rangle}{\Delta f} = 2qI_{GS} + \frac{KfI_{GS}^{Af}}{f^{Ffe}}$$

$$\frac{\langle i_{gd}^{2} \rangle}{\Delta f} = 2qI_{GD} + \frac{KfI_{GD}^{Af}}{f^{Ffe}}$$

Thermal Noise Equations

Thermal noise of resistance Rgd, Rd, Rg and Rs:

$$\frac{\langle i^{2} \rangle}{\Delta f} = 4kT/R$$

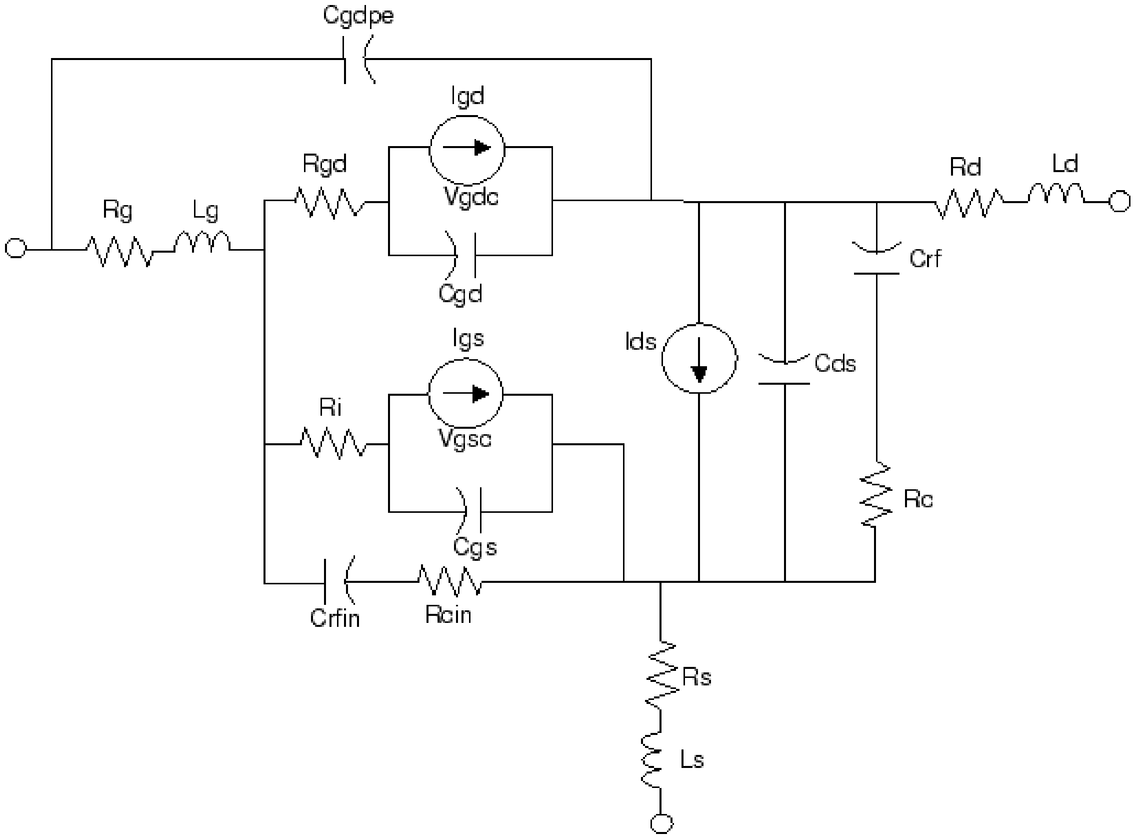
Thermal noise of resistance Ri:

$$\frac{\langle i^{2} \rangle}{\Delta f} = 4kTg'/Ri$$

$$Tg' = Tg([1 + (1 + \tanh(\Psi)) \cdot \left|\tanh(\alpha V_{DS})\right| \cdot (1 + Lambda \cdot V_{DS})])$$

where Ψ
and α
are functions calculated for the Ids equation.

Equivalent Circuit

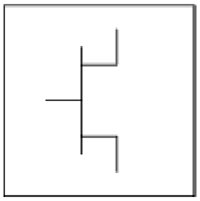


References

1. I. Angelov, H. Zirath, N. Rorsmann, "A New Empirical Nonlinear Model for HEMT and MESFET Devices," *IEEE MTT* Vol. 40, No. 12, December 1992.
2. I. Angelov, L. Bengtsson, M. Garcia, "Extensions of the Chalmers Nonlinear HEMT and MESFET Model," *IEEE MTT* Vol. 44, No. 10, October 1996.
3. M. Pospieszalski, "Modelling of noise parameters of MESFETs and MOSFETs and their frequency and temperature dependence," *IEEE Trans. MTT* ., Vol. 37, pp. 1340-1350, Sept. 1989.
4. B. Hughes, "A Temperature Noise Model for Extrinsic FETs," *IEEE Trans. MTT* ., Vol. 40, pp. 1821-1832, Sept. 1992.
5. I. Angelov, "On the Performance of Low-Noise Low-DC-Power-Consumption Cryogenic Amplifiers," *IEEE Trans. MTT* ., Vol. 50, No. 6, June 2002.
6. I. Angelov, L. Bengtsson, M. Garcia, F. van Raay, G. Kompa, "Extensions and model verification of the Chalmers Nonlinear HEMT and MESFET Model" Kassel 1997.

Curtice2_Model (Curtice-Quadratic GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	1
Vto †	threshold voltage	V	-2.0
Beta † , ††	transconductance	A/V^2	1.0e-4
Lambda	channel length modulation	1/V	0.0
Alpha	hyperbolic tangent function	1/V	2.0
Tau	transit time under gate	sec	0.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Idstc	Ids temperature coefficient		0.0
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	BETA Exponential Temperature Coefficient	%/°C	0.0
Rin †††	channel resistance	Ohm	0.0
Rf †††	gate-source effective forward- bias resistance	Ohm	infinity ‡
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs † , ††	zero bias gate-source junction capacitance	F	0.0
Cgd † , ††	zero bias gate-drain junction capacitance	F	0.0
Rgd †††	gate drain resistance	Ohm	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Rd †††	drain ohmic resistance	Ohm	fixed at 0.0
Rg	gate resistance	Ohm	fixed at 0.0

Rs [†††]	source ohmic resistance	Ohm	fixed at 0.0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds [††]	drain-source capacitance	F	0.0
Rc [†††]	used with Crf to model frequency dependent output conductance	Ohm	infinity [‡]
Crf [††]	used with Rc to model frequency dependent output conductance	F	0.0
Gsfwd	0=none, 1=linear, 2=diode	None	linear
Gsrev	0=none, 1=linear, 2=diode	None	None
Gdfwd	0=none, 1=linear, 2=diode	None	None
Gdrev	0=none, 1=linear, 2=diode	None	linear
R1 [†††]	approximate breakdown resistance	Ohm	infinity [‡]
R2 [†††]	resistance relating breakdown voltage to channel current	Ohm	infinity [‡]
Vbi [†]	built-in gate potential	V	0.85
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with Vds < 0)	V	1e100
Vjr	breakdown junction potential		0.025
Is [†], [††]	gate junction saturation current (diode model)	A	1.0e-14
Ir	gate reverse saturation current	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 2)	A	defaults to Imax
Xti	temperature exponent for saturation current	None	3.0
Eg	energy gap for temperature effect on Is	eV	1.11
N	gate junction emission coefficient (diode model)	None	1
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate-drain noise correlation coefficient	None	0.9
Taumdl	use second order Bessel polynomial to model tau effect in transient simulation: yes or no	None	no
Kf	Flicker Noise Coefficient	None	0.0
Af	Flicker Noise Exponent	None	1.0
wVgfwd	gate junction forward bias warning	V	
wBvgs	gate-source reverse breakdown voltage warning	V	
wBvgd	gate-drain reverse breakdown voltage warning	V	
wBvds	drain-source breakdown voltage warning	V	
wIdsmax	maximum drain-source current warning	A	
wPmax	maximum power dissipation warning	W	
AllParams	DataAccessComponent for file-based model parameter values	None	None

[†] Parameter value varies with temperature based on model Tnom and device Temp. [††] Parameter value scales with Area. [†††] Parameter value scales inversely with Area. [‡] A value of 0.0 is interpreted as infinity.

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

Equations/Discussion

Drain-Source Current

Drain current in the Curtice quadratic model is based on the work of W. R. Curtice [1]. The quadratic dependence of the drain current with respect to the gate voltage is calculated with the following expression in the region $V_{ds} \geq 0.0V$.

$I_{ds} = Beta \times (V_{gs} - Vto)^2 \times (1 + Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$.

Assuming symmetry, in the reverse region, the drain and source swap roles and the expression becomes:

$I_{ds} = Beta \times (V_{gd} - Vto)^2 \times (1 - Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$.

The drain current is set to zero in either case if the junction voltage (V_{gs} or V_{gd}) drops below the threshold voltage Vto.

Junction Charge (Capacitance)

Two options are available for modeling the junction capacitance of a device: model the junction as a linear component (a constant capacitance); model the junction using a diode depletion capacitance model. If a non-zero value of Cgs is specified and Gscap is set to 1 (linear), the gate-source junction will be modeled as a linear component. Similarly, specifying a non-zero value for Cgd and Gdcap = 1 result in a linear gate-drain model. A non-zero value for either Cgs or Cgd together with Gscap =2 (junction) or Gdcap = 2 will force the use of the diode depletion capacitance model for that particular junction. Note that each junction is modeled independent of the other; therefore, it is possible to model one junction as a linear component while the other is treated nonlinearly. The junction depletion charge and capacitance equations are summarized below.

Gate-source junction

For $V_{gc} <$ Fc × Vbi

$$Q_{gs} = 2 \times V_{bi} \times Cgs\left[1 - \sqrt{1 - \frac{V_{gc}}{Vbi}}\right]$$

$$Capacitance_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{\sqrt{1 - \frac{V_{gc}}{Vbi}}}$$

For $V_{gc\{}$ } ≥ Fc × Vbi

$$Q_{gs} = 2 \times Vbi \times Cgs[1 - \sqrt{1 - Fc}] + \frac{Cgs}{(1 - Fc)^{3/2}}$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times (V_{gc} - Fc \times Vbi) + \frac{V_{gc}^2 - (Fc \times Vbi)^2}{4 \times Vbi}\right]$$

$$Capacitance_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gc}}{2 \times Vbi}\right]$$

Gate-drain junction

For $V_{gd} <$ Fc × Vbi

$$Q_{gd} = 2 \times Vbi \times Cgd \times \left[1 - \sqrt{1 - \frac{V_{gd}}{Vbi}}\right]$$

$$Capacitance_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{\sqrt{1 - \frac{V_{gd}}{Vbi}}}$$

For $V_{gd} \geq$ Fc × Vbi

$$Q_{gd} = 2 \times Vbi \times Cgd[1 - \sqrt{1 - Fc}] + \frac{Cgd}{(1 - Fc)^{3/2}}$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times (V_{gd} - Fc \times Vbi) + \frac{V_{gd}^2 - (Fc \times Vbi)^2}{4 \times Vbi}\right]$$

$$Capacitance_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{(1-Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gd}}{2 \times Vbi}\right]$$

Gate forward conduction and breakdown

Agilent's implementation of the Curtice quadratic model provides a few options for modeling gate conduction current between the gate-source and gate-drain junctions. The simplest model is that proposed by Curtice for his cubic polynomial model (see Curtice3). This model assumes an *effective value* of forward bias resistance Rf and an approximate breakdown resistance R1. With model parameters Gsfwd = 1 (linear) and Rf reset to non-zero, gate-source forward conduction current is given by:

I_{gs} = (V_{gs} - Vbi)/Rf when $V_{gs} > Vbi$

= 0 when $V_{gs} \leq Vbi$.

If Gsfwd = 2 (diode), the preceding expression for I_{gs} is replaced with the following diode expression:

$$I_{gs} = Is \times \left[exp\left(\frac{V_{gs}}{N \times v_t}\right) - 1\right]$$

Similarly, with parameter Gdfwd = 1 (linear) and Rf set to non-zero, gate-drain forward conduction current is given by:
$I_{gd} = (V_{gd} - Vbi)/Rf$ when $V_{gd} > Vbi$

= 0 when $V_{gd} \leq Vbi$.

If Gdfwd is set to 2 (diode), the preceding expression for Igd is replaced with a diode expression:

$$I_{gd} = Is \times \left[exp\left(\frac{V_{gd}}{N \times v_t}\right) - 1\right]$$

The reverse breakdown current (I_{dg}) is given by the following expression if R1 is set non-zero and Gdrev = 1 (linear):
$I_{gd} = V_{dg} - V_b)/R1$ when $V_{dg} \geq V_b$ and $V_b > 0$

= 0 when $V_{dg} < V_b$ or $V_b \leq 0$

$V_b = Vbr + R2 \times I_{ds}$
If Gdrev is set to 2, the preceding Igd expression is replaced with a diode expression:

$$I_{gd} = -Ir \times \left[exp\left(\frac{Vdg - Vb}{Vjr}\right) - 1\right]$$

With Gsrev -= 1 (linear) and R1 set to non-zero, the gate-source reverse breakdown current Igs is given by the following expression:

I_{gs} = (V_{sg} - Vb)/R1 when V_{sg} ≥ Vbi and Vb > 0

= 0 when V_{sg} £ Vbi or Vb ≤ 0

If Gsrev is set to 2, the preceding Igs expression is replaced with a diode expression.

$$I_{gs} = -Ir \times \left[exp\left(\frac{Vsg - Vb}{Vjr}\right) - 1\right]$$

When the diode equations are both enabled, the DC model is symmetric with respect to the drain and source terminals. The AC model will also be symmetric if, in addition to the latter, Cgs=Cgd.

Time delay

This implementation models the delay as an ideal time delay. In the time domain, the drain source current for the ideal delay is given by:

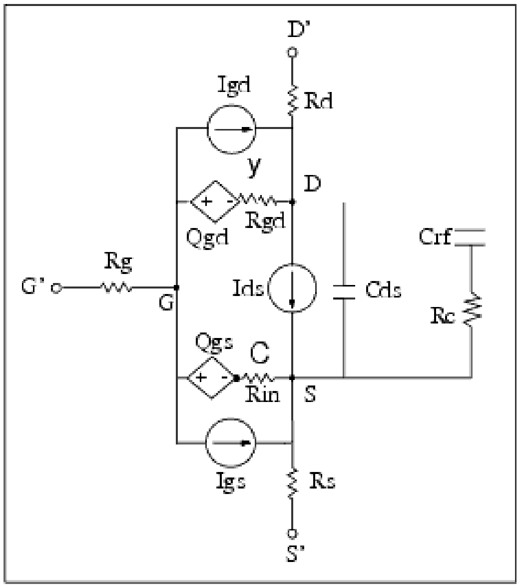
$I_{ds}(t) = I_{ds}(V_j(t - Tau), V_{ds}(t))$

where $V_j = V_{gs}$ or $V_j = V_{gd}$ (depending on whether V_{ds} is positive or negative). In the frequency domain, only the transconductance is impacted by this delay and the familiar expression for transconductance is obtained

$y_m = g_m \times exp(-j \times \omega \times Tau)$

High-frequency output conductance

The series-RC network in Curtice2_Model Schematic is comprised of the parameters Crf and Rc and is included to provide a correction to the AC output conductance at a specific bias condition. At a frequency high enough such that CRF is an effective short, the output conductance of the device can be increased by the factor 1/Rc. (For more on this, see Reference [2].)



Curtice2_Model Schematic

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation current Is scales as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

The gate depletion capacitances Cgs and Cgd vary as:

$$Cgs^{NEW} = Cgs\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

$$Cgd^{NEW} = Cgd\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.

The gate junction potential Vbi varies as:

$$Vbi^{NEW} = \frac{Temp}{Tnom} \times Vbi + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

where n_i is the intrinsic carrier concentration for silicon, calculated at the appropriate temperature.

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

The transconductance Beta varies as:

$$Beta^{NEW} = Beta \times 1.01^{Betatce(Temp - Tnom)}$$

If Betatc = 0 and Idstc ≠ 0

$Ids^{NEW} = Ids \times (1 + Idstc \times (Temp - Tnom))$

Noise Model

Thermal noise generated by resistors Rg, Rs, and Rd is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Parameters P, R, and C model drain and gate noise sources.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P + 4kTg_m\ PFnc\ /f + Kf\ Ids^{Af}\ /f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^{\ 2}\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega\sqrt{PR}\ C$$

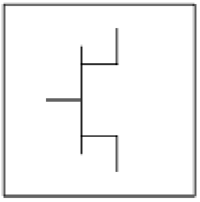
For Series IV compatibility, set P=2/3, R=0, C=0, and Fnc=0; copy Kf, Af, and Ffe from the Series IV model.

References

1. W. R. Curtice, "A MESFET model for use in the design of GaAs integrated circuits," *IEEE Trans Microwave Theory Tech* , vol. MTT-28, pp. 448-456, May 1980.
2. C. Camacho-Penalosa and C.S. Aitchison, "Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies," *Electron. Lett.,* Vol. 21, pp. 528-529, June 6, 1985.
3. P. Antognetti and G. Massobrio, *Semiconductor device modeling with SPICE* , New York: McGraw-Hill, Second Edition 1993.
4. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Curtice3_Model (Curtice-Cubic GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	2
Beta2	Coefficient for pinch-off change with respect to Vds	1/V	0.0
Rds0 †††	DC D-S resistance at Vgs=0	Ohm	0
Vout0	output voltage (Vds) at which A0, A1, A2, A3 were evaluated	V	0
Vdsdc	Vds at Rds0 measured bias	V	0
Tau	transit time under gate	sec	0.0
Gamma	current saturation	1/V	2.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Idstc	Ids temperature coefficient	None	0
A0 †, ††	cubic polynomial Ids equation coefficient 1	A	0
A1 †, ††	cubic polynomial Ids equation coefficient 2	A/V	0
A2 †, ††	cubic polynomial Ids equation coefficient 3	A/V^2	0
A3 †, ††	cubic polynomial Ids equation coefficient 4	A/V^3	0
Vtotc	VTO temperature coefficient	V/°C	0.0
Betatce	BETA Exponential Temperature Coefficient	%/°C	0.0
Rin †††	channel resistance	Ohm	0.0
Rf †††	gate-source effective forward-bias resistance	Ohm	infinity ‡
Fc	forward-bias depletion capacitance coefficient (diode model)	None	0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs ††	zero-bias gate-source capacitance	F	0.0

Cgd [††]	zero-bias gate-drain capacitance	F	0.0
Rgd [†††]	gate drain resistance	Ohm	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Rd [††]	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs [†††]	source ohmic resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds [††]	drain-source capacitance	F	0.0
Crf [††]	with Rds, models frequency dependent output conductance	F	0.0
Rds [†††]	additional output resistance for RF operation	Ohm	0.0
Gsfwd	0=none, 1=linear, 2=diode	None	linear
Gsrev	0=none, 1=linear, 2=diode	None	None
Gdfwd	0=none, 1=linear, 2=diode	None	None
Gdrev	0=none, 1=linear, 2=diode	None	linear
R1 [†††]	approximate breakdown resistance	Ohm	infinity [‡]
R2 [†††]	resistance relating breakdown voltage to channel current	Ohm	fixed at infinity [‡]
Vbi [†]	built-in gate potential	V	0.85
Vbr	gate-drain junction reverse bias breakdown voltage (gate- source junction reverse bias breakdown voltage with Vds < 0)	V	1e100
Vjr	breakdown junction potential		0.025
Is [†] [††]	gate junction saturation current (diode model)	A	1.0e-14
Ir	gate reverse saturation current	A	1.0e-14
Xti	Saturation Current Temperature Exponent	None	3.0
Eg	energy gap for temperature effect on Is	None	1.11
N	gate junction emission coefficient (diode model)	None	1
A5	time delay proportionality constant for Vds	None	fixed at 0.0
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 3)	A	defaults to Imax
Taumdl	Use 2nd order Bessel polynomial to model tau effect in transient: yes or no	None	no
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate-drain noise correlation coefficient	None	0.9
Vto	(not used in this model)	None	None
wVgfwd	gate junction forward bias (warning)	V	None
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None

wPmax	maximum power dissipation (warning)	W	None
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
AllParams	DataAccessComponent for file-based model parameter values	None	None
† Parameter value varies with temperature based on model Tnom and device Temp. †† Parameter value scales with Area. ††† Parameter value scales inversely with Area. ‡ A value of 0.0 is interpreted as infinity.			

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. The Curtice cubic model is based on the work of Curtice and Ettenberg. Curtice3_Model contains most of the features described in Curtice's original paper plus some additional features that may be turned off. The following subsections review the highlights of the model. Refer to Curtice's paper [1] for more information.
3. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
4. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

Equations/Discussion

Drain-Source Current

Drain current in Curtice3_Model is calculated with the following expression:

$$I_{ds} = I_{dso} \times \tanh(\mathrm{Gamma} \times V_{ds}),\ \mathrm{Tau}_{NEW} = \mathrm{Tau} + A5 \times Vds$$

where:

$$I_{dso} = [A0 + A1 \times V_1 + A2 \times V_1^2 + A3 \times V_1^3\ ] + (Vds - Vdsdc)/Rds0$$

$$V_1 = V_{gs}(t - \mathrm{Tau}_{NEW}) \times (1 + \mathrm{Beta2} \times (\mathrm{Vout0} - V_{ds})),\ \text{when } V_{ds} \geq 0.0\ \mathrm{V}$$

$$V_1 = V_{gd}(t - \mathrm{Tau}_{NEW}) \times (1 + \mathrm{Beta2} \times (\mathrm{Vout0} + V_{ds})),\ \text{when } V_{ds} < 0.0\ \mathrm{V}$$

The latter results in a symmetrical drain-source current that is continuous at V_{ds}=0.0 V.

For values of V below the internal calculated maximum pinchoff voltage Vpmax, which is

1

the voltage at the local minimum of the function:

$A0 + A1 \times n + A2 \times n^2 + A3 \times n^3$

I_{dso} is replaced with the following expression:

$I_{dso} = [A0 + A1 \times Vpmax + A2 \times Vpmax^2 + A3 \times Vpmax^3] + (Vds - Vdsdc)/Rds0$

If the I_{dso} value is negative (for $V_{ds} > 0.0V$), current is set to 0.

This implementation models the delay as an ideal time delay.

Note
When Rds0 is defaulted to 0, the term (Vds − Vdsdc)/Rds0 is simply ignored and there is no divide by zero.

Junction Charge (Capacitance)

Two options are provided for modeling the junction capacitance of a device: to model the junction as a linear component (a constant capacitance); to model the junction using a diode depletion capacitance model. If a non-zero value of Cgs is specified and Gscap is set to 1 (linear), the gate-source junction will be modeled as a linear component. Similarly, specifying a non-zero value for Cgd and Gdcap=1 result in a linear gate-drain model. A non-zero value for either Cgs or Cgd together with Gscap=2 (junction) or Gdcap=2 will force the use of the diode depletion capacitance model for that particular junction. Note that each junction is modeled independent of the other; therefore, it is possible to model one junction as a linear component while the other is treated nonlinearly. The junction depletion charge and capacitance equations are summarized next.

Gate-Source Junction

For $V_{gc} < Fc \times Vbi$

$$Q_{gs} = 2 \times V_{bi} \times Cgs \times \left[1 - \sqrt{1 - \frac{V_{gc}}{Vbi}}\right]$$

$$Capacitance_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{\sqrt{1 - \frac{V_{gc}}{Vbi}}}$$

For $V_{gc} \geq Fc \times Vbi$

$$Q_{gs} = 2 \times V_{bi} \times Cgs \times [1 - \sqrt{1 - Fc}] + \frac{Cgs}{(1 - Fc)^{3/2}}$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times (V_{gc} - Fc \times Vbi)\left(\frac{V_{gc}^2 - (Fc \times Vbi)^2}{4 \times Vbi}\right)\right]$$

$$Capacitance_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gc}}{2 \times Vbi}\right]$$

Gate-Drain Junction

For $V_{gd} < Fc \times Vbi$

$$Q_{gd} = 2 \times V_{bi} \times Cgd \times \left[1 - \sqrt{1 - \frac{V_{gd}}{Vbi}}\right]$$

$$Capacitance_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{\sqrt{1 - \frac{V_{gd}}{Vbi}}}$$

For $V_{gd} \geq Fc \times Vbi$

$$Q_{gd} = 2 \times V_{bi} \times Cgd \times \left([1 - \sqrt{1 - Fc}] + \frac{Cgd}{(1 - Fc)^{3/2}}\right)$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times \left(V_{gd} - F(c \times Vbi) + \frac{V_{gd}^2 - (Fbi)^2}{4 \times Vbi}\right)\right]$$

$$Capacitance_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gd}}{2 \times Vbi}\right]$$

Gate Forward Conduction and Breakdown

Agilent's implementation of the Curtice quadratic model provides a few options for modeling gate conduction current between the gate-source and gate-drain junctions. The simplest model is that proposed by Curtice for his cubic polynomial model (see Curtice3). This model assumes an *effective value* of forward bias resistance Rf and an approximate breakdown resistance R1. With model parameters Gsfwd = 1 (linear) and Rf reset to non-zero, gate-source forward conduction current is given by:

$I_{gs} = (V_{gs} - Vbi)/Rf$ when $V_{gs} > Vbi$

$= 0$ when $V_{gs} \leq Vbi$.

If Gsfwd = 2 (diode), the preceding expression for I is replaced with the following diode gs

expression:

$$I_{gs} = Is \times \left[exp\left(\frac{V_{gs}}{N \times v_t} \right) - 1 \right]$$

Similarly, with parameter Gdfwd = 1 (linear) and Rf set to non-zero, gate-drain forward conduction current is given by:

I_{gd} = (V_{gd} - Vbi)/Rf when V_{gd} > Vbi

= 0 when $V_{gd} \leq$ Vbi.

If Gdfwd is set to 2 (diode), the preceding expression for Igd is replaced with a diode expression:

$$I_{gd} = Is \times \left[exp\left(\frac{V_{gd}}{N \times v_t} \right) - 1 \right]$$

The reverse breakdown current (I_{dg}) is given by the following expression if R1 is set non-zero and Gdrev = 1 (linear):

I_{gd} = V_{dg} - V_b)/R1 when $V_{dg} \geq V_b$ and $V_b > 0$

= 0 when $V_{dg} < V_b$ or $V_b \leq 0$

V_b = Vbr + R2 × I_{ds}

If Gdrev is set to 2, the preceding Igd expression is replaced with a diode expression:

$$I_{gd} = -Ir \times \left[exp\left(\frac{Vdg - Vb}{Vjr} \right) - 1 \right]$$

With Gsrev -= 1 (linear) and R1 set to non-zero, the gate-source reverse breakdown current Igs is given by the following expression:

I_{gs} = (V_{sg} - Vb)/R1 when $V_{sg} \geq$ Vbi and Vb > 0

= 0 when $V_{sg} \leq$ Vbi or Vb ≤ 0

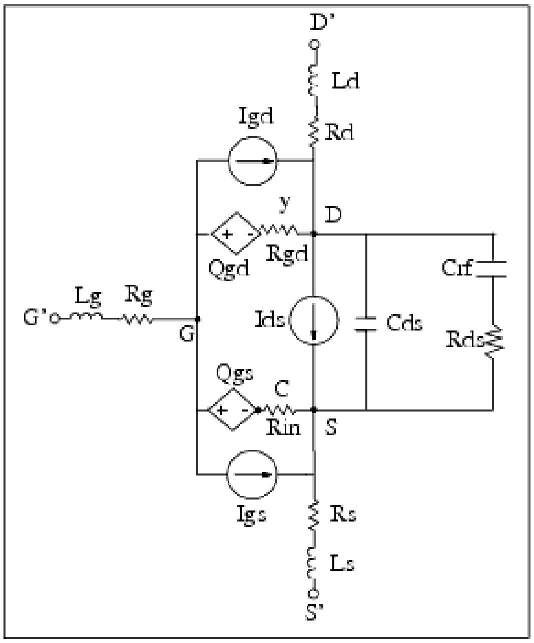
If Gsrev is set to 2, the preceding Igs expression is replaced with a diode expression.

$$I_{gs} = -Ir \times \left[exp\left(\frac{Vsg - Vb}{Vjr} \right) - 1 \right]$$

When the diode equations are both enabled, the DC model is symmetric with respect to the drain and source terminals. The AC model will also be symmetric if, in addition to the latter, Cgs=Cgd.

High-Frequency Output Conductance

Curtice3_Model provides the user with two methods of modeling the high frequency output conductance. The series-RC network dispersion model (Curtice Cubic Model) is comprised of the parameters Crf and Rds and is included to provide a correction to the AC output conductance at a specific bias condition. At a frequency high enough such that Crf is an effective short, the output conductance of the device can be increased by the factor 1/Rds. (Also see [2]).



Curtice Cubic Model

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation current Is scales as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

The gate depletion capacitances Cgso and Cgdo vary as:

$$Cgs^{NEW} = Cgs\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

$$Cgd^{NEW} = Cgd\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

where *y* is a function of junction potential and energy gap variation with temperature.

The gate junction potential Vbi varies as:

$$Vbi^{NEW} = \frac{Temp}{Tnom} \times Vbi + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

where n_i is the intrinsic carrier concentration for silicon, calculated at the appropriate temperature.

The cubic polynomial coefficients A0, A1, A2, and A3 vary as:

$$\Delta = Vtotc(Temp - Tnom)$$

$$A0^{NEW} = (A0 - \Delta \times A1 + \Delta^2 \times A2 - \Delta^3 \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A1^{NEW} = (A1 - 2\Delta \times A2 + 3\Delta^2 \times A3 - \Delta^3 \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A2^{NEW} = (A2 - 3\Delta \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A3^{NEW} = (A3) \times 1.01^{Betatce(Temp - Tnom)}$$

If Betatc = 0 and Idstc ≠ 0

$Ids^{NEW} = Ids \times (1 + Idstc \times (Temp - Tnom))$

Noise Model

Thermal noise generated by resistors Rg, Rs and Rd is characterized by the spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Parameters P, R, and C model drain and gate noise sources.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P + 4kTg_m\ PFnc\ /f + Kf\ Ids^{Af}\ /f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^2\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega\sqrt{PR}\ C$$

For Series IV compatibility, set P=2/3, R=0, C=0, and Fnc=0; copy Kf, Af, and Ffe from the Series IV model.

Calculation of Vto Parameter

The Vto parameter is not used in this model. Instead, it is calculated internally to avoid the discontinuous or non-physical characteristic in ids versus vgs if A0, A1, A2, A3 are not properly extracted.

For a given set of As, ADS will try to find the maximum cutoff voltage (Vpmax), which satisfies the following conditions:

$f(Vpmax) = A0 + A1 \times Vpmax + A2 \times Vpmax^2 \times 2 + A3 \times Vpmax^3 \times 3 \leq 0$
first derivative of f(Vpmax) = 0 (inflection point)
second derivative of f(Vpmax) > 0 (this is a minimum)

If Vpmax cannot be found, a warning message is given *cubic model does not pinch off* . During analysis, the following are calculated:

$vc = vgs \times (1 + Beta2 \times (Vout0 - vds))$
$ids = ((A0 + A1 \times vc + A2 \times vc\times^2 + A3 \times vc\times^3) + (vds - Vdsdc) / Rds0) \times \tanh(Gamma \times vds)$

If ids < 0 then sets ids = 0.

If ids > 0 and Vc ≤ Vpmax then calculates ivc as follows:

$ivc = (f(Vpmax) + (vds - Vdsdc) / Rds0) \times \tanh(Gamma \times vds)$
If ivc > 0 then sets ids = ivc and gives a warning message *Curtice cubic model does not pinch off, Ids truncated at minimum*.

else set ids = 0

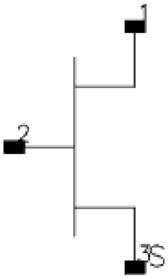
To ensure the model is physical and continuous, it is important to obtain a meaningful set of As that Vpmax can be found.

References

1. W. R. Curtice and M. Ettenberg, "A nonlinear GaAsFET model for use in the design of output circuits for power amplifiers," *IEEE Trans of Microwave Theory Tech* , vol. MTT-33, pp. 1383-1394, Dec. 1985.
2. C. Camacho-Penalosa and C.S. Aitchison, "Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies," *Electron. Lett.,* Vol. 21, pp. 528-529, June 6, 1985.
3. P. Antognetti and G. Massobrio, *Semiconductor device modeling with SPICE,* New York: McGraw-Hill, Second Edition 1993.
4. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

EE_FET3 (EEsof Scalable Nonlinear GaAsFet, Second Generation)

Symbol



Parameters

Name	Description	Units	Default
Model	name of an EE_FET3_Model	None	EEFET3M1
Ugw	unit gate width	None	0.0
N	number of gate fingers	None	1
Temp	device operating temperature	°C	25
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Range of Usage

Ugw > 0
N > 0

Notes/Equations

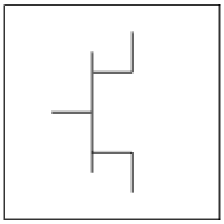
1. Ugw and N are used for scaling device instance as described in the EE_FET3_Model information.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	siemens
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	siemens
Ggs	Gate-source conductance	siemens
Ggd	Gate-drain conductance	siemens
dIgd_dVgs	(dIgd/dVgs)	siemens
Cgc	Gate-source capacitance (dQgc/dVgc)	farads
dQgc_dVgy	(dQgc/dVgy)	farads
Cgy	Gate-drain capacitance (dQgy/dVgy)	farads
dQgy_dVgc	(dQgy/dVgc)	farads
Vgs	Gate-source voltage	volts
Vds	Gate-drain voltage	volts

EE_FET3_Model (EEsof Scalable Nonlinear GaAsFet Model)

Symbol



Parameters

Name	Description	Units	Default
Vto	zero bias threshold	V	-1.5
Gamma	Transconductance	1/V	0.05
Vgo	gate-source voltage where transconductance is a maximum	V	0.0
Vdelt	controls linearization point for transconductance characteristic	V	0.0
Vch	gate-source voltage where Gamma no longer affects I-V curves	V	1.0
Gmmax	peak transconductance	S	70.0e-03
Vdso	Drain voltage where Vo dependence is nominal	V	2.0
Vsat	drain-source current saturation	V	1.0
Kapa	output conductance	S	1.0
Peff	channel to backside self-heating	W	2.0
Vtso	subthreshold onset voltage	V	-10.0
Is	gate junction reverse saturation current	A	1.0e-14
N	gate junction ideality factor	None	1.0
Ris	source end channel resistance	Ohm	0.0
Rid	drain end channel resistance	Ohm	0.0
Tau	gate transit time delay	sec	0.0
Cdso	drain-source inter-electrode capacitance	F	80.0e-15
Rdb	dispersion source output impedance	Ohm	1.0e+9
Cbs	trapping-state capacitance	F	1.6e-13
Vtoac	zero bias threshold (AC)	V	-1.5
Gammaac	Vds dependent threshold (AC)	1/V	0.05
Vdeltac	controls linearization point for transconductance characteristic (AC)	V	0.0
Gmmaxac	peak transconductance (AC)	S	60.0e-03
Kapaac	output conductance (AC)	S	0.0
Peffac	channel to backside self-heating (AC)	W	10.0
Vtsoac	subthreshold onset voltage (AC)	V	-10.0
Gdbm	additional d-b branch conductance at Vds = Vdsm	0.0	

Kdb	controls Vds dependence of additional d-b branch conductance.	None	0.0
Vdsm	voltage where additional d-b branch conductance becomes constant	V	1.0
C11o	maximum input capacitance for Vds=Vdso and Vdso>Deltds	F	0.3e-12
C11th	minimum (threshold) input capacitance for Vds=Vdso	F	0.03e-12
Vinfl	inflection point in C11-Vgs characteristic	V	-1.0
Deltgs	C11th to C110 transition voltage	V	0.5
Deltds	linear region to saturation region transition	V	1.0
Lambda	C11-Vds characteristic slope	1/V	1.0
C12sat	input transcapacitance for Vgs=Vinfl and Vds>Deltds	F	0.03e-12
Cgdsat	gate drain capacitance for Vds>Deltds	F	0.05e-12
Kbk	breakdown current coefficient at threshold	None	0.0
Vbr	drain-gate voltage where breakdown source begins conducting	V	15.0
Nbr	breakdown current exponent	None	2.0
Idsoc	open channel (maximum) value of Ids	A	100.0e-03
Rd	drain contact resistance	Ohm	1.0
Rs	source contact resistance	Ohm	1.0
Rg	gate metallization resistance	Ohm	1.0
Ugw	unit gate width of device	None	0.0
Ngf	number of device gate fingers	None	1.0
Tnom	Nominal ambient temperature	°C	25.0
Rgtc	linear temperature coefficient for RG	1/°C	0.0
Rdtc	linear temperature coefficient for RD	1/°C	0.0
Rstc	linear temperature coefficient for RS	1/°C	0.0
Vtotc	Vto temperature coefficient	V/°C	0.0
Gmmaxtc	Gmmax temperature coefficient	S/°C	0.0
Gammatc	Gamma temperature coefficient	None	0.0
Vinfltc	Vinfl temperature coefficient	V/°C	0.0
Vtoactc	Vtoac temperature coefficient	V/°C	0.0
Gmmaxactc	Gmmaxac temperature coefficient	S/°C	0.0
Gammaactc	Gammaac temperature coefficient	None	0.0
Xti	Temperature Exponent for Saturation Current	None	3.0
wVgfwd	gate junction forward bias (warning)	V	None
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Notes

1. This model supplies values for an EE_FET3 device.
2. To prevent numerical problems, the setting of some model parameters to 0 is trapped by the simulator. The parameter values are changed:
   Rd = 10^{-4}
   Rs = 10^{-4}
   Rg = 10^{-4}

Ris = 10^{-4}
Rid = 10^{-4}
Vsat = 0.1
Peff = 10^{-6}
Peffac = 10^{-6}
Deltds = 0.1
Deltgs = 0.1
Idsoc = 0.1
Is = 10^{-50}

3. Model parameters such as Ls, Ld, and Lg (as well as other package related parameters that are included as part of the output from the EEFET3 IC-CAP model file) are not used by the EE_FET3 device in the simulator. Only those parameters listed are part of the EE_FET3 device. Any extrinsic devices must be added externally by the user.

Equations/Discussion

EE_FET3 is an empirical analytic model that was developed by Agilent EEsof for the express purpose of fitting measured electrical behavior of GaAs FETs. The model represents a complete redesign of the previous generation model EEFET1-2 and includes the following features:

- Accurate isothermal drain-source current model fits virtually all processes.
- Self-heating correction for drain-source current.
- Improved charge model more accurately tracks measured capacitance values.
- Dispersion model that permits simultaneous fitting of high-frequency conductances and DC characteristics.
- Improved breakdown model describes gate-drain current as a function of both V_{gs} and V_{ds}.
- Well-behaved (non-polynomial) expressions permit accurate extrapolations outside of the measurement range used to extract the model.

The model equations were developed concurrently with parameter extraction techniques to ensure the model would contain only parameters that were extractable from measured data. Although the model is amenable to automated parameter extraction techniques, it was designed to consist of parameters that are easily estimated (visually) from measured data such as g_m -V_{gs} plots. The increased number of model parameters is commensurate with the improvement in accuracy as compared with other popular empirical models. Since the model equations are all well-behaved analytic expressions, EE_FET3 possesses no inherent limitations with respect to its usable power range. Agilent EEsof's IC-CAP program provides the user with the capability of extracting EEFET3 models from measured data.

Drain-Source Current

The drain-source current model in EE_FET3 is comprised of various analytic expressions that were developed through examination of g_m vs. bias plots on a wide class of devices from various manufacturers. The expressions below are given for V_{ds} > 0.0V although the model is equally valid for $V_{ds} < 0.0V$. The model assumes the device is symmetrical, and one need only replace V_{gs} with V_{gd} and V_{ds} with $-V_{ds}$ in order to obtain the reverse region ($V_{ds} < 0.0V$) equations. The g_m, g_{ds} and I_{ds} equations take on four different forms depending on the value of V_{gs} relative to some of the model parameters. The I_{ds} expression is continuous through at least the second derivative everywhere.

if $V_{gs} \geq V_g$ and $V_{delt} \leq 0.0$

$$g_{mo} = Gmmax\{1 + Gamma(Vdso - V_{ds})\}$$

$$I_{dso} = Gmmax\left\{V_x(V_{gs}) - \frac{(Vgo + Vto)}{2} + Vch\right\}$$

$$g_{dso} = -Gmmax(Gamma(V_{gs} - Vch))$$

else if $V_{Delt} > 0.0$ and $V_{gs} > V_{gb}$

$$g_{mo} = g_{mm}(V_{gb}) + m_{g_{mm}} \times (V_{gs} - V_{gb})$$

$$I_{dso} = g_{mm}(V_{gb}) \times (V_{gs} - V_{gb}) + \frac{m_{g_{mm}}}{2}(V_{gs} - V_{gb})^2 + I_{dsm}(V_{gb})$$

$$g_{dso} = \frac{\partial(g_{mm}(V_{gb}))}{\partial V_{ds}}(V_{gs} - V_{gb}) + \frac{1}{2}(V_{gs} - V_{gb})^2 \times \frac{\partial m_{g_{mm}}}{\partial V_{ds}} - \frac{\partial V_{gb}}{\partial V_{ds}} g_{mo}$$

else if $V_{gs} \leq V_t$

$$g_{mo} = 0.0$$

$$I_{dso} = 0.0$$

$$g_{dso} = 0.0$$

else

$$g_{mo} = g_{mm}(V_{gs})$$

$$I_{dso} = I_{dsm}(V_{gs})$$

$$g_{dso} = -\frac{Gmmax}{2} Gamma(V_{gs} - Vch)$$

$$\times \left\{\cos\left[\pi \times \frac{V_x(V_{gs}) - (Vgo - Vch)}{Vto - Vgo}\right] + 1\right\}$$

where:

$$g_{mm}(V) = \frac{Gmmax}{2}[1 + Gamma(Vdso - V_{ds})]$$

$$\times\left\{\cos\left[\pi\times\frac{V_x(V)-(Vgo-Vch)}{Vto-Vgo}\right]+1\right\}$$

$$I_{dsm}(V) = \frac{Gmmax}{2}\Bigg(((Vto-Vgo)/\pi)\sin\left[\pi\times\frac{V_x(V)-(Vgo-Vch)}{Vto-Vgo}\right]$$

$$+V_x(V)-(Vto-Vch)\Bigg)$$

$$V_x(V) = (V-Vch)[1+Gamma(Vdso-V_{ds})]$$

$$V_g = \frac{Vgo-Vch}{1+Gamma(Vdso-V_{ds})}+Vch$$

$$V_t = \frac{Vto-Vch}{1+Gamma(Vdso-V_{ds})}+Vch$$

$$V_{gb} = \frac{(Vgo-Vdelt)-Vch}{1+Gamma(Vdso-V_{ds})}+Vch$$

$$m_{g_{mm}} = \left.\frac{\partial g_{mm}}{\partial V}\right|_{V=V_{gb}}$$

$$= -\frac{Gmmax\pi}{2(Vto-Vgo)}[1+Gamma(Vdso-V_{ds})]^2$$

$$\times\sin\left[-\pi\times\frac{Vdelt}{Vto-Vgo}\right]$$

$$g_{mm}(V_{gb}) = \frac{Gmmax}{2}[1+Gamma(Vdso-V_{ds})]$$

$$\times\left\{\cos\left[-\pi\times\frac{Vdelt}{Vto-Vgo}\right]+1\right\}$$

$$I_{dsm}(V_{gb}) = \frac{Gmmax}{2}\Bigg(((Vto-Vgo)/\pi)\sin\left[-\pi\times\frac{Vdelt}{Vto-Vgo}\right]$$

$$+(Vgo-Vdelt-Vto)\Bigg)$$

$$\frac{\partial(g_{mm}(V_{gb}))}{\partial V_{ds}} = -\frac{Gmmax}{2}Gamma\left\{\cos\left[-\pi\times\frac{Vdelt}{Vto-Vgo}\right]+1\right\}$$

$$\frac{\partial m_{g_{mm}}}{\partial V_{ds}} = \frac{Gmmax\pi}{(Vto - Vgo)}(Gamma)[1 + Ganna(Vdso - V_{ds})]$$

$$\times \sin\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right]$$

$$\frac{\partial V_{gb}}{\partial V_{ds}} = \frac{(Vgo - Vdelt) - Vch}{[1 + Gamma(Vdso - V_{ds})]^2} \times Gamma$$

The preceding relations for I_{dso}, g_{mo} and g_{dso} can now be substituted in the following equations that model the current saturation and output conductance. This portion of the model can be recognized from the work of Curtice [1].

$$g'_m = g_{mo}(1 + Kapa \times V_{ds})\tanh\left(\frac{3V_{ds}}{Vsat}\right)$$

$$I'_{ds} = I_{dso}(1 + Kapa \times V_{ds})\tanh\left(\frac{3V_{ds}}{V(sat)}\right)$$

$$g'_{ds} = \{g_{dso}(1 + Kapa \times V_{ds}) + I_{dso}Kapa\}\tanh\left(\frac{3V_{ds}}{Vsat}\right)$$

$$+ I_{dso} \times \frac{3(1 + Kapa \times V_{ds})}{Vsat}\operatorname{sech}^2\left(\frac{3V_{ds}}{Vsat}\right)$$

These expressions do an excellent job of fitting GaAs FET I-V characteristics in regions of low power dissipation; they will also fit pulsed (isothermal) I-V characteristics. In order to model negative conductance effects due to self-heating, the thermal model of Canfield was incorporated [2]. With this final enhancement, the DC expressions for I_{ds} and associated conductances become:

$$I_{ds} = \frac{I'_{ds}}{1 + \frac{P_{diss}}{Peff}}$$

$$g_m = \frac{g'_m}{\left[1 + \frac{P_{diss}}{Peff}\right]^2}$$

$$g_{ds} = \frac{g'_{ds} - \frac{I'^{2}_{ds}}{Peff}}{\left[1 + \frac{P_{diss}}{Peff}\right]^{2}}$$

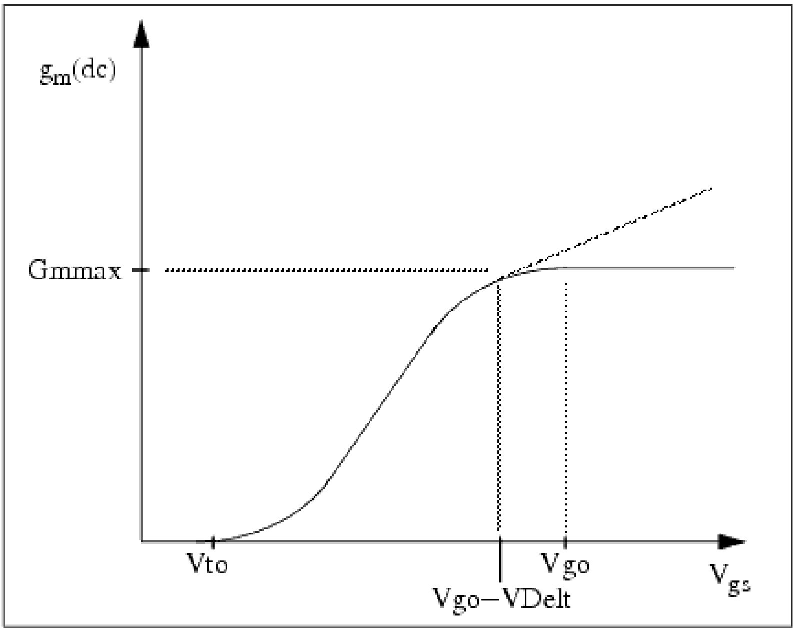
where:

$$P_{diss} = I'_{ds}V_{ds}$$

Qualitatively, operation of the drain-source model can be described as follows. The V_{ds} dependence of the equations is dominated by the parameters Vsat, Gamma, Kapa, and Peff. Isothermal output conductance is controlled by Gamma and Kapa. The impact of Gamma on output conductance is more significant near threshold. At V_{gs}=Vch, the output conductance is controlled only by Kapa. The parameter Peff provides a correction to the isothermal model for modeling the self-heating effects manifested as a negative resistance on the I-V curves. The parameter Vsat represents the drain-source voltage at which the current saturates and output conductance becomes a constant (approximately).

The overall impact of Vch on the I-V characteristics is second order at best, and many different values of Vch will provide good fits to I-V plots. For most applications encountered, it is our experience that the default value of 1.0V is an adequate value for Vch. Similar to Vch, Vdso is a parameter that should be set rather than optimized. At V_{ds} =Vdso, the drain-source model collapses to a single voltage dependency in V_{gs}. It is recommended that the user set Vdso to a typical V_{ds} operating point in saturation. At this point, many of the parameters can be extracted right off a I_{ds} -V_{gs} plot for V_{ds}=Vdso or preferably, a g_m(DC)-V_{gs} plot at V_{ds}=Vdso.

When V_{ds}=Vdso and Peff is set large (to disable the self-heating model), the significance of the parameters Vto, Vgo, Vdelt, Gmmax are easily understood from a plot of g_m(DC)−V_{gs}. Gmmax is the peak constant transconductance of the model that occurs at V_{gs}=Vgo. The parameter Vto represents the gate-source voltage where g_m goes to zero. If Vdelt is set to a positive value, then it causes the transconductance to become linear at V_{gs} = Vgo−Vdelt with a slope equal to that of the underlying cosine function at this voltage. The parameter definitions are shown in the following illustration.



EEFET3 g_m -V $_{gs}$ Parameters

Dispersion Current (Idb)

Dispersion in a GaAs MESFET drain-source current is evidenced by the observation that the output conductance and transconductance beyond some transition frequency is higher than that inferred by the DC measurements. A physical explanation often attributed to this phenomenon is that the channel carriers are subject to being trapped in the channel-substrate and channel-surface interfaces. Under slowly varying signal conditions, the rate at which electrons are trapped in these sites is equal to the rate at which they are emitted back into the channel. Under rapidly varying signals, the traps cannot follow the applied signal and the *high-frequency* output conductance results.

The circuit used to model conductance dispersion consists of the devices Rdb, Cbs (these linear devices are also parameters) and the nonlinear source $I_{db}(V_{gs}, V_{ds})$. The model is a large-signal generalization of the dispersion model proposed by Golio et al. [3]. At DC, the drain-source current is just the current I_{ds}. At high frequency (well above transition frequency), drain source current will be equal to I_{ds}(high frequency) = I_{ds}(dc) + I_{db}. Linearization of the drain-source model yields the following expressions for y_{21} and y_{22} of the intrinsic EE_FET3 model.

$$y_{21} = g_{dsgs} + g_{dbgs} - \frac{g_{dbgs}}{1 + j\omega \times Cbs(Rdb)}$$

$$y_{22} = g_{dsds} + g_{dbds} + \frac{1}{Rdb} - \frac{\left(g_{dbds} + \frac{1}{Rdb}\right)}{1 + j\omega \times Cbs(Rdb)}$$

where:

$$g_{dsgs} = \frac{\partial I_{ds}}{\partial V_{gs}}$$

$$g_{dsds} = \frac{\partial I_{ds}}{\partial V_{ds}}$$

$$g_{dbgs} = \frac{\partial I_{db}}{\partial V_{gs}}$$

$$g_{dbds} = \frac{\partial I_{db}}{\partial V_{ds}}$$

Evaluating these expressions at the frequencies ω=0 and ω=infinity produces the following results for transconductance and output conductance:

for ω=0,

$$Re[y_{21}] = g_m = g_{dsgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds}$$

for ω=infinity,

$$Re[y_{21}] = g_m = g_{dsgs} + g_{dbgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds} + g_{dbds} + \frac{1}{Rdb}$$

Between these two extremes, the conductances make a smooth transition, the abruptness of which is governed by the time constant τ_{disp} = Rdb × Cbs. The frequency f_0 at which the conductances are midway between these two extremes is defined as:

$$f_0 = \frac{1}{2\pi\tau_{disp}}$$

The parameter Rdb should be set large enough so that its contribution to the output conductance is negligible. Unless the user is specifically interested in simulating the device near f_0, the default values of Rdb and Cbs will be adequate for most microwave applications.

The EE_FET3 I_{ds} model can be extracted to fit either DC or AC characteristics. In order to simultaneously fit both DC I-V and AC conductances, EE_FET3 uses a simple scheme for modeling the I_{db} current source whereby different values of the same parameters can be used in the I_{ds} equations. The DC and AC drain-source currents can be expressed as follows:

$$I_{ds}^{dc}(Voltages, Parameters) = I_{ds}(Voltages, Gmmax, Vdelt, Vto, \mathrm{Gamma},$$

$$Kapa, Peff, Vtso, Vgo, Vch, Vdso, Vsat)$$

$$I_{ds}^{ac}(Voltages, Parameters) = I_{ds}(Voltages, Gmmaxac, Vdeltac, Vtoac,$$

$$Gammaac, Kappaac, Peffac, Vtsoac,$$

$$Vgo, Vch, Vdso, Vsat)$$

Parameters such as Vgo that do not have an AC counterpart (there is no Vgoac parameter) have been found to not vary significantly between extractions using DC measurements versus those using AC measurements. The difference between the AC and DC values of I_{ds}, plus an additional term that is a function of V_{ds} only, gives the value of I_{db} for the dispersion model

$$I_{db}(V_{gs}, V_{ds}) = I_{ds}^{ac}(V_{gs}, V_{ds}) - I_{ds}^{dc}(V_{gs}, V_{ds}) + I_{dbp}(V_{ds})$$

where I_{dbp} and its associated conductance are given by:

for V_{ds} > Vdsm and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}}\tan^{-1}((V_{ds} - Vdsm)\sqrt{Kdb(Gdbm)})$$

$$+ Gdbm(Vdsm)$$

$$g_{dbp} = \frac{Gdbm}{(Kdb(Gdbm(V_{ds} - Vdsm)^2 + 1))}$$

for V_{ds} < -Vdsm and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}}\tan^{-1}((V_{ds} + Vdsm)\sqrt{Kdb(Gdbm)})$$

$$-Gdbm \times Vdsm$$

$$g_{dbp} = \frac{Gdbm}{(Kdb(Gdbm(V_{ds} + Vdsm)^2 + 1))}$$

for $-Vdsm \leq V_{ds} \leq Vdsm$

or $Kdb = 0$:

$$I_{dbp} = Gdbm \times V_{ds}$$

$$g_{dbp} = Gdbm$$

By setting the 7 high-frequency parameters equal to their DC counterparts, the dispersion model reduces to $I_{db}=I_{dbp}$. Examination of the I_{dbp} expression reveals that the additional setting of Gdbm to 0 disables the dispersion model entirely. The I_{dbp} current is a function of V_{ds} only, and will impact output conductance only. However, the current function I_{ds}^{ac} will impact g_m and g_{ds}.

Therefore, the model is primarily to use g_m data as a means for tuning I_{ds}^{ac}.
Once this *fitting* is accomplished, Gdbm, Kdb and Vdsm can be tuned to optimize the g_{ds} fit.

Gate Charge Model

The EE_FET3 gate charge model was developed through careful examination of extracted device capacitances over bias. The model consists of simple closed form charge expressions whose derivatives fit observed bias dependencies in capacitance data. This capacitances data can be obtained directly from measured Y-parameter data.

$$C_{11} = \frac{im[y_{11}]}{\omega} = \frac{\partial q_g}{\partial V_{gs}}$$

$$C_{12} = \frac{im[y_{12}]}{\omega} = \frac{\partial q_g}{\partial V_{ds}}$$

The capacitance data is remarkably self-consistent. In other words, a single q_g function's derivatives will fit both C_{11} data and C_{12} data. The EE_FET3 gate charge expression is:

$$q_g(V_j, V_o) = \left[\frac{(C11o - C11th)}{2} g(V_j) + C11th(V_j - Vinfl)\right] \times [1 + Lambda(V_o - Vdso)] - C11sat \times V_o$$

where:

$$g(V_j) = V_j - Vinfl + \frac{Deltgs}{3}\log\left(\cosh\left(\frac{3}{Deltgs}(V_j - Vinfl)\right)\right)$$

This expression is valid for both positive and negative V_{ds}. Symmetry is forced through the following smoothing functions proposed by Statz [4]:

$$V_j = \frac{1}{2}\left(2V_{gs} - V_{ds} + \sqrt{V_{ds}^2 + Deltds^2}\right)$$

$$V_o = \sqrt{V_{ds}^2 + Deltds^2}$$

Differentiating the gate charge expression wrt V_{gs} yields the following expression for the gate capacitance C_{11}:

$$C_{11}(V_j, V_o) = \left[\frac{(C11o - C11th)}{2} \times g'(V_j) + C11th\right]$$

$$\times [1 + Lambda(V_o - Vdso)]$$

where:

$$g'(V_j) = \frac{dg(V_j)}{dV_j} = 1 + \tanh\left[\frac{3}{Deltds}(V_j - Vinfl)\right]$$

The gate transcapacitance C_{12} is defined as:

$$C_{12}(V_j, V_o) = \frac{\partial q_g}{\partial V_{ds}} = \frac{\partial q_g}{\partial V_j}\frac{\partial V_j}{\partial V_{ds}} + \frac{\partial q_g}{\partial V_o}\frac{\partial V_o}{\partial V_{ds}}$$

$$= C_{11}(V_j, V_o) \times \frac{1}{2}\left[\frac{V_{ds}}{\sqrt{V_{ds}^2 + Deltds^2}} - 1\right]$$

$$+ [[g'(V_j) + C11th(V_j - Vinfl)] \times Lambda(-C12sat)]$$

$$\times \frac{V_{ds}}{\sqrt{V_{ds}^2 + Deltds^2}}$$

The EE_FET3 topology requires that the gate charge be subdivided between the respective charge sources q_{gc} and q_{gy}. Although simulation could be performed directly from the nodal gate charge q_g, division of the charge into branches permits the inclusion of the resistances Ris and Rid that model charging delay between the depletion region and the channel. EE_FET3 assumes the following form for the gate-drain charge in saturation:

$$q_{gy}(V_{gy}) = Cgdsat(V_{gy} + q_{gyo})$$

which gives rise to a constant gate-drain capacitance in saturation. The gate-source charge q_{gc} can now be obtained by subtracting the latter from the gate charge equation.

Smoothing functions can then be applied to these expressions in saturation in order to extend the model's applicable bias range to all V_{ds} values.

These smoothing functions force symmetry on the q_{gy} and q_{gc} charges such that

$q_{gy} = q_{gc} = \frac{q_g}{2}$ at $V_{gc} = V_{gy}$. Under large negative V_{ds} (saturation at the source end of the device), q_{gy} and q_{gc} swap roles:

$$q_{gc}(V_{gc}) = \boldsymbol{Cgdsat}(V_{gc} + q_{gco})$$

The following continuous charge equations satisfy these constraints and are specified in terms of the gate charge.

$$q_{gy}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - \boldsymbol{Cgdsat} \times V_{gc}\} \times f_2$$

$$+ \boldsymbol{Cgdsa} \times V_{gy} \times f_1$$

$$q_{gc}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - C(\boldsymbol{gdsat} \times V_{gy})\} \times f_1$$

$$+ \boldsymbol{Cgdsat} \times V_{gc} \times f_2$$

where f_1 and f_2 are smoothing functions defined by

$$f_1 = \frac{1}{2}\left[1 + \tanh\left(\frac{3}{\boldsymbol{Deltds}}(V_{gc} - V_{gy})\right)\right]$$

and

$$f_2 = \frac{1}{2}\left[1 - \tanh\left(\frac{3}{\boldsymbol{Deltds}}(V_{gc} - V_{gy})\right)\right]$$

The capacitances associated with these *branch* charge sources can be obtained through differentiation of the q_{gc} and q_{gy} equations and by application of the chain rule to capacitances C_{11} and C_{12}. The gate charge derivatives re-formulated in terms of V_{gc} and V_{gy} are:

$$C_{ggy} = \frac{\partial q_g}{\partial V_{gy}} = -C_{12}(V_{gc}, V_{gc} - V_{gy})$$

$$C_{ggc} = \frac{\partial q_g}{\partial V_{gc}} = C_{11}(V_{gc}, V_{gc} - V_{gy}) + C_{12}(V_{gc}, V_{gc} - V_{gy})$$

The branch charge derivatives are:

$$C_{gygy} = \frac{\partial q_{gy}}{\partial V_{gy}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gy}}$$

$$+ f_2 \times C_{ggy} + Cgdsat \times \left[V_{gy} \times \frac{\partial f_1}{\partial V_{gy}} + f_1\right]$$

$$C_{gygc} = \frac{\partial q_{gy}}{\partial V_{gc}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gc}}$$

$$+ f_2 \times [C_{ggc} - Cgdsat] + Cgdsat \times V_{gy} \times \frac{\partial f_1}{\partial V_{gc}}$$

$$C_{gcgc} = \frac{\partial q_{gc}}{\partial V_{gc}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times \frac{\partial f_1}{\partial V_{gc}}$$

$$+ f_1 \times C_{ggc} + Cgdsat \times \left[V_{gc} \times \frac{\partial f_2}{\partial V_{gc}} + f_2\right]$$

$$C_{gcgy} = \frac{\partial q_{gc}}{\partial V_{gy}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - C(gdsat \times V_{gy})\} \times \frac{\partial f_1}{\partial V_{gy}}$$

$$+ f_1 \times [C_{ggy} - Cgdsat] + Cgdsat \times V_{gc} \times \frac{\partial f_2}{\partial V_{gy}}$$

where:

$$\frac{\partial f_1}{\partial V_{gc}} = \frac{3}{2 \times Deltds} \operatorname{sech}^2\left(\frac{3(V_{gc} - V_{gy})}{Deltds}\right)$$

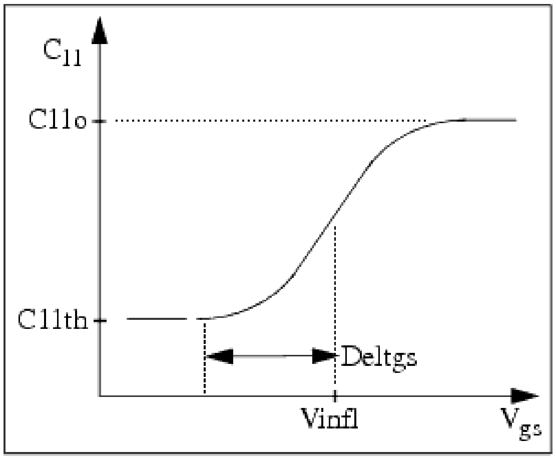
$$\frac{\partial f_1}{\partial V_{gy}} = -\frac{\partial f_1}{\partial V_{gc}}$$

$$\frac{\partial f_2}{\partial V_{gc}} = -\frac{\partial f_1}{\partial V_{gc}}$$

$$\frac{\partial f_2}{\partial V_{gy}} = \frac{\partial f_1}{\partial V_{gc}}$$

When V_{ds}=Vdso and Vdso > Deltds, the gate capacitance C_{11} reduces to a single voltage dependency in V_{gs}. Similar to the I_{ds} model then, the majority of the important gate charge parameters can be estimated from a single trace of a plot. In this case, the plot of interest is $C_{11}-V_{gs}$ at V_{ds} = Vdso.

The parameter definitions are shown in the following illustration. The parameter Deltds models the gate capacitance transition from the linear region of the device into saturation. Lambda models the slope of the $C_{11}-V_{ds}$ characteristic in saturation. C12sat is used to fit the gate transcapacitance (C_{12}) in saturation.



EE_FET3 C_{11}-V_{gs} Parameters

Output Charge and Delay

EE_FET3 uses a constant output capacitance specified with the parameter Cdso. This gives rise to a drain-source charge term of the form

$$q_{ds}(V_{ds}) = Cdso \times V_{ds}$$

The drain-source current previously described in this section is delayed with the parameter Tau according to the following equation:

$$I_{ds}(t) = I_{ds}(V_{gs}(t - Tau), V_{ds}(t))$$

In the frequency domain, only the transconductance is impacted by this delay and the familiar expression for transconductance is obtained:

$y_m = g_m \times \exp(-j \times \omega \times Tau)$

Gate Forward Conduction and Breakdown

Forward conduction in the gate junction is modeled using a standard 2-parameter diode expression. The current for this gate-source current is:

$$I_{gs}(V_{gs}) = Is \times \left[e^{\frac{qV_{gs}}{nkT}} - 1 \right]$$

where q is the charge on an electron, k is Boltzmann's constant and T is the junction temperature.

The EE_FET3 breakdown model was developed from measured DC breakdown data and includes the voltage dependency of both gate-drain and gate-source junctions. EE_FET3 models breakdown for V_{ds}>0V only, breakdown in the V_{ds}<0V region is not handled. The model consists of 4 parameters that are easily optimized to measured data. The breakdown current is given by:

for $-V_{gd} > Vbr$

$$I_{gd}(V_{gd}, V_{gs}) = -Kbk\left(\left[1 - \frac{Ids(V_{gs}, V_{ds})}{I(dsoc)}\right] \times (-V_{gd} - Vbr)^{Nbr}\right)$$

for $-V_{gd} \leq V_{br}$

$$I_{gd}(V_{gd}, V_{gs}) = 0$$

Idsoc should be set to the maximum value attainable by I_{ds} to preclude the possibility of the gate-drain current flowing in the wrong direction.

Scaling Relations

Scaling of EE_FET3 model parameters is accomplished through the use of the model parameters Ugw and Ngf and device parameters Ugw and N. From these four parameters, the following scaling relations can be defined:

$$sf = \frac{Ugw^{new} \times N}{Ugw(Ngf)}$$

$$sfg = \frac{Ugw \times N}{Ugw^{new} \times Ngf}$$

where Ugw^{new} represents the device parameter Ugw, the new unit gate width.
Scaling will be disabled if any of the 4 scaling parameters are set to 0. The new EE_FET3 parameters are calculated internally by the simulator according to these equations:

$$Ris^{new} = \frac{Ris}{sf}$$

$$Rid^{new} = \frac{Rid}{sf}$$

$$Gmmax^{new} = Gmmax(sf)$$

$$Gmmaxac^{new} = Gmmaxac(sf)$$

$$Peff^{new} = Peff \times sf$$

$$Peffac^{new} = Peffac(sf)$$

$$Rdb^{new} = \frac{Rdb}{sf}$$

$$Gdbm^{new} = Gdbm(sf)$$

$$Kdb^{new} = \frac{Kdb}{sf}$$

$$Is^{new} = Is \times sf$$

$$Kbk^{new} = Kbk(sf)$$

$$Idsoc^{new} = Idsoc(sf)$$

$$Rg^{new} = \frac{Rg}{sfg}$$

$$Rd^{new} = \frac{Rd}{sf}$$

$$Rs^{new} = \frac{Rs}{sf}$$

$$Cbs^{new} = Cbs \times sf$$

$$C11o^{new} = C11o \times sf$$

$$C11th^{new} = C11th \times sf$$

$$C12sat^{new} = C12sat \times sf$$

$$Cgdsat^{new} = Cgdsat \times sf$$

$$Cdso^{new} = Cdso \times sf$$

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation current Is scales as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

where:

E_g = 1.11

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

Following are additional equations for the temperature scaling parameters:

$$RG^{NEW} = Rg[1 + Rgtc(Temp - Tnom)]$$

$$RD^{NEW} = Rd[1 + Rdtc(Temp - Tnom)]$$

$$RS^{NEW} = Rs[1 + Rstc(Temp - Tnom)]$$

$$VTOAC^{NEW} = Vtoac + Vtoactc(Temp - Tnom)$$

$$VTSO^{NEW} = Vtso + Vtotc(Temp - Tnom)$$

$$VTSOAC^{NEW} = Vtsoac + Vtoactc(Temp - Tnom)$$

$$GAMMA^{NEW} = GAMMA\left(\left[\frac{Temp}{Tnom}\right]^{GAMMATC}\right)$$

$$GAMMAAC^{NEW} = GAMMAAC\left(\left[\frac{Temp}{Tnom}\right]^{GAMMAACTC}\right)$$

$$GMMAX^{NEW} = GMMAX + GMMAXTC(Temp - Tnom)$$

$$GMMAXAC^{NEW} = GMMAXAC + GMMAXACTC(Temp - Tnom)$$

$$VINFL^{NEW} = Vinfl + Vinfltc(Temp - Tnom)$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd, Ris, Rid, and Rdb is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

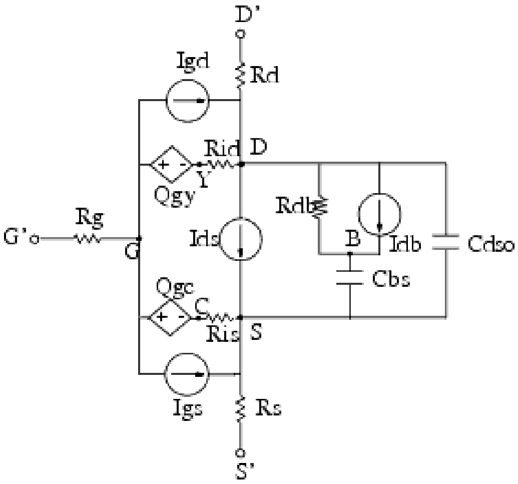
Channel noise generated by the DC transconductance gm is characterized by the following spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3}$$

In these expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, and Δ *f* is the noise bandwidth.

Flicker noise for this device is not modeled in this version of the simulator. However, the bias-dependent noise sources I_NoiseBD and V_NoiseBD can be connected external to the device to model flicker noise.

Equivalent Circuit



Device Operating Point Data

This model generates device operating point data during a DC simulation. The procedure for viewing device operating point data for a component is in *Using Circuit Simulators* (cktsim). Data displayed for EE_FET3_Model (and EE_HEMT1_model) is:

Id	0.167708
Ig	-9.99941e-0
Is	-0.167708
Power	0.838539
Gm	0.119883
Gds	0.0109841
GmAc	0.0487499
GdsAc	0.00342116
Ggs	2.31388e-017
Ggd	0
dIgd_dVgs	0
Cgc	1.40818e-012
dQgc_dVgy	-2.28547e-013
Cgy	5e-014
dQgy_dVgc	-4.57459e-025
Vgs	-0.25
Vds	5

Conductance Model

The detailed operating point analysis returns information on the internal calculations of EEfet3. Since the model accounts for dynamic affects found in conductance and transconductance of GaAs devices, both DC and AC operation are reported for Gm and Gds.

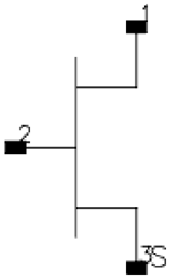
- Gm, Gds DC transconductance, output conductance
- GmAc, GdsAC High-frequency transconductance and output conductance
- dIgd_dVgs Transconductance effects of the gate-drain voltage.

References

1. W. R Curtice. "A MESFET model for use in the design of GaAs integrated circuits," *IEEE Transactions of Microwave Theory and Techniques* , Vol. MTT-28, pp. 448-456, May 1980.
2. P. C. Canfield, "Modeling of frequency and temperature effects in GaAs MESFETs" *IEEE Journal of Solid-State Circuits,* Vol. 25, pp. 299-306,Feb. 1990.
3. J.M. Golio, M. Miller, G. Maracus, D. Johnson, "Frequency dependent electrical characteristics of GaAs MESFETs," *IEEE Trans. Elec. Devices* , vol. ED-37, pp. 1217-1227, May 1990.
4. H. Statz, P. Newman, I. Smith, R. Pucel, H. Haus, "GaAs FET device and circuit simulation in SPICE," *IEEE Trans. Elec. Devices* , vol. ED-34, pp. 160-169, Feb. 1987.

EE_HEMT1 (EEsof Scalable Nonlinear HEMT)

Symbol



Parameters

Name	Description	Units	Default
Model	name of an EE_HEMT1_Model	None	EEHEMTM1
Ugw	new unit gate width	None	0.0
N	new number of gate fingers	None	1.0
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Range of Usage

Ugw > 0
N > 0

Notes/Equations

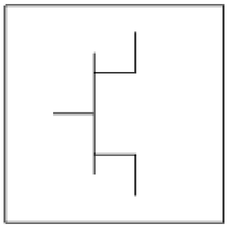
1. Ugw and N are used for scaling device instance; refer to *EE_HEMT1_Model (EEsof Scalable Nonlinear HEMT Model)* (ccnld).
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	siemens
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	siemens
Ggs	Gate-source conductance	siemens
Ggd	Gate-drain conductance	siemens
dIgd_dVgs	(dIgd/dVgs)	siemens
Cgc	Gate-source capacitance (dQgc/dVgc)	farads
dQgc_dVgy	(dQgc/dVgy)	farads
Cgy	Gate-drain capacitance (dQgy/dVgy)	farads
dQgy_dVgc	(dQgy/dVgc)	farads
Vgs	Gate-source voltage	volts
Vds	Gate-drain voltage	volts

EE_HEMT1_Model (EEsof Scalable Nonlinear HEMT Model)

Symbol



Parameters

Name	Description	Units	Default
Vto	zero bias threshold	V	-1.5
Gamma	Transconductance parameter	1/V	0.05
Vgo	gate-source voltage where transconductance is a maximum	V	0.0
Vdelt	Parameter which controls linearization point	V	0.0
Vch	gate-source voltage where Gamma no longer affects I-V curves	V	1.0
Gmmax	peak transconductance	S	70.0e-03
Vdso	Drain voltage where Vo dependence is nominal	V	2.0
Vsat	drain-source current saturation	V	1.0
Kapa	output conductance	S	1.0
Peff	channel to backside self-heating	W	2.0
Vtso	subthreshold onset voltage	V	-10.0
Is	gate junction reverse saturation current	A	1.0e-14
N	gate junction ideality factor	None	1.0
Ris	source end channel resistance	Ohm	0.0
Rid	drain end channel resistance	Ohm	0.0
Tau	gate transit time delay	sec	0.0
Cdso	drain-source inter-electrode capacitance	F	80.0e-15
Rdb	dispersion source output impedance	Ohm	1.0e+9
Cbs	trapping-state capacitance	F	1.6e-13
Vtoac	zero bias threshold (AC)	V	-1.5
Gammaac	Transconductance parameter (AC)	1/V	0.05
Vdeltac	Parameter which controls linearization point (AC)	V	0.0
Gmmaxac	peak transconductance (AC)	S	60.0e-03
Kapaac	output conductance (AC)	S	0.0
Peffac	channel to backside self-heating (AC)	W	10.0
Vtsoac	subthreshold onset voltage (AC)	V	-10.0
Gdbm	additional d-b branch conductance at Vds = VDSM		0.0

Kdb	Dependence of d-b branch conductance with Vds	None	0.0
Vdsm	voltage where additional d-b branch conductance becomes constant		1.0
C11o	maximum input capacitance for Vds=Vdso and Vdso>Deltds	F	0.3e-12
C11th	minimum (threshold) input capacitance for Vds=Vdso	F	0.03e-12
Vinfl	inflection point in C11-Vgs characteristic	V	1.0
Deltgs	C11th to C11o transition voltage	V	0.5
Deltds	linear region to saturation region transition	V	1.0
Lambda	C11-Vds characteristic slope	1/V	1.0
C12sat	input transcapacitance for Vgs=Vinfl and Vds>Deltds	F	0.03e-12
Cgdsat	gate drain capacitance for Vds>Deltds	F	0.05e-12
Kbk	breakdown current coefficient at threshold	None	0.0
Vbr	Breakdown onset voltage	V	15.0
Nbr	breakdown current exponent	None	2.0
Idsoc	open channel (maximum) value of Ids	A	100.0e-03
Rd	drain contact resistance	Ohm	1.0
Rs	source contact resistance	Ohm	1.0
Rg	gate metallization resistance	Ohm	1.0
Ugw	unit gate width of device		0.0
Ngf	number of device gate fingers	None	1.0
Vco	voltage where transconductance compression begins for Vds=Vdso	V	10.0
Vba	transconductance compression tail-off	V	1.0
Vbc	transconductance roll-off to tail-off transition voltage	V	1.0
Mu	Vo dependent transconductance compression	None	1.0
Deltgm	slope of transconductance compression characteristic	None	0.0
Deltgmac	slope of transconductance compression characteristic (AC)	None	0.0
Alpha	transconductance saturation to compression transition	V	1.0e-03
Tnom	Nominal ambient temperature	°C	25
Rgtc	linear temperature coefficient for RG	1/°C	0.0
Rdtc	linear temperature coefficient for RD	1/°C	0.0
Rstc	linear temperature coefficient for RS	1/°C	0.0
Vtotc	Vto temperature coefficient	V/°C	0.0
Gmmaxtc	Gmmax temperature coefficient	S/°C	0.0
Gammatc	Gamma temperature coefficient	None	0.0
Vinfltc	Vinfl temperature coefficient	V/°C	0.0
Vtoactc	Vtoac temperature coefficient	V/°C	0.0
Gmmaxactc	Gmmaxac temperature coefficient	S/°C	0.0
Gammaactc	Gammaac temperature coefficient	None	0.0
Xti	Temperature Exponent for Saturation Curren	None	3.0
Kmod	library model number	None	1
Kver	version number	None	1
wVgfwd	gate junction forward bias (warning)	V	None
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Notes/Equations

1. This model supplies values for an EE_HEMT1 device.
2. Model parameters such as Ls, Ld, and Lg (as well as other package related parameters that are included as part of the output from the EE_HEMT1 IC-CAP model file) are not used by the EE_HEMT1 component in the simulator. Only those parameters listed are part of the EE_HEMT1 component. Any extrinsic components must be added externally by the user.
3. To prevent numerical problems, the setting of some model parameters to 0 is trapped by the simulator. Parameter values are changed internally as follows:
   Rd = 10^{-4}
   Rs = 10^{-4}
   Rg = 10^{-4}
   Ris = 10^{-4}
   Rid = 10^{-4}
   Vsat = 0.1
   Peff = 10^{-6}
   Peffac = 10^{-6}
   Deltds = 0.1
   Deltgs = 0.1
   Idsoc = 0.1
   Is = 10^{-50}
4. When g_m is computed from operating point details, the result does not include the effects of parasitic resistance such as R_g or R_s. This generates a different result from the g_m that is computed using I_{ds} and V_{gs}.
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

Equations/Discussion

EE_HEMT1 is an empirical analytic model that was developed by Agilent EEsof for the express purpose of fitting measured electrical behavior of HEMTs. The model includes the following features:

- Accurate isothermal drain-source current model fits virtually all processes
- Flexible transconductance formulation permits accurate fitting of g_m compression found in HEMTs
- Self-heating correction for drain-source current
- Charge model that accurately tracks measured capacitance values
- Dispersion model that permits simultaneous fitting of high-frequency conductances and DC characteristics
- Accurate breakdown model describes gate-drain current as a function of both V_{gs} and V_{ds}.
- Well-behaved (non-polynomial) expressions permit accurate extrapolations outside of

the measurement range used to extract the model.

The model equations were developed concurrently with parameter extraction techniques to ensure the model would contain only parameters that were extractable from measured data. Although the model is amenable to automated parameter extraction techniques, it was designed to consist of parameters that are easily estimated (visually) from measured data such as g_m-V_{gs} plots. The increased number of model parameters is commensurate with the improvement in accuracy as compared with other popular empirical models. Since the model equations are all well behaved analytic expressions, EE_HEMT1 possesses no inherent limitations with respect to its usable power range. With the parameters Vdelt and Vdeltac set to zero, EE_FET3 becomes a subset of EE_HEMT1. The linear transconductance region modeled with the parameter Vdelt in EE_FET3 is omitted from EE_HEMT1 and replaced with a series of parameters designed to model transconductance compression. Agilent EEsof's IC-CAP program provides the user with the capability of extracting EE_HEMT1 models from measured data.

Drain-Source Current

The drain-source current model in EE_HEMT1 is comprised of various analytic expressions that were developed through examination of g_m versus bias plots on a wide class of devices from various manufacturers. The expressions below are given for V_{ds} > 0.0V although the model is equally valid for V_{ds} < 0.0V. The model assumes the device is symmetrical, and one need only replace V_{gs} with V_{gd} and V_{ds} with $-V_{ds}$ in order to obtain the reverse region (V_{ds} < 0.0V) equations. The g_m, g_{ds} and I_{ds} equations take on four different forms depending on the value of V_{gs} relative to some of the model parameters. The I_{ds} expression is continuous through at least the second derivative everywhere.

$$V_{ts} = \frac{Vtso - Vch}{1 + Gamma(Vdso - Vds)} + Vch$$

if V_{gs} < Vts and Vtso > Vto

V_{gs} = Vts

if $V_{gs} \geq V_g$

$$g_{mo} = Gmmax\{1 + Gamma(Vdso - V_{ds})\}$$

$$I_{dso} = Gmmax\left\{V_x(V_{gs}) - \frac{(Vgo + Vto)}{2} + Vch\right\}$$

$$g_{dso} = -Gmmax \times Gamma(V_{gs} - Vch)$$

else if $V_{gs} \leq V_t$

$$g_{mo} = 0.0$$
$$I_{dso} = 0.0$$
$$g_{dso} = 0.0$$

else

$$g_{mo} = g_{mm}(V_{gs})$$
$$I_{dso} = I_{dsm}(V_{gs})$$
$$g_{dso} = -\frac{Gmmax}{2} Gamma(V_{gs} - Vch)$$

$$\times \left\{ \cos\left[\pi \times \frac{V_x(V_{gs}) - (Vgo - Vch)}{Vto - Vgo}\right] + 1 \right\}$$

where:

$$g_{mm}(V) = \frac{Gmmax}{2}[1 + Gamma(Vdso - V_{ds})]$$

$$\times \left\{ \cos\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right] + 1 \right\}$$

$$I_{dsm}(V) = \frac{Gmmax}{2}\Big(((Vto - Vgo)/\pi) \sin\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right]$$

$$+ V_x(V) - (Vto - Vch) \Big)$$

$$V_x(V) = (V - Vch)[1 + Gamma(Vdso - V_{ds})]$$
$$V_g = \frac{Vgo - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch$$
$$V_t = \frac{Vto - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch .$$

The following voltages define regions of operation that are used in the g_m compression terms:

$$V_c = Vco + Mu \times (Vdso - V_{ds})$$

$$V_b = Vbc + V_c$$

$$V_a = V_b - Vba$$

For $V_{gs} > V_c$, the basic I_{dso}, g_{mo} and g_{dso} relations are modified as follows:

for $V_{gs} < V_b$,

$$g_{mo}^{comp} = g_{mo} - g_{mv}(V_{gs}, V_{ds})$$

$$I_{dso}^{comp} = I_{dso} - I_{dsv}(V_{gs}, V_{ds})$$

$$g_{dso}^{comp} = g_{dso} - g_{dsv}(V_{gs}, V_{ds})$$

for $V_{gs} \geq V_b$ and $b \neq -1$,

$$g_{mo}^{comp} = g_{mo} - [a(V_{gs} - V_a)^b + g_{moff}]$$

$$I_{dso}^{comp} = I_{dso} - \frac{a}{b+1}[(V_{gs} - V_a)^{b+1} - Vba^{b+1}] - g_{moff} \times (V_{gs} - V_b)$$

$$-I_{dsv}(V_b, V_{ds})$$

$$g_{dso}^{comp} = g_{dso} - Mu[a(V_{gs} - V_a)^b + g_{moff}] - g_{dsv}(V_b, V_{ds})$$

for $V_{gs} \geq V_b$ and $b = -1$,

$$g_{mo}^{comp} = g_{mo} - [a(V_{gs} - V_a)^b + g_{moff}]$$

$$I_{dso}^{comp} = I_{dso} - a[\log(V_{gs} - V_a) - \log(Vba)] - g_{moff} \times (V_{gs} - V_b)$$

$$-I_{dsv}(V_b, V_{ds})$$

$$g_{dso}^{comp} = g_{dso} - \frac{Mu \times a}{(V_{gs} - V_a)} - Mu \times g_{moff} - g_{dsv}(V_b, V_{ds})$$

where:

$$a = \frac{g_{mv}(V_b, V_{ds}) - g_{moff}}{Vba^b}$$

$$b = \frac{s_{vb} \times Vba}{g_{mv}(V_b, V_{ds}) - g_{moff}}$$

$$s_{vb} = Deltgm \times \frac{Vbc}{\sqrt{Alpha^2 + Vbc^2}}$$

$$g_{mv}(V, V_{ds}) = Deltgm \times \left[\sqrt{Alpha^2 + (V - V_c)^2} - Alpha\right]$$

$$I_{dsv}(V - V_{ds}) = Deltgm\left(\frac{1}{2}\left((V - V_c)\sqrt{Alpha^2 + (V - V_c)^2} + Alpha^2 \right.\right.$$
$$\left.\left. * \, log\left[\frac{(V - V_c) + \sqrt{Alpha^2 + (V - V_c)^2}}{Alpha}\right]\right) - Alpha * (V - V_c)\right)$$

$g_{dsv}(V, V_{ds})$ =

$$Deltgm \times Mu\left(\frac{1}{2}\left(\frac{2(V - V_c)^2 + Alpha^2}{\sqrt{Alpha^2 + (V - V_c)^2}} + \frac{Alpha^2}{(V - V_c) + \sqrt{Alpha^2 + (V - V_c)^2}} \times \left[1 + \frac{(V - V_c)}{\sqrt{Alpha^2 + (V - V_c)^2}}\right]\right) - Alpha\right)$$

where $g_{moff} = g_{mo}(Vco, Vdso)$ means replace *Vgs* by *Vco*, *Vds* by *Vdso*; i.e.,

if *Vco* > *Vgo*

g_{moff} = Gmmax

else if *Vco* < *Vto*

g_{moff} = 0

else

$$gmoff = \frac{Gmmax}{2}\left[\cos\left(\pi \times \frac{Vco - Vgo}{Vto - Vgo}\right) + 1\right]$$

If junction voltage drops below the onset of subthreshold (*Vts*), current and conductances are modified to decay exponentially from their value at *Vgs* = *Vts* .

if *Idso* ≠ 0 and *Vgs* < *Vts* and *Vtso* > *Vto* and *gmo* / *Idso* > 0

$$\arg = -\left(\frac{gmo}{Idso}\right) \times (Vts - Vgs)$$

$$Idso = Idso \times \exp(\arg)$$

$$gmo = gmo \times \exp(\arg)$$

$$gdso = gdso \times \exp(\arg)$$

where:

Idso, *gmo* are $Idso^{comp}$, gmo^{comp} if *Vgs* > *Vc*

To prevent g_m from becoming negative at high gate-source biases, it is advisable to use the parameter Deltgm under the following value:

$$Deltgm < \frac{g_{moff}}{\sqrt{Alpha^2 + Vbc^2} - Alpha}$$

The preceding relations for I_{dso}^{comp}, g_{mo}^{comp} and g_{dso}^{comp} can now be substituted in the following equations that model current saturation and output conductance. This portion of the model can be recognized from the work of Curtice [1].

$$g'_m = g_{mo}^{comp}(1 + Kapa \times V_{ds})\tanh\left(\frac{3V_{ds}}{Vsat}\right)$$

$$I'_{ds} = I_{dso}^{comp}(1 + Kapa \times V_{ds})\tanh\left(\frac{3V_{ds}}{Vsat}\right)$$

$$g'_{ds} = \left\{g_{dso}^{comp}(1 + Kapa \times V_{ds}) + I_{dso}^{comp} Kapa\right\}\tanh\left(\frac{3V_{ds}}{Vsat}\right)$$

$$+ I_{dso}^{comp} \times \frac{3(1 + Kapa \times V_{ds})}{Vsat}\operatorname{sech}^2\left(\frac{3V_{ds}}{Vsat}\right)$$

These expressions do an excellent job of fitting HEMT I-V characteristics in regions of low power dissipation. They will also fit pulsed (isothermal) I-V characteristics. To model negative conductance effects due to self-heating, the thermal model of Canfield was incorporated [2]. With this final enhancement, the DC expressions for I_{ds} and its associated conductances become:

$$I_{ds} = \frac{I'_{ds}}{1 + \frac{P_{diss}}{Peff}}$$

$$g_m = \frac{g'_m}{\left[1 + \frac{P_{diss}}{Peff}\right]^2}$$

$$g_{ds} = \frac{g'_{ds} - \frac{I'^2_{ds}}{Peff}}{\left[1 + \frac{P_{diss}}{Peff}\right]^2}$$

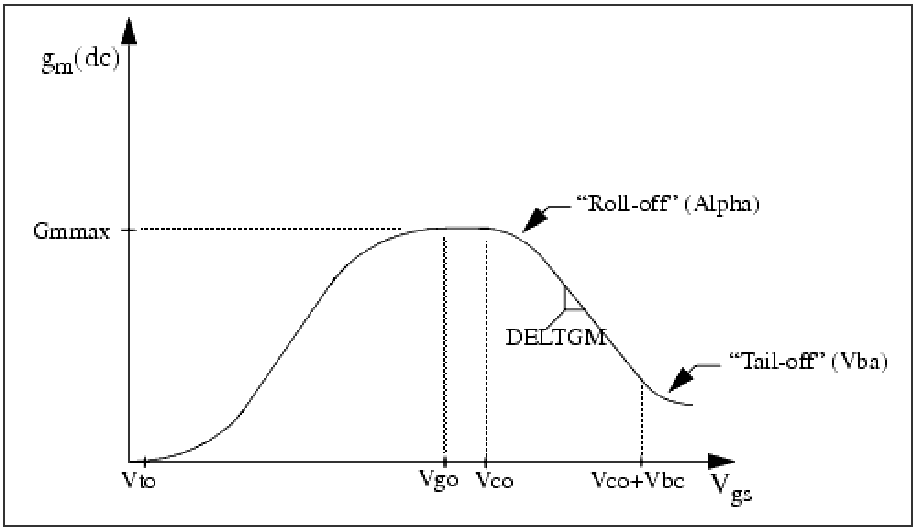
where:

$$P_{diss} = I'_{ds} V_{ds}$$

Qualitatively, the operation of the drain-source model can be described as follows. The V_{ds} dependence of the equations is dominated by the parameters Vsat, Gamma, Kapa, and Peff. Isothermal output conductance is controlled by Gamma and Kapa. The impact of Gamma on output conductance is more significant near threshold. At V_{gs} =Vch, the output conductance is controlled only by Kapa. Peff provides a correction to the isothermal model for modeling the self-heating effects manifested as a negative resistance on the I-V curves. Vsat represents the drain-source voltage at which the current saturates and output conductance becomes a constant (approximately). Mu also impacts the I-V curves in the g_m compression region, but its effect is second order. In most cases, the g_m fit is more sensitive to the parameter Mu.

The overall impact of Vch on the I-V characteristics is second order at best, and many different values of Vch will provide good fits to I-V plots. For most applications encountered, the default value of 1.0V is an adequate value for Vch. Similar to Vch, Vdso is a parameter that should be set rather than optimized. At V_{ds}=Vdso, the drain-source model collapses to a single voltage dependency in V_{gs}. It is recommended that the user set Vdso to a typical V_{ds} operating point in saturation. At this point, many of the parameters can be extracted from a I_{ds}-V_{gs} plot for V_{ds}=Vdso or, preferably, a g_m(dc)-V_{gs} plot at V_{ds}=Vdso.

When V_{ds}=Vdso and Peff is set large (to disable the self-heating model), the significance of Vto, Vgo, Gmmax, Vco, Vba, Vbc, Deltgm and Alpha are easily understood from a plot of g_m(dc)-V_{gs}. Gmmax is the peak transconductance of the model that occurs at V_{gs}=Vgo. Vto represents the gate-source voltage where g_m goes to zero. Transconductance compression begins at V_{gs}=Vco. Alpha controls the abruptness of this transition while Deltgm controls the slope of the g_m characteristic in compression. At V_{gs}=Vco+Vbc, the linear g_m slope begins to tail-off and asymtotically approach zero. The shape of this *tail-off* region is controlled by Vba. The parameter definitions are illustrated in EE_HEMT1 gm−Vgs Parameters.



EE_HEMT1 g_m–V_{gs} Parameters

Dispersion Current (Idb)

Dispersion in a GaAs MESFET or HEMT drain-source current is evidenced by the observation that the output conductance and transconductance beyond some transition frequency is higher than that inferred by the DC measurements. A physical explanation often attributed to this phenomenon is that the channel carriers are subject to being trapped in the channel-substrate and channel-surface interfaces. Under slowly varying signal conditions, the rate at which electrons are trapped in these sites is equal to the rate at which they are emitted back into the channel. Under rapidly varying signals, the traps cannot follow the applied signal and the *high-frequency* output conductance results.

The circuit used to model conductance dispersion consists of the Rdb, Cbs (these linear components are also parameters) and the nonlinear source $I_{db}(V_{gs}, V_{ds})$. The model is a large-signal generalization of the dispersion model proposed by Golio et al. [3]. At DC, the drain-source current is just the current I_{ds}. At high frequency (well above the transition frequency), the drain source current will be equal to I_{ds}(high frequency) = I_{ds}(dc) + I_{db}. Linearization of the drain-source model yields the following expressions for y_{21} and y_{22} of the intrinsic EE_HEMT1 model:

$$y_{21} = g_{dsgs} + g_{dbgs} - \frac{g_{dbgs}}{1 + j\omega \times Cbs(Rdb)}$$

$$y_{22} = g_{dsds} + g_{dbds} + \frac{1}{Rdb} - \frac{\left(g_{dbds} + \frac{1}{Rdb}\right)}{1 + j\omega \times Cbs(Rdb)}$$

where:

$$g_{dsgs} = \frac{\partial I_{ds}}{\partial V_{gs}}$$

$$g_{dsds} = \frac{\partial I_{ds}}{\partial V_{ds}}$$

$$g_{dbgs} = \frac{\partial I_{db}}{\partial V_{gs}}$$

$$g_{dbds} = \frac{\partial I_{db}}{\partial V_{ds}}$$

Evaluating these expressions at the frequencies ω=0 and ω=infinity, produces the following results for transconductance and output conductance:
for ω = 0,

$$Re[y_{21}] = g_m = g_{dsgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds}$$

for ω = infinity,

$$Re[y_{21}] = g_m = g_{dsgs} + g_{dbgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds} + g_{dbds} + \frac{1}{Rdb}$$

Between these two extremes, the conductances make a smooth transition, the abruptness of which is governed by the time constant τdisp = Rdb × Cbs. The frequency f_0 at which the conductances are midway between these two extremes is defined as:

$$f_0 = \frac{1}{2\pi\tau_{disp}}$$

The parameter Rdb should be set large enough so that its contribution to the output conductance is negligible. Unless the user is specifically interested in simulating the device near f_0, the default values of Rdb and Cbs will be adequate for most microwave applications.

The EE_HEMT1 I_{ds} model can be extracted to fit either DC or AC characteristics. In order to simultaneously fit both DC I-V characteristics and AC conductances, EE_HEMT1 uses a simple scheme for modeling the I_{db} current source whereby different values of the same parameters can be used in the I equations. The DC and AC drain-source currents can be ds

expressed as follows:

$I_{ds}^{dc}(\text{Voltages, Parameters}) =$ I_{ds}

(Voltages, Gmmax, Vdelt, Vto, Gamma, Kapa, Peff, Vtso, Deltgm, Vgo, Vch, Vdso, Vsat)

$I_{ds}^{ac}\ (\text{Voltages, Parameters}) =$ I_{ds}

(Voltages, Gmmaxac, Vdeltac, Vto, Gammaac, Kapaac, Peffac, Vtsoac, Deltgmac, Vgo, Vch, Vdso, Vsat)

Parameters such as Vgo that do not have an AC counterpart (there is no Vgoac parameter) have been found not to vary significantly between extractions utilizing DC measurements versus those using AC measurements. The difference between the AC and DC values of Ids, plus an additional term that is a function of Vds only, gives the value of Idb for the dispersion model:

$$I_{db}(V_{gs}, V_{ds}) = I_{ds}^{ac}(V_{gs}, V_{ds}) - I_{ds}^{dc}(V_{gs}, V_{ds}) + I_{dbp}(V_{ds})$$

where I_{dbp} and its associated conductance are given by:

for $V_{ds} > Vdsm$ and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}}\tan^{-1}((V_{ds} - Vdsm)\sqrt{Kdb(Gdbm)} + Gdbm \times Vdsm)$$

$$g_{dbp} = \frac{Gdbm}{(Kdb(Gdbm(V_{ds} - Vdsm)^2 + 1))}$$

for $V_{ds} \leq Vdsm$ and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}}\tan^{-1}((V_{ds} + Vdsm)\sqrt{Kdb(Gdbm)}) - Gdsm \times Vdsn$$

$$g_{dbp} = \frac{(Gdbm)}{(Kdb(Gdbm(V_{ds} + Vdsm)^2 + 1))}$$

for $-Vdsm \leq V_{ds} \leq Vdsm$ or $Kdb = 0$:

$$I_{dsm} = Gdbm \times V_{ds}$$

$$g_{dbm} = Gdbm$$

By setting the eight high-frequency parameters equal to their DC counterparts, the dispersion model reduces to $I_{db} = I_{dbp}$. Examination of the I_{dbp} expression reveals that the additional setting of Gdbm to zero disables the dispersion model entirely. Since the I_{dbp} current is a function of V_{ds} only, it will impact output conductance only. However, the current function:

$$I_{ds}^{AC}$$

will impact both g_m and g_{ds}. For this reason, the model is primarily intended to utilize g_m data as a means for tuning:

$$I_{ds}^{AC}$$

Once this *fitting* is accomplished, the parameters Gdbm, Kdb and Vdsm can be tuned to optimize the g_{ds} fit.

Gate Charge Model

The EE_HEMT1 gate charge model was developed through careful examination of extracted device capacitances over bias. The model consists of simple closed form charge expressions whose derivatives fit observed bias dependencies in capacitance data. This capacitance data can be obtained directly from measured Y-parameter data:

$$C_{11} = \frac{im[y_{11}]}{\omega} = \frac{\partial q_g}{\partial V_{gs}}$$

$$C_{12} = \frac{im[y_{12}]}{\omega} = \frac{\partial q_g}{\partial V_{ds}}$$

The capacitance data is remarkably self-consistent. In other words, a single q_g function's derivatives will fit both C 11 data and C 12 data. The EE_HEMT1 gate charge expression is:

$$q_g(V_j, V_o) = \left[\frac{C11o - C11th}{2} g(V_j) + C11th(V_j - Vinfl)\right]$$

$$\times [1 + Lambda(V_o - Vdso)] - C12sat \times V_o$$

where:

$$g(V_j) = V_j - Vinfl + \frac{Deltgs}{3} \ln\left(\cosh\left(\frac{3}{Deltgs}(V_j - Vinfl)\right)\right)$$

This expression is valid for both positive and negative V_{ds}. Symmetry is forced through the following smoothing functions proposed by Statz [4]:

$$V_j = \frac{1}{2}\left(2V_{gs} - V_{ds} + \sqrt{V_{ds}^2 + Deltds^2}\right)$$

$$V_o = \sqrt{V_{ds}^2 + Deltds^2}$$

Differentiating the gate charge expression wrt V_{gs} yields the following expression for the gate capacitance C 11:

$$C_{11}(V_j, V_o) = \left[\frac{C11o - C11th}{2} g'(V_j) + C11th\right] \times [1 + Lambda(V_o - Vdso)]$$

where:

$$g'(V_j) = \frac{dg(V_j)}{dV_j} = 1 + \tanh\left[\frac{3}{Deltgs}(V_j - Vinfl)\right]$$

The gate transcapacitance C_{12} is defined as:

$$C_{12}(V_j, V_o) = \frac{\partial q_g}{\partial V_{ds}} = \frac{\partial q_g}{\partial V_j}\frac{\partial V_j}{\partial V_{ds}} + \frac{\partial q_g}{\partial V_o}\frac{\partial V_o}{\partial V_{ds}}$$

$$= C_{11}(V_j, V_o) \times \frac{1}{2}\left[\frac{V_{ds}}{\sqrt{V_{ds}^2 + Deltds^2}} - 1\right]$$

$$+ \left[\frac{C11o - C11th}{2} g(V_j - Vinfl)\right]$$

$$\times Lambda - C12sat \times \frac{V_{ds}}{\sqrt{V_{ds}^2 + Deltds^2}}$$

The EE_HEMT1 topology requires that the gate charge be subdivided between the respective charge sources q gc and q gy. Although simulation could be performed directly from the nodal gate charge q_g, division of the charge into branches permits the inclusion of the resistances Ris and Rid that model charging delay between the depletion region and the channel. EE_HEMT1 assumes the following form for the gate-drain charge in saturation:

$$q_{gy}(V_{gy}) = Cgdsat \times (V_{gy} + q_{gyo})$$

which gives rise to a constant gate-drain capacitance in saturation.

The gate-source charge q_{gc} can now be obtained by subtracting the latter from the gate charge equation. Smoothing functions can then be applied to these expressions in saturation in order to extend the model's applicable bias range to all V_{ds} values. These smoothing functions force symmetry on the q_{gy} and q_{gc} charges such that:

$$q_{gy} = q_{gc} = \frac{q_g}{2}$$

at V gc = V gy. Under large negative V_{ds} (saturation at the source end of the device), q_{gy} and q_{gc} swap roles, i.e:

$$q_{gc}(V_{gc}) = Cgdsat \times (V_{gc} + q_{gco})$$

The following continuous charge equations satisfy these constraints and are specified in terms of the gate charge:

$$q_{gy}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times f_2$$

$$+ Cgdsat \times V_{gy} \times tf_1$$

$$q_{gc}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times f_1$$

$$+ C(Ggdsat) \times V_{gc} \times f_2$$

where f_1 and f_2 are smoothing functions defined by:

$$f_1 = \frac{1}{2}\left[1 + \tanh\left(\frac{3}{Deltds}(V_{gc} - V_{gy})\right)\right]$$

and

$$f_2 = \frac{1}{2}\left[1 - \tanh\left(\frac{3}{Deltds}(V_{gc} - V_{gy})\right)\right]$$

The capacitances associated with these *branch* charge sources can be obtained through differentiation of the q_{gc} and q_{gy} equations and by application of the chain rule to the capacitances $C11$ and $C12$. The gate charge derivatives re-formulated in terms of V_{gc} and V_{gy} are:

$$C_{ggy} = \frac{\partial q_g}{\partial V_{gy}} = -C_{12}(V_{gc}, V_{gc} - V_{gy})$$

$$C_{ggc} = \frac{\partial q_g}{\partial V_{gc}} = C_{11}(V_{gc}, V_{gc} - V_{gy}) + C_{12}(V_{gc}, V_{gc} - V_{gy})$$

The branch charge derivatives are:

$$C_{gygy} = \frac{\partial q_{gy}}{\partial V_{gy}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gy}}$$

$$+ f_2 \times C_{ggy} + Cgdsat \times \left[V_{gy} \times \frac{\partial f_1}{\partial V_{gy}} + f_1\right]$$

$$C_{gygc} = \frac{\partial q_{gy}}{\partial V_{gc}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gc}}$$

$$+ f_2 \times [C_{ggc} - Cgdsat] + Cgdsat \times V_{gy} \times \frac{\partial f_1}{\partial V_{gc}}$$

$$C_{gcgc} = \frac{\partial q_{gc}}{\partial V_{gc}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times \frac{\partial f_1}{\partial V_{gc}}$$

$$+ f_1 \times C_{ggc} + Cdsat \times \left[V_{gc} \times \frac{\partial f_2}{\partial V_{gc}} + f_2\right]$$

$$C_{gcgy} = \frac{\partial q_{gc}}{\partial V_{gy}} = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times \frac{\partial f_1}{\partial V_{gy}}$$

$$+ f_1 \times [C_{ggy} - Cgdsat] + Cgdsat \times V_{gc} \times \frac{\partial f_2}{\partial V_{gy}}$$

where:

$$\frac{\partial f_1}{\partial V_{gc}} = \frac{3}{2 \times Deltds} \operatorname{sech}^2\left(\frac{3(V_{gc} - V_{gy})}{Deltds}\right)$$

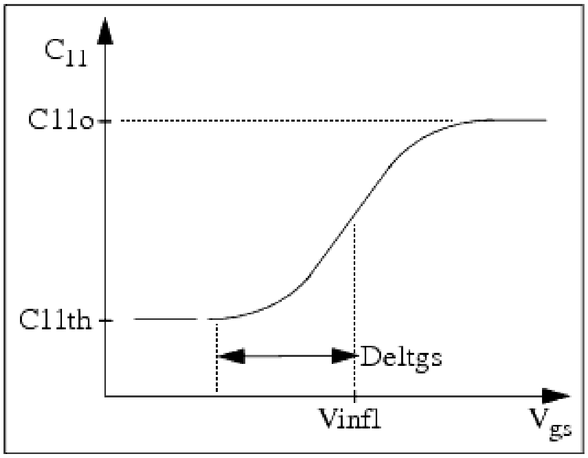
$$\frac{\partial f_1}{\partial V_{gy}} = -\frac{\partial f_1}{\partial V_{gc}}$$

$$\frac{\partial f_2}{\partial V_{gc}} = -\frac{\partial f_1}{\partial V_{gc}}$$

$$\frac{\partial f_2}{\partial V_{gy}} = \frac{\partial f_1}{\partial V_{gc}}$$

When V_{ds}=Vdso and Vdso>>Deltds, the gate capacitance *C*11 reduces to a single voltage dependency in V_{gs}. Similar to the I_{ds} model, the majority of the important gate charge parameters can then be estimated from a single trace of a plot. In this case, the plot of interest is *C*11-V_{gs} at V_{ds} = Vdso. The parameter definitions are shown in the following illustration, "EE_HEMT1 C11-Vgs Parameters".

The parameter Deltds models the gate capacitance transition from the linear region of the device into saturation. Lambda models the slope of the *C*11-V_{ds} characteristic in saturation. C12sat is used to fit the gate transcapacitance (*C*12) in saturation.



EE_HEMT1 C_{11}-V_{gs} Parameters

Output Charge and Delay

EE_HEMT1 uses a constant output capacitance specified with the parameter Cdso. This gives rise to a drain-source charge term of the form:

$$q_{ds}(V_{ds}) = Cdso \times V_{ds}$$

The drain-source current described previously, is delayed with the parameter TAU according to the following equation:

$$I_{ds}(t) = I_{ds}(V_{gs}(t - Tau), V_{ds}(t))$$

In the frequency domain, only the transconductance is impacted by this delay and the familiar expression for transconductance is obtained:

$$y_m = g_m \times \exp(-j \times \omega \times Tau)$$

Gate Forward Conduction and Breakdown

Forward conduction in the gate junction is modeled using a standard 2-parameter diode expression. The current for this gate-source current is:

$$I_{gs}(V_{gs}) = IS \times \left[e^{\frac{qV_{gs}}{nkT}} - 1 \right]$$

where *q* is the charge on an electron, *k* is Boltzmann's constant, and *T* is the junction temperature.

The EE_HEMT1 breakdown model was developed from measured DC breakdown data and includes the voltage dependency of both gate-drain and gate-source junctions. EE_HEMT1 models breakdown for Vds > 0V only, breakdown in the Vds < 0V region is not handled. The model consists of four parameters that are easily optimized to measured data. The breakdown current is given by:

for $-V_{gd} > Vbr$

$$I_{gd}(V_{gd}, V_{gs}) = -Kbk\left[1 - \frac{Ids(V_{gs}, V_{ds})}{Idsoc}\right] \times (-V_{gd} - Vbr)^{Nbr}$$

for $-V_{gd} \le Vbr$

$$I_{gd}(V_{gd}, V_{gs}) = 0$$

Care must be exercised in setting Idsoc. This parameter should be set to the maximum value attainable by I_{ds}. This precludes the possibility of the gate-drain current flowing in the wrong direction.

Scaling Relations

Scaling of EE_HEMT1 model parameters is accomplished through model parameters Ugw and Ngf and device parameters Ugw (same name as the model parameter) and N. From these four parameters, the following scaling relations can be defined:

$$sf = \frac{Ugw^{new} \times N}{Ugw \times Ngf}$$

$$sfg = \frac{Ugw \times N}{Ugw^{new} \times Ngf}$$

where Ugw^{new} represents the device parameter Ugw, the new unit gate width.

Scaling will be disabled if any of the four scaling parameters are set to 0. The new EE_HEMT1 parameters are calculated internally by the simulator according to the following equations:

$$Ris^{new} = \frac{Ris}{sf}$$

$$Rid^{new} = \frac{Rid}{sf}$$

$$Gmmax^{new} = Gmmax \times sf$$

$$Gmmaxac^{new} = Gmmaxac \times sf$$

$$Deltgm^{new} = Deltgm \times sf$$

$$Deltgmac^{new} = Deltgmac \times sf$$

$$Peff^{new} = Peff \times sf$$

$$Peffac^{new} = Peffac \times sf$$

$$Rdb^{new} = \frac{Rdb}{sf}$$

$$Gdbm^{new} = Gdbm \times sf$$

$$Kdb^{new} = \frac{Kdb}{sf}$$

$$Is^{new} = Is \times sf$$

$$Kbk^{new} = Kbk \times sf$$

$$Idsoc^{new} = Idsocs \times sf$$

$$Rg^{new} = \frac{Rg}{sfg}$$

$$Rd^{new} = \frac{Rd}{sf}$$

$$Rs^{new} = \frac{Rs}{sf}$$

$$Cbs^{new} = Cbs \times sf$$

$$C11o^{new} = C11o \times sf$$

$$C11th^{new} = C11th \times sf$$

$$C12sat^{new} = C12sat \times sf$$

$$Cgdsat^{new} = Cgdsat \times sf$$

$$Cdso^{new} = Cdso \times sf$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd, Ris, Rid, and Rdb is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Channel noise generated by the DC transconductance g_m is characterized by the following spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3}$$

In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, and Δ *f* is the noise bandwidth.

Flicker noise for this device is not modeled in this version of the simulator. However, the bias-dependent noise sources I_NoiseBD and V_NoiseBD can be connected external to the device to model flicker noise.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation current Is scales as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

where

$$E_g = 1.11$$

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

Following are additional equations for the temperature scaling parameters:

$$RG^{NEW} = Rg[1 + Rgtc(Temp - Tnom)]$$

$$RD^{NEW} = Rd[1 + Rdtc(Temp - Tnom)]$$

$$RS^{NEW} = Rs[1 + Rstc(Temp - Tnom)]$$

$$VTOAC^{NEW} = Vtoac + Vtoactc(Temp - Tnom)$$

$$VTSO^{NEW} = Vtso + Vtotc(Temp - Tnom)$$

$$VTSOAC^{NEW} = Vtsoac + Vtoactc(Temp - Tnom)$$

$$GAMMA^{NEW} = GAMMA\left(\left[\frac{Temp}{Tnom}\right]^{GAMMATC}\right)$$

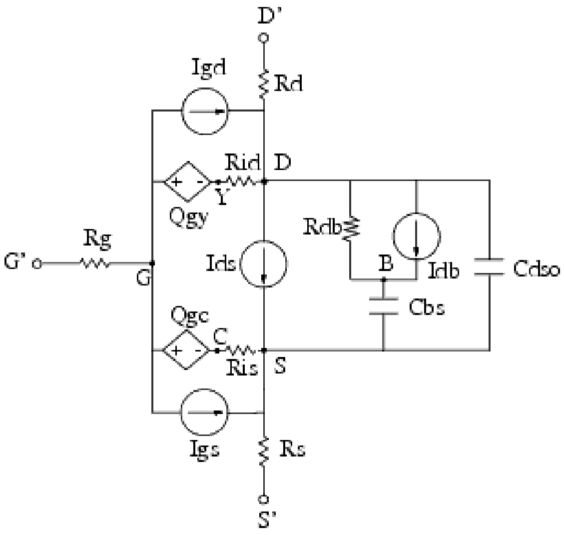
$$GAMMAAC^{NEW} = GAMMAAC\left(\left[\frac{Temp}{Tnom}\right]^{GAMMAACTC}\right)$$

$$GMMAX^{NEW} = GMMAX + GMMAXTC(Temp - Tnom)$$

$$GMMAXAC^{NEW} = GMMAXAC + GMMAXACTC(Temp - Tnom)$$

$$VINFL^{NEW} = Vinfl + Vinfltc(Temp - Tnom)$$

Equivalent Circuit

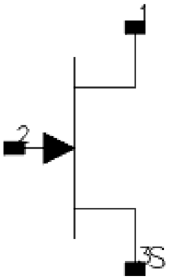


References

1. W. R. Curtice, "A MESFET model for use in the design of GaAs integrated circuits," *IEEE Transactions of Microwave Theory and Techniques,* Vol. MTT-28, pp. 448-456, May 1980.
2. P. C. Canfield, "Modeling of frequency and temperature effects in GaAs MESFETs" *IEEE Journal of Solid-State Circuits,* Vol. 25, pp. 299-306, Feb. 1990.
3. J. M. Golio, M. Miller, G. Maracus, D. Johnson, "Frequency dependent electrical characteristics of GaAs MESFETs," *IEEE Trans. Elec. Devices* , vol. ED-37, pp. 1217-1227, May 1990.
4. H. Statz, P. Newman, I. Smith, R. Pucel, H. Haus. "GaAs FET device and circuit simulation in SPICE," *IEEE Trans. Elec. Devices,* vol. ED-34, pp. 160-169, Feb. 1987.

GaAsFET (Nonlinear Gallium Arsenide FET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a GaAsFET model	None	MESFETM1
Area	scaling factor that scales certain parameter values of the associated model item	None	1.0
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient	°C	0
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Range of Usage

Area > 0

Notes/Equations

1. Advanced_Curtice2_Model, Curtice2_Model, Curtice3_Model, Materka_Model, Modified_Materka_Model, Statz_Model, and Tajima_Model are the nonlinear model items that define the GaAsFET.
2. The Area parameter permits changes to a specific semiconductor because semiconductors may share the same model.
    - Parameters scaled proportionally to Area: A0, A1, A2, A3, Beta, Cgs, Cgd, Cgs, Cds, Is.
    - Resistive parameters scaled inversely proportional to Area: Rd, Rg, Rs. For example, Model = Curtice2 and Area=3 use the following calculations:
      Rd/3: Cgs × 3 Beta × 3
      Rg/3: Cgdo × 3
      Rs/3: Cds × 3
      These calculations have the same effect as placing three devices in parallel to simulate a larger device and are much more efficient.
3. The Temp parameter specifies the physical (operating) temperature of the device. If

this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated model item) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the appropriate model to see which parameter values are scaled.

4. The following table lists the DC operating point parameters that can be sent to the dataset.

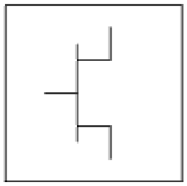
DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Ggs	Gate to source conductance	siemens
Ggd	Gate to drain conductance	siemens
dIgs_dVgd	(dIgs/dVgd)	siemens
dIgd_dVgs	(dIgd/dVgs)	siemens
dIds_dVgb	Backgate transconductance (dIds/dVgb)	siemens
Cgs	Gate-source capacitance	farads
Cgd	Gate-drain capacitance	farads
Cds	Drain-source capacitance	farads
dQgs_dVgd	(dQgs/dVgd)	farads
dQgd_dVgs	(dQgd/dVgs)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts

5. This device has no default artwork associated with it.

Materka_Model (Materka GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	4
Idss	saturation drain current	A	0
Vto †	Value of V1 below which Ids = Ids(V1=VTO,Vds)	V	-2.0
Alpha	hyperbolic tangent function	V	2.0
Beta2	coefficient for pinch-off change with respect to Vds	1/V	0
Tau	transit time under gate	sec	0
Lambda	channel length modulation	1/V	0.0
Rin	channel resistance	Ohm	0.0
Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgd	zero bias gate-drain junction capacitance	F	0.0
Rd	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs	source resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds	Drain-source cap.	F	0.0
Gsfwd	0-none, 1=linear, 2=diode	None	linear

Gsrev	0-none, 1=linear, 2=diode	None	None
Gdfwd	0-none, 1=linear, 2=diode	None	None
Gdrev	0-none, 1=linear, 2=diode	None	linear
Vbi †	built-in gate potential	V	0.85
Vjr	Breakdown junction potential	V	0.025
Is	gate junction reverse saturation current (diode model)	A	1.0e-14
Ir	gate reverse saturation current	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 2)	A	defaults to Imax
N	gate junction ideality factor (diode model)	None	1
Vbr	gate junction reverse bias breakdown voltage	V	1e100
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1
C	gate-drain noise correlation coefficient	None	0.9
Taumdl	Use 2nd order Bessel polynomial to model tau effect in transient: yes or no	None	no
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
wVgfwd	gate junction forward bias (warning)	V	None
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

† Parameter value varies with temperature based on model Tnom and device Temp.

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
3. Drain current in the Materka_Model is calculated with the following expression:

   $Vp = Vto + Beta2 \times Vds$
   if $(Vfc - Vp \leq 0$ or $Vp \geq 0)$

   else

TI = ABS (Alpha × Vds)
TanhF = tanh (TI/(Vgc − Vp))

$$Ids = Idss \times \left(\frac{Vgc}{V_P} - 1\right)^2 \times TanhF \times (1 + Lambda \times Vds)$$

4. The P, R, and C parameters model drain and gate noise sources.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m P\left(1 + {f_{NC}}/{f}\right)$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kTC_{gs}^2 \omega^2 R / g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTjC_{gs}\omega\sqrt{PR}C$$

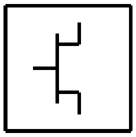
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

References

1. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Mesfet_Form (Symbolic MESFET Model)

Symbol



Parameters

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	6
Ids	user-defined equation for drain-source current	None	see Note 1
Qgs	user-defined equation for gate-source charge	None	see Note 1
Qgd	user-defined equation for gate-drain charge	None	see Note1
Igd	user-defined equation for gate-drain current	None	see Note 1
Igs	user-defined equation for gate-source current	None	see Note 1
Beta	transconductance	A/V^2	1.0e-4
Lambda	channel length modulation parameter	1/V	0.0
Alpha	current saturation	1/V	2.0
B	doping tail extending	None	0.3
Tnom	nominal ambient temperature	°C	25
Idstc	IDS temperature coefficient	None	0.0
Vbi	built-in gate potential	V	0.85
Tau	transit time under gate	sec	0.0
Rds0	dc drain-source resistance at Vgs = 0	Ohm	0
Betatce	BETA exponential temperature coefficient	%/°C	0.0
Delta1	capacitance transition voltage	V	0.3
Delta2	capacitance threshold transition voltage	V	0.2
Gscap	0=none, 1=linear, 2 = junction, 3 = Statz Charge, 4 = Symbolic, 5 = Statz Cap	None	linear
Gdcap	0=none, 1=linear, 2 = junction, 3 = Statz Charge, 4 = Symbolic, 5 = Statz Cap	None	linear
Cgs	zero-bias G-S junction cap	F	0.0
Cgd	zero-bias G-D junction cap	F	0.0
Rgs	G-S resistance	Ohm	0.0
Rgd	gate drain resistance	Ohm	0.0

Rf	G-S effective forward-bias resistance	Ohm	infinity†
Tqm	temperature coefficient for triquint junction capacitance	None	0.2
Vmax	maximum junction voltage before capacitance limiting		0.5
Fc	coefficient for forward-bias depletion cap	None	0.5
Rd	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs	source ohmic resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds	drain-source cap	F	0.0
Crf	used with RC to model frequency-dependent output conductance	F	10^{100}
Rc	used with CRC to model frequency-dependent output conductance	Ohm	infinity†
Gsfwd	0=none, 1=linear, 2=diode	None	linear
Gdfwd	0=none, 1=linear, 2=diode	None	None
Gsrev	0=none, 1=linear, 2=diode, 3=custom	None	None
Gdrev	gate junction forward bias warning	None	linear
Vjr	breakdown junction potential		0.025
Is	gate-junction saturation current	A	1.0e-14
Ir	gate rev saturation current	A	1.0e-14
Imax	expression current	A	1.6
Xti	saturation current temperature exponent	None	3.0
N	gate junction emission coefficient	None	1
Eg	energy tap for temperature effect on IS	None	1.1.1
Vbr†	gate junction reverse bias breakdown voltage	V	1e100
Vtotc	VTO temperature coefficient	V/°C	0.0
Rin	channel resistance	Ohm	0.0
Taumdl	use 2nd order Bessel polynomial to model tau effect in transient: yes or no	None	no
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
C	gate-drain noise correlation coefficient	None	0.9
P	drain noise coefficient	None	1.0
wVgfwd	gate junction forward bias (warning	V	None
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None
† Value of 0.0 is interpreted as infinity.			

Notes/Equations

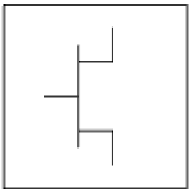
1. Equations for default settings:
   Ids = (100mA) × ((1+_v2))^{2}) × tanh(_v1)
   Qgs = (1pf) × (_v1) - (1pf) × ((_v2) -(_v1)) × (_v1)
   Qgd = (1prf) × (_v1) - ((v2) -(v1)) × (_v1)
   Igd = ramp ((10 + (_v1)) / 10)
   Igs = ramp ((10 + (_v1)) / 10)
2. Imax and Imelt Parameters

   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.

   If the *Imelt* value is less than the *Imelt* value, the *Imelt* value is increased to the *Imelt* value.
   If *Imelt* is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if *Imax* is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model *Imelt* default value (which is the same as the model *Imelt* default value).

Modified_Materka_Model (Modified Materka GaAsFET Model)

Symbol



Parameters

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	8
Idss	saturation drain current	A	0
Vto	threshold voltage	V	-2.0
Beta2	coefficient for pinch-off change with respect to Vds	1/V	0
Ee	exponent defining dependence of saturation current	1/V	2.0
Ke	description of dependence on gate voltage	V	0.0
Kg	dependence on Vgs of drain slope in linear region	V	0.0
Sl	linear region slope of Vgs-0 drain characteristic	None	1.0
Ss	saturation region drain slope characteristic at vgs=0	None	0.0
Tau	transit time under gate	sec	0.0
Rgs	channel resistance	Ohm	0.0
Rgd	gate drain resistance	Ohm	0.0
Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgd	zero bias gate-drain junction capacitance	F	0.0
Rd	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs	source ohmic resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds	drain-source capacitance	F	fixed at 0.0
Gsfwd	0-none, 1=linear, 2=diode	None	linear

Gsrev	0-none, 1=linear, 2=diode	None	None
Gdfwd	0-none, 1=linear, 2=diode	None	None
Gdrev	0-none, 1=linear, 2=diode	None	linear
Vbi [†]	built-in gate potential	V	0.85
Vjr	Breakdown junction potential	V	0.025
Is	gate junction saturation current (diode model)	A	1.0e-14
Ir	gate reverse saturation current	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 3)	A	defaults to Imax
N	gate junction emission coefficient (diode model)	None	1
Fnc	flicker noise corner frequency	Hz	0.0
Lambda	channel length modulation	1/V	0.0
Vbr	reverse bias breakdown voltage	V	1e100
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1
C	gate-drain noise correlation coefficient	None	0.9
Taumdl	Use 2nd order Bessel polynomial to model tau effect in transient simulation: yes or no	None	no
wVgfwd	gate junction forward bias warning	V	None
wBvgs	gate-source reverse breakdown voltage warning	V	None
wBvgd	gate-drain reverse breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. Drain current in the Modified_Materka_Model is calculated as follows:

   $$Vp = Vto + Beta2 \times Vds$$

   if (Vfc - Vp ≤ 0 or Vp ≥ 0)
   and Ids=0

   else

   $$power0 = \left(1 - \frac{Vgc}{Vp}\right)^{(Ee + Ke \times Vgc)}$$

   $fi = Idss \times power0$
   $gi = \tanh (Sl \times Vds/(Idss \times (1-Kg \times Vgc)))$
   $hi = 1 + Ss \times Vds/Idss$
   $Ids = fi \times gi \times hi$
3. Imax and Imelt Parameters

   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.

If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.

If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).

4. The P, R, and C parameters model drain and gate noise sources.

$$\frac{\langle i_d^2\rangle}{\Delta f} = 4kTg_m P(1+f_{NC}/f)$$

$$\frac{\langle i_g^2\rangle}{\Delta f} = 4kT C_{gs}^2 \omega^2 R/g_m$$

$$\frac{\langle i_g, i_d^*\rangle}{\Delta f} = 4kTj C_{gs} \omega\sqrt{PR}\, C$$

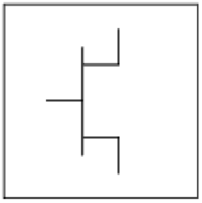
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

References

1. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Statz_Model (Statz Raytheon GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	**Description**	**Units**	**Default**
NFET	N-channel type: yes or no	None	yes
PFET	P-channel type: yes or no	None	no
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	3
Vto ††	threshold voltage	V	-2.0
Beta †, ††	transconductance	A/V^2	1.0e-4
Lambda	output conductance	1/V	0.0
Alpha	current saturation	1/V	2.0
B	Doping tail extending parameter	None	0.3
Tnom	nominal ambient temperature	°C	25
Trise	Temperature rise over ambient	°C	None
Idstc	Ids temperature coefficient	None	0.0
Vbi ††	built-in gate potential	V	0.85
Tau	transit time under gate	sec	0.0
Betatce	drain current exponential temperature coefficient	%/°C	0.0
Delta1	capacitance saturation transition voltage	V	0.3
Delta2	capacitance threshold transition voltage	V	0.2
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs †, ††	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgd †, ††	zero bias gate-drain junction capacitance	F	0.0
Rgd‡	gate drain resistance	Ohm	0.0
Tqm	junction capacitance temperature coefficient	None	0.2
Vmax	maximum junction voltage before capacitance limiting		0.5

Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Rd [‡]	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs [‡]	source ohmic resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds [†]	drain-source capacitance	F	0.0
Crf [†]	used with Rc to model frequency dependent output conductance	F	0.0
Rc [‡]	used with Crf to model frequency dependent output conductance	Ohm	infinity [†††]
Gsfwd	0-none, 1=linear, 2=diode	None	linear
Gsrev	0-none, 1=linear, 2=diode	None	none
Gdfwd	0-none, 1=linear, 2=diode	None	none
Gdrev	0-none, 1=linear, 2=diode	None	linear
Vjr	breakdown junction potential		0.025
Is [†]	gate junction saturation current (diode model)	A	1.0e-14
Ir [†]	gate reverse saturation current	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 3)	A	defaults to Imax
Xti	temperature exponent for saturation current	None	3.0
N	gate junction emission coefficient	None	1
Eg	energy gap for temperature effect on Is	None	1.11
Vbr	Gate junction reverse bias breakdown voltage	V	1e100
Vtotc	Vto temperature coefficient	V/°C	0.0
Rin [‡]	channel resistance	Ohm	0.0
Taumdl	Use 2nd order Bessel polynomial to model tau effect in transient: yes or no	None	no
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
C	gate-drain noise correlation coefficient	None	0.9
P	drain noise coefficient	None	1.0
wVgfwd	gate junction forward bias warning	V	None
wBvgs	gate-source reverse breakdown voltage warning	V	None
wBvgd	gate-drain reverse breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
AllParams	DataAccessComponent for file-based model parameter values	None	None

† Parameter value scales with Area.†† Parameter value varies with temperature based on model Tnom and

device Temp.††† Value of 0.0 is interpreted as infinity.‡ Parameter value scales inversely with Area.

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname GaAs Idsmod=3[parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by GaAsFET components to refer to the model. The third parameter indicates the type of model; for this model it is *GaAs* . Idsmod=3 is a required parameter that is used to tell the simulator to use the Statz equations. Use either parameter NFET=yes or PFET=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model  gf1  GaAs Idsmod=3 \
 Vto=-2.5 Beta=1e-3 NFET=yes
```

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. Statz_Model implementation is based on the work of Statz et al [1].
   In particular, the expressions for drain source current and gate charge are implemented exactly as published in [1]. The Statz model also includes a number of features that (although not described in the Statz article) are generally accepted to be important features of a GaAsFET model. These include a gate delay factor (Tau), an input charging resistance (Ri), gate junction forward conduction and breakdown.
3. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
4. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by

an AllParams association.

Equations/Discussion

Drain-Source Current

Statz_Model DC drain-source current is given by these expressions:

For 0 < Vds < 3 / α

$$I_{ds} = \frac{\beta V_{gs} - Vto^2}{1 + \beta V_{gs} - Vto}\left[1 - \left[1 - \frac{\alpha V_{ds}}{3}\right]^3\right](1 + \lambda V_{ds})$$

where α is Alpha, β is Beta, Θ is B.
For Vds ≥ 3/α

$$I_{ds} = \frac{\beta(V_{gs} - Vto)^2}{1 + \beta(V_{gs} - Vto)}(1 + \lambda V_{ds})$$

The current is set to zero for V_{gs} < Vto.

where α is Alpha, β is Beta, Θ is B.

Gate Charge

You are provided with two options in modeling the junction capacitance of a device. The first is to model the junction as a linear component (a constant capacitance). The second is to model the junction using a diode depletion capacitance model. If a non-zero value of Cgs is specified and Gscap is set to 1 (linear), the gate-source junction will be modeled as a linear component. Similarly, specifying a non-zero value for Cgd and Gdcap = 1 result in a linear gate-drain model. A non-zero value for either Cgs or Cgd together with Gscap =2 (junction) or Gdcap = 2 will force the use of the diode depletion capacitance model for that particular junction. Note that each junction is modeled independent of the other; hence, it is possible to model one junction as a linear component while the other is treated nonlinearly. The junction depletion charge and capacitance equations are summarized below.
The gate charge in Statz_Model is given by,
for $V_{new} > V_{max}$,

$$Q_g = Cgs\left(2 \times Vbi\left(1 - \sqrt{1 - \frac{V_{max}}{Vbi}}\right) + \frac{V_{new} - V_{max}}{\sqrt{1 - \frac{V_{max}}{Vbi}}}\right) + Cgd \times V_{eff2}$$

for $V_{new} \le V_{max}$

$$Q_g = Cgs \times 2 \times Vbi\left(1 - \sqrt{1 - \frac{V_{new}}{Vbi}}\right) + Cgd \times V_{eff2}$$

where:

V_{max} = Min (Fc x Vbi, V_{max})

$$V_{new} = \frac{1}{2}\left(V_{eff1} + Vto + \sqrt{(V_{eff1} - Vto)^2 + Delta2^2}\right)$$

$$V_{eff1} = \frac{1}{2}\left\{V_{gc} + V_{gd} + \sqrt{(V_{gc} - V_{gd})^2 + Delta1^2}\right\}$$

and

$$V_{eff2} = \frac{1}{2}\left\{V_{gc} + V_{gd} - \sqrt{(V_{gc} - V_{gd})^2 + Delta1^2}\right\}$$

The inclusion of Ri requires that one of the controlling voltages be switched from V_{gs} to V_{gc}. This results in a symmetry between the d-c nodes instead of the d-s nodal symmetry described in the Statz paper (of course, if Ri is set to zero, the model reduces to the exact representation in the Statz paper).

To implement this model in a simulator, the gate charge must be partitioned between the g-c and g-d branches. Implementation of the Statz model partitions the gate charge according to the work of Divekar [2]. Under this partitioning scheme, the gate-source charge is given by:

for $V_{new} > V_{max}$,

$$Q_{gs} = Cgs\left(2 \times Vbi\left(1 - \sqrt{1 - \frac{V_{max}}{Vbi}}\right) + \frac{V_{new} - V_{max}}{\sqrt{1 - \frac{V_{max}}{Vbi}}}\right)$$

for $V_{new} \le V_{max}$

$$Q_{gs} = Cgs \times 2 \times Vbi\left(1 - \sqrt{1 - \frac{V_{new}}{Vbi}}\right)$$

while the gate-drain charge is,

$$Q_{gd} = Cgd \times V_{eff2}$$

The small-signal capacitances (equations 16 and 17 in the Statz paper) are related to the charge partial derivatives through the following expressions:

$$C_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} + \frac{\partial Q_{gd}}{\partial V_{gc}}$$

$$C_{gd} = \frac{\partial Q_{gs}}{\partial V_{gd}} + \frac{\partial Q_{gd}}{\partial V_{gd}}$$

Although the drain-source current model and the gate-conduction model (next section) are well behaved for negative V_{ds} (as well as the zero crossing), the charge model may cause convergence problems in the region $V_{ds} < 0.0$V. The reason for this is that the charge partitioning is somewhat artificial in that Q_{gs} and Q_{gd} should *swap* roles for negative V_{ds} but don't. It is recommended that this model be used for positive V_{ds} only.

Gate forward conduction and breakdown

Implementation of Statz_Model places a diode model in both the gate-source and gate-drain junctions to model forward conduction current and reverse breakdown current. These currents are calculated with these expressions:

Gate-Source Current

for $V_{gs} > -10 \times N \times v_t$

$$I_{gs} = Is \times \left[exp\left(\frac{V_{gs}}{N \times v_t}\right) - 1\right]$$

for $-Vbr + 50 \times v_t < V_{gs} \leq -10 \times N \times v_t$

$$I_{gs} = Is \times [exp(-10) - 1] + g_{gs} \times (V_{gs} - 10 \times N \times v_t)$$

where:

$$g_{gs} = Is \times \frac{exp(-10)}{N \times v_t}$$

for $V_{gs} \leq -Vbr + 50 \times v_t$

$$I_{gs} = -Is \times \exp\left(\frac{-Vbr + V_{gs}}{N \times v_t}\right) + Is \times [exp(-10) - 1] + g_{gs} \times (V_{gs} - 10 \times N \times v_t)$$

Gate-Drain Current

for $V_{gd} > -10 \times N \times v_t$

$$I_{gd} = Is \times \left[exp\left(\frac{V_{gd}}{N \times v_t}\right) - 1 \right]$$

for $-Vbr + 50 \times v_t < V_{gd} \leq -10 \times N \times v_t$

$$I_{gd} = Is \times [exp(-10) - 1] + g_{gd} \times (V_{gd} - 10 \times N \times v_t)$$

where:

$$g_{gd} = Is \times \frac{exp-10}{N \times v_t}$$

for $V_{gd} \leq -Vbr + 50 \times v_t$

$$I_{gd} = -Is \times \exp\left(\frac{-(Vbr + V_{gd})}{N \times v_t}\right) Is \times [exp(-10) - 1] + g_{gd} \times (V_{gd} - 10 \times N \times v_t)$$

Time Delay

Like Curtice2_Model and Curtice3 _Model, Statz_Model uses an ideal time delay to model transit time effects under the gate. In the time domain, the drain source current for the ideal delay is given by:

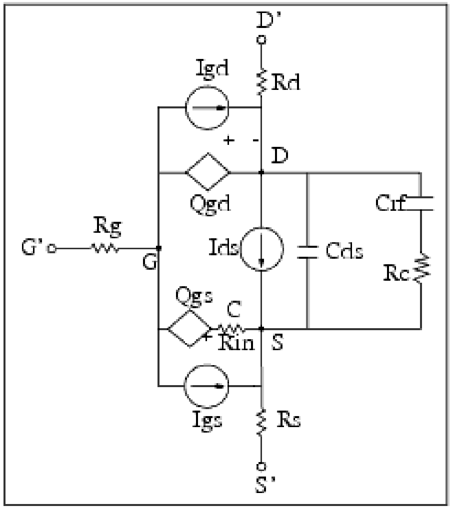
$I_{ds}(t) = I_{ds}(V_j(t\text{-}Tau), V_{ds}(t))$

where $V_j = V_{gs}$ or $V_j = V_{gd}$ (depending on whether V_{ds} is positive or negative). In the frequency domain, only the transconductance is impacted by this delay and the familiar expression for transconductance is obtained:

$y_m = g_m \times \exp(-j \times \omega \times Tau)$

High-Frequency Output Conductance

The series-RC network, shown below, is comprised of the Crf and Rc parameters and is included to provide a correction to the AC output conductance at a specific bias condition. At a frequency high enough such that Crf is an effective short, the output conductance of the device can be increased by the factor 1/Rc. (Also see [3].)



Statz_Model Schematic

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation current Is scales as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

The gate depletion capacitances Cgs and Cgd vary as:

$$Cgs^{NEW} = Cgs\left(1 + Tqm\left(4 \times 10^{-4}(Temp - Tnom) - \left(\frac{Vbi^{NEW}}{Vbi}\right) - 1\right)\right)$$

$$Cgd^{NEW} = Cgd\left(1 + Tqm\left(4 \times 10^{-4}(Temp - Tnom) - \left(\frac{Vbi^{NEW}}{Vbi}\right) - 1\right)\right)$$

Where VbiNEW is the temperature scaled value of Vbi at Temp.

The gate junction potential Vbi varies as:

$$Vbi^{NEW} = \frac{Temp}{Tnom} \times Vbi + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

where n_i is the intrinsic carrier concentration for silicon, calculated at the appropriate temperature.

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

The transconductance Beta varies as:

$$Beta^{NEW} = Beta \times 1.01^{Betatce(Temp - Tnom)}$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd and Rin is characterized by the spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Parameters P, R, and C model drain and gate noise sources.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P + 4kTg_m\ PFnc\ /f + Kf\ Ids^{Af}\ \ /f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^{\ 2}\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega\sqrt{PR}\ C$$

For Series IV compatibility, set P=2/3, R=0, C=0, and Fnc=0; copy Kf, Af, and Ffe from the Series IV model.

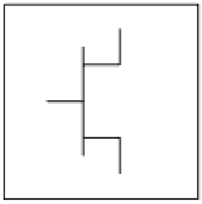
References

1. H. Statz, P. Newman, I. Smith, R. Pucel and H. Haus. "GaAs FET device and circuit simulation in SPICE," *IEEE Trans, on Electron Devices,* vol. ED-34, pp. 160-169, Feb. 1987.
2. D. Divekar, *Comments on `GaAs FET device and circuit simulation in SPICE, ' IEEE Transactions on Electron Devices,* Vol. ED-34, pp. 2564-2565, Dec. 1987.
3. C. Camacho-Penalosa and C.S. Aitchison. "Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies," *Electron. Lett.* , Vol. 21, pp. 528-529, June 6, 1985.
4. P. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE,* New York: McGraw-Hill, Second Edition 1993.

5. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Tajima_Model (Tajima GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel model type: yes or no	None	yes
PFET	P-channel model type: yes or no	None	no
Idsmod	Ids model type: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	5
Vdss	drain current saturation voltage	V	1.0
Vto	value of V1 below which Ids = Ids(V1=VT0,Vds)	V	-2.0
Beta2	coefficient for pinch-off change with respect to Vds	1/V	0
Ta	`a' coefficient	None	2
Tb	`b' coefficient	None	0.6
Tm	`m' coefficient	None	3.0
Idss	saturation drain current	A	0
Rin [††]	channel resistance	Ohm	0.0
Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgs [††]	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	linear
Cgd [††]	zero bias gate-drain junction capacitance	F	0.0
Rd	drain ohmic resistance	Ohm	fixed at 0
Rg	gate resistance	Ohm	fixed at 0
Rs	source ohmic resistance	Ohm	fixed at 0
Ld	drain inductance	H	fixed at 0.0
Lg	gate inductance	H	fixed at 0.0
Ls	source inductance	H	fixed at 0.0
Cds [††]	drain-source capacitance	F	0.0

Crf [††]	used to model frequency-dependent output conductance	F	0.0
Rc [†††]	additional output resistance for RF operation	Ohm	infinity‡
Gsfwd	0=none, 1=linear, 2=diode	None	linear
Gsrev	0=none, 1=linear, 2=diode	None	none
Gdfwd	0=none, 1=linear, 2=diode	None	none
Gdrev	0=none, 1=linear, 2=diode	None	linear
Vbi [†]	built-in gate potential	V	0.85
Is	gate junction reverse saturation current (diode model)	A	1.0e-14
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 4)	A	defaults to Imax
N	gate junction emission coefficient (diode model)	None	1
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate-drain noise correlation coefficient	None	0.9
Tnom	nominal ambient temperature	° C	25
wVgfwd	gate junction forward bias warning	V	None
wBvgs	gate-source reverse breakdown voltage warning	V	None
wBvgd	gate-drain reverse breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

[†] Parameter value varies with temperature based on model Tnom and device Temp. [††] Parameter value scales with Area. [†††] Parameter value scales inversely with Area. [‡] A value of 0.0 is interpreted as infinity.

Notes/Equations

1. This model supplies values for a GaAsFET device.
2. The P, R, and C parameters model drain and gate noise sources.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\, P(1 + f_{NC}/f)$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\, C_{gs}^{2}\, \omega^2\, R/g_m$$

$$\frac{\langle i_g, i_d^{*} \rangle}{\Delta f} = 4kTj\, C_{gs}\, \omega \sqrt{PR}\, C$$

3. Additional parameter equations are given:
   u_p = Vto − Beta^2 × Vds − Vbi
   uc = (ugs − Vbi - up)/up
   If $u_p \geq 0$ or $u_c \geq 0$, then ids = 0

else:

$$id_1 = \left[\frac{\left(\exp(Tm \bullet \upsilon c)^{-1}\right)}{Tm} - \upsilon c\right] \Big/ \left[1 - \frac{(1 - \exp(-Tm))}{Tm}\right]$$

$$id_2 = Idss \bullet \left[1 - \exp\left(\left(\frac{\upsilon ds}{Vdss}\right) - Ta\left(\frac{\upsilon ds}{Vdss}\right)^2 - Tb\left(\frac{\upsilon ds}{Vdss}\right)^3\right)\right]$$

$ids = id_1 \times id_2$

4. Imax and Imelt Parameters

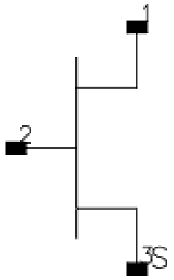
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

References

1. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

TOM3 (TriQuint TOM3 Scalable Nonlinear FET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a TOM3_Model	None	TOM3M1
W	gate width	m	no scaling
Ng	number of gate fingers	None	no scaling
Temp	device instance temperature	°C	25
Trise	device temperature relative to circuit ambient (if Temp not specified)	°C	0
Noise	noise generation option: yes or no	None	yes
_M	number of devices in parallel	None	1

Range of Usage

W > 0
Ng > 0

Notes/Equations

1. W and Ng are used for scaling device instance. See TOM3_Model information for details. Area/finger scaling is performed only if both W and Ng are specified and their values are positive.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

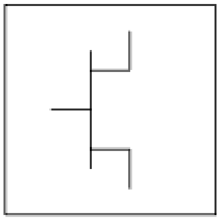
DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgsi)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Cgs	Gate-source capacitance (dQg/dVgsi)	farads
Cgd	Gate-drain capacitance (dQg/dVgdi)	farads
Ggse	Gate-source diode conductance	siemens
Ggde	Gate-drain diode conductance	siemens
Ggsi	Gate-source leakage conductance	siemens
Ggdi	Gate-drain leakage conductance	siemens
Vgse	Gate-source voltage	volts
Vgde	Gate-drain voltage	volts
Vcvs	Gate voltage offset	volts
dVcvs_dVc	Controlling coefficient for VCVS	
Vgs	External gate-source voltage	volts
Vds	External drain-source voltage	volts

3. This device has no default artwork associated with it.

TOM3_Model (TriQuint TOM3 Scalable Nonlinear FET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NFET	N-channel type: yes or no	None	YES
PFET	P-channel type: yes or no	None	NO
Tnom	model temperature at which all parameters were derived	°C	25
Ugw	gate width to which model parameters are normalized	m	1e-6
Ngf	number of gate fingers to which model parameters are normalized	None	1
Vto [†]	threshold voltage	V	-2.0
Alpha [†]	saturation parameter in Ids equation	1/V	3.0
Beta [†], [†††]	transconductance parameter in Ids equation	A/V^Q	0.05
Lambda	channel length modulation / output conductance	1/V	0
Gamma [†]	coefficient for pinch-off change with respect to Vds	None	0.1
Q	power generalizing the square-law for Ids current	None	2.0
K	knee function power law coefficient	None	3.0
Vst [†]	subthreshold slope voltage	V	0.05
Mst [†]	parameter for subthreshold slope voltage dependence on Vds	1/V	0
Ilk [†††]	reverse leakage saturation current - diode models	A	0.1e-6
Plk	reverse leakage reference voltage - diode models	V	2.25
Kgamma	feedback coefficient for the internal VCVS	None	0.33
Taugd	series Ctau-Rtau time constant (implicit definition of Rtau)	sec	1.0e-9
Ctau	dispersion model capacitance	F	1.0e-15
Qgql [†††]	low-power gate charge nonlinear term coefficient	C	0.2e-12
Qgqh [†††]	high-power gate charge nonlinear term coefficient	C	0.1e-12
[†††]	reference current in high-power gate charge nonlinear Ids term	A	0.1e-3

Qgi0			
Qgag	low-power gate charge nonlinear term exponential coefficient	1/V	0.75
Qgad	low-power gate charge nonlinear term exponential Vds coefficient	1/V	0.65
Qggb [††]	transition coefficient for combined low-high power charge	1/W	3.0
Qgcl [†††]	low-power gate charge linear terms coefficient	F	0.1e-12
Qgsh [†††]	high-power gate charge linear Vgsi term coefficient	F	0.2e-12
Qgdh [†††]	high-power gate charge linear Vgdi term coefficient	F	0.1e-12
Qgg0 [†††]	combined low-high power additional linear terms coefficient	F	0
Capmod	capacitance model: 1=bias-dependent capacitances, 2=charge	None	2
Cds [†††]	drain-source capacitance	F	0
Tau	transit time under gate	sec	0
Rd [†, ††]	drain ohmic resistance	Ohm	0
Rdtc	temperature linear coefficient for Rd	1/°C	0
Rg [‡]	gate resistance	Ohm	0
Rgmet [‡]	gate metal resistance	Ohm	0
Rs [†, ††]	source ohmic resistance	Ohm	0
Rstc	temperature linear coefficient for Rs	1/°C	0
Is [†, †††]	saturation current in forward gate current diode models	A	1e-12
Eta	emission coefficient for gate diode models	None	1.25
Alphatce	temperature exponential coefficient for Alpha	1/°C	0
Gammatc	temperature linear coefficient for Gamma	1/°C	0
Msttc	temperature linear coefficient for Mst	1/(V °C)	0
Vsttc	temperature linear coefficient for Vst	V/°C	0
Vtotc	temperature linear coefficient for Vto	V/°C	0
Betatce	temperature exponential coefficient for Beta	1/°C	0
Xti	temperature exponent for saturation current	None	2.5
Eg	energy gap for temperature effect on Is	eV	1.11
Imax	explosion current	A	1.6
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate-drain noise correlation coefficient	None	0.9
Kf	flicker noise coefficient	None	0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
wVgfwd	gate junction forward bias warning	V	None
wBvgs	gate-source reverse breakdown voltage warning	V	None
wBvgd	gate-drain reverse breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

† Parameter value varies with temperature based on model Tnom and device Temp. †† Parameter value scales inversely with area. ††† Parameter value scales with area. ‡ Total gate resistance is Rg + Rgmet.

Notes/Equations

1. The published TOM3 model [1, 2] is capacitance-based, which corresponds to setting Capmod=1 (refer to Gate Capacitances). In general, the bias-dependent capacitor models are known to be less robust, which sometimes leads to non-convergence problems. ADS implementation of TOM3 is enhanced by providing a charge-based model, which corresponds to setting Capmod=2 (refer to Gate Charge Model). Charge-based models are normally more robust and they are better justified theoretically.
   Please note that the distribution of the charge between the drain and source is not exactly the same for the two modes of the capacitance model. Therefore, simulation results for the two modes may slightly differ.
2. This model supplies values for a TOM3 device.
3. Implementation of the TOM3 model is based on [1] and [2].
4. All model parameters except for Vto (and Vtotc) are identical for the corresponding N- and P-channel devices. The signs of Vto and Vtotc must be changed in order to generate consistent results for N- and P-type transistors.
5. The dispersion branch consists of a series connection of a capacitance Ctau and a resistance Rtau. Rtau does not appear among the model parameters; instead, the model parameters include the time constant Taugd of that branch, and thus Rtau is implicitly defined as Rtau = Taugd / Ctau.
6. To prevent numerical problems, the setting of some model parameters to 0 is trapped by the simulator. The following parameters are maintained by the simulator at a minimum value:

   Rd = 1e-4
   Rs = 1e-4
   Rg = 1e-4

   If the user wants any of the extrinsic resistances Rd, Rg, and Rs to be exactly zero, their values should not be entered. The default is a short circuit. If a value is entered, it must be positive.
7. Imax and Imelt Parameters
   Imax specifies the P-N junction explosion current for D1, D2, D3 and D4 diodes. Imax can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   The Imelt parameter, available in several other ADS models, is not currently implemented in the TOM3 model.
8. For SDD compatibility use Taugd = 1.0e-6 if "tau_gd = Slow" mode was used, Taugd= 10.0e-9 if "taug_gd=Fast" mode was used, and Rgmet = 0.1, Rdtc = 0.0044, Rstc = 0.0016, Xti = 2 × Eta, Eg = 0.9, Imax = 1.0e6.
9. Several parameters are restricted to values > 0. If the user violates this restriction, an error message will be written in the status window, and the simulation will not proceed.
10. Model parameters such as Ls, Ld, Lg are not currently used by the TOM3 device in the simulator. Extrinsic components must be added externally by the user.

DC Drain-Source Current

The TOM3 DC drain-source current is calculated using the following equations [2].

$$I_{ds} = I_0 \times (1 + \lambda V_{ds})$$

where:

$$I_0 = \beta \times (V_G)^Q \times f_k$$

$$f_k = \frac{\alpha V_{ds}}{(1 + (\alpha V_{ds})^k)^{1/k}}$$

$$V_G = Q \times V_{ST} \times \ln(1 + \exp(u))$$

$$u = \frac{V_{gsi} - V_{TO} + \gamma V_{ds}}{Q \times V_{ST}}$$

$$V_{ST} = V_{ST0} \times (1 + M_{ST0} \times V_{ds})$$

The model parameters for the drain current are: λ (Lambda), β (Beta), Q (Q), α (Alpha), *k* (K), V_{TO}(Vto), γ (Gamma), V_{ST0}(Vst) and MST0 (Mst).

For time-varying drain-source current, the voltage V_{gsi} is delayed by the transit time Tau.

Gate Capacitances

The gate capacitances in the TOM3 model are derived from the following charge equations (see [1, 2]). The total gate charge is given as:

$$Q_{GG} = Q_{GL} \times f_T + Q_{GH} \times (1 - f_T) + Q_{GG0} \times (V_{gsi} + V_{gdi})$$

where

$$f_T = \exp(-Q_{GGB} \times I_{ds} \times V_{ds})$$

is a transition function combining the *low power* charge

$$Q_{GL} = Q_{GQL} \times \exp(Q_{GAG} \times (V_{gsi} + V_{gdi})) \times \cosh(Q_{GAD} \times V_{ds}) + Q_{GCL} \times (V_{gsi} + V_{gdi})$$

with the *high power* charge

$$Q_{GH} = \left(Q_{GQH} \times \ln\left(1 + \frac{I_{ds}}{Q_{GI0}}\right) + Q_{GSH} \times V_{gsi}\right) + Q_{GDH} \times V_{gdi}$$

The model parameters for the gate charge are: Q_{GG0} (Qgg0), Q_{GGB} (Qggb), Q_{GQL} (Qgql), Q_{GAG} (Qgag), Q_{GAD} (Qgad), Q_{GCL} (Qgcl), Q_{GQH} (Qgqh), Q_{GI0} (Qgi0), Q_{GSH} (Qgsh) and Q_{GDH} (Qgdh).

There are two capacitance models in the TOM3 implementation in ADS. The first model corresponds to other TriQuint implementations of the TOM3 model, including the SDD implementation in ADS. That model is invoked by setting Capmod = 1 (bias-dependent capacitances). The gate-source and gate-drain self-capacitances are then defined as:

$$C_{gs} = \left.\frac{\partial Q_{GG}}{\partial V_{gsi}}\right|_{V_{gdi} = \mathrm{const}}$$

$$C_{gd} = \left.\frac{\partial Q_{GG}}{\partial V_{gdi}}\right|_{V_{gsi} = \mathrm{const}}$$

and, correspondingly, their contribution to the drain, gate and source currents follows the partitioning as:

$$I_{Cgsi} = C_{gs}(V_{gsi}, V_{gdi}) \times \frac{dV_{gsi}}{dt}$$

and

$$I_{Cgdi} = C_{gd}(V_{gsi}, V_{gdi}) \times \frac{dV_{gdi}}{dt}$$

Gate Charge Model

The other capacitance model in the TOM3 implementation in ADS is invoked by setting Capmod = 2 (charge model). The total gate charge is partitioned 50/50 onto the gate-source and gate-drain charges. Their derivatives with respect to the voltages V_{gsi} and V_{gdi} define the corresponding self- and trans-capacitances.
For this release the user cannot control how the gate charge is partitioned.

Gate Diode Currents

The four diodes in the TOM3 model are intended to account for gate diode, leakage and breakdown. The following equations are used for the respective diodes [2].

Diodes D1 and D2:

$$I_{gse} = I_s \times \left(\exp\left(\frac{V_{gse}}{\eta V_T}\right) - 1\right)$$

$$I_{gde} = I_s \times \left(\exp\left(\frac{V_{gde}}{\eta V_T}\right) - 1\right)$$

Diodes D3 and D4:

$$I_{Dgsi} = I_{LK} \times \left(1 - \exp\left(\frac{-V_{gsi}}{\varphi_{LK}}\right)\right)$$

$$I_{Dgdi} = I_{LK} \times \left(1 - \exp\left(\frac{-V_{gdi}}{\varphi_{LK}}\right)\right)$$

where VT is the thermal voltage:

$$V_T = \frac{k \times T}{q}$$

$k = 1.38 \times 10^{-23}$ (Boltzmann's constant)

$q = 1.602 \times 10^{-19}$ (electron charge)

I_s (Is), η (Eta), I_{LK} (Ilk), φ_{LK} (Plk) are the model parameters. T is either equal to the device instance parameter Temp, or if Temp is not specified then T = ambient_circuit_temperature + Trise. V_{gse}, V_{gde}, V_{gsi} and V_{gdi} are instantaneous voltages across the respective diodes. Please note that the models are symmetric for the drain and source diodes.

Dimensional Scaling Relations

For each device instance, area/finger scaling is performed only if both W and Ng device parameters are specified and their values are positive. The width scaling factor is determined as:

width_scale = W / Ugw

where W is the actual device gate width and Ugw is a model parameter whose meaning is the gate width to which all model parameters have been normalized (or Ugw is the actual gate width of the measured device if the extracted model parameters have not been normalized).

Similarly, the finger scaling factor is determined as;

finger_scale = Ng / Ngf

where Ng is the actual device number of fingers and Ngf is a model parameter whose meaning is the number of gate fingers to which all the model parameters have been normalized (or Ngf is the actual number of gate fingers of the measured device if the extracted model parameters have not been normalized).

It is strongly recommended that model parameters Ugw and Ngf are always specified without relying on their default values.

The following model parameters are scaled with *area* = *width_scale* * *finger_scale*

Beta, Is, Cds, Qgql, Qgqh, Qgi0, Qgcl, Qgsh, Qgdh, Qgg0, Ilk

The following model parameters are scaled inversely with *area*:

Qggb, Rd, Rs, Rg

Rgmet is scaled with:

width_scale / *finger_scale*

Drain Dispersion and Self-Heating Effects

The TOM3 model topology is almost identical to other GaAs FET models. The main difference is an addition of a VCVS which modifies the internal gate voltages based on a portion of V_{ds}. According to the authors of the model, this internal feedback accounts well for self-heating effects.

The branch Rtau-Ctau, as in other GaAs FET models, accounts for drain dispersion.

Temperature Scaling Relations

The TOM3 model uses an extensive set of temperature scaling relations that permit the analysis of drain current, gate current, capacitances, and even parasitic resistances over ambient temperature changes. The scaling relations assume the unscaled (nominal) parameters were extracted at Tnom.

It is strongly recommended that the model parameter Tnom is always specified without relying on its default value.

The parameters are scaled to an arbitrary operating temperature through the temperature scaling relations. Note that the user specifies the temperatures in °C and the program converts them to units of Kelvin. Three types of scaling equations are used for the TOM3 model parameters: linear, exponential and diode.

The following equations summarize temperature scaling. The value of T is either the device instance parameter Temp, or if Temp is not specified then it is evaluated as:

T = ambient_circuit_temperature + Trise.

For linear scaling, absolute scale, the equation is:

$$Par = Par_{nom} + scale \times (T - T_{nom})$$

For linear scaling, relative scale, the equation is:

$$Par = Par_{nom} \times (1 + scale \times (T - T_{nom}))$$

For exponential scaling, the equation is:

$$Par = Par_{nom} \times (1.01)^{scale \times (T - T_{nom})}$$

For diode saturation current scaling, the equation is:

$$Is = Is_{nom} \times \exp\left(\frac{E_g}{\eta \frac{kT_{nom}}{q}} - \frac{E_g}{\eta \frac{kT}{q}} + \frac{X_{ti}}{\eta} \ln\left(\frac{T}{T_{nom}}\right)\right)$$

where:

Is_{nom} (Is), E_g (Eg), X_{ti} (Xti) and η (Eta) are model parameters
$k = 1.38 \times 10^{-23}$ (Boltzmann's constant)
$q = 1.602 \times 10^{-19}$ (electron charge)

This type of temperature scaling applies to Is, the saturation current for D1 and D2 diodes. The energy gap Eg is not scaled with the temperature.
The following parameters are scaled linearly (absolute scale) with temperature:

Vto, Gamma, Vst, and Mst

Scale factors are Vtotc, Gammatc, Vsttc, and Msttc, respectively.

The following parameters are scaled linearly (relative scale) with temperature:

Rd and Rs

Scale factors are Rdtc and Rstc, respectively.

The following parameters are scaled exponentially with temperature:

Alpha, Beta

Scale factors are Alphatce and Betatce, respectively.

Noise Model

Thermal noise generated by resistors Rg, Rs and Rd is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Parameters P, R, and C model drain and gate noise sources [3].

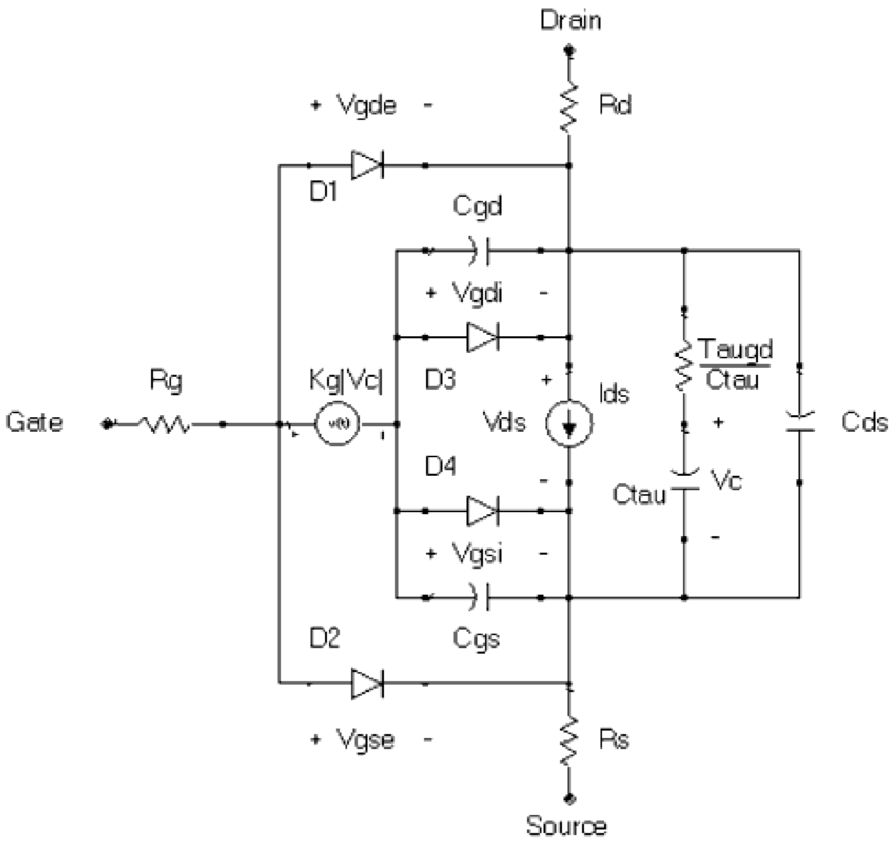
$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\, P + 4kTg_m\, PFnc\ /f + Kf\, Ids^{Af}\ /f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\, C_{gs}^{\ 2}\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\, C_{gs}\ \omega\sqrt{PR}\ C$$

For SDD compatibility, set P=2/3, R=0, C=0, and Fnc=0; copy Kf, Af, and Ffe from the SDD model.

Equivalent Circuit



References

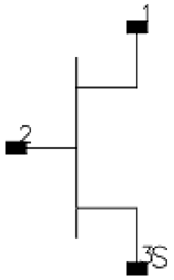
1. R. B. Hallgren and P. H. Litzenberg, "TOM3 Capacitance Model: Linking Large- and Small-Signal MESFET Models in SPICE," *IEEE Trans. Microwave Theory and Techniques* , vol. 47, 1999, pp. 556-561.
2. R. B. Hallgren and D. S. Smith, "TOM3 Equations," a document provided by TriQuint, Revised: 2 December 1999.
3. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

TOM4 (TriQuint TOM4 Scalable Nonlinear FET)

Note
Some information for this model was not available when ADS 2008 Update 1 was released. For updated documentation see our website at:

> http://www.agilent.com/find/eesof-docs
> Select ADS 2008 Update 1, then choose **Components** > **Analog/RF** > **Nonlinear Devices** > **TOM4**

Symbol



Parameters

Name	Description	Units	Default
Model	Name of a TOM4_Model	None	TOM4M1
W	Gate width	m	no scaling
Ng	Number of gate fingers	None	no scaling
Temp	Device instance temperature	°C	25
Trise	Device temperature relative to circuit ambient (if Temp not specified)	°C	0
Mode	Nonlinear spectral model on/off	None	1
Noise	Noise generation option: yes (1) or no (0)	None	1

Netlist syntax

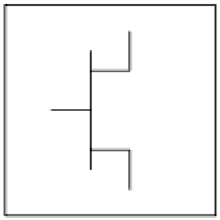
```
modelName:instanceName d g s parm=value
```

TOM4_Model (TriQuint TOM4 Scalable Nonlinear FET Model)

Note
Some information for this model was not available when ADS 2008 Update 1 was released. For updated documentation see our website at:

http://www.agilent.com/find/eesof-docs
Select ADS 2008 Update 1, then choose **Components** > **Analog/RF** > **Nonlinear Devices** > **TOM4 Model**

Symbol



Parameters

Model parameters must be specified in SI units.

Name (Alias)	Description	Units	Default
Tnom	Parameter measurement temperature	°C	25
BETA	Channel current scaling parameter	A / µm	0.0002
LAMBDA	Channel channel current slope parameter	1/V	-0.044
ALF0	Knee function parameter	1 / V	2.8
KALF	Knee parameter correction factor	1 / V	-0.7
GAMMA	Threshold voltage reduction parameter	None	0.062
VTO	Threshold voltage	V	-0.5
Q_0	Channel current power law exponent	None	1.6
KQ1	First order Q correction factor	1 / V	0
KQ2	Second order Q correction factor	1 / V	0
VST	Channel current subthreshold parameter	V	0.05
MST	Subthreshold slope parameter	1 / V	0
ISO	Gate diode saturation current	A / µm	1.4e-014
ETA	Gate diode ideality factor	None	1.25
KGAMMA	GD feedback parameter	None	0.033
R_S	Extrinsic Source resistance	Ω-µm	370
R_D	Eextrinsic Drain resistance	Ω-µm	715
R_G	Extrinsic Gate resistance	Ω-µm	750
CDS	Drain-source capacitance	F /µm	2.6e-016
TAU	Channel conductance time delay	sec	4e-012
C_J	Junction capacitance scaling parameter	F / µm	1e-012
V_J	Junction capacitance voltage parameter	V	0.6
M_J	Junction capacitance slope parameter	None	0.5
F_C	Junction voltage limit parameter	None	0.9

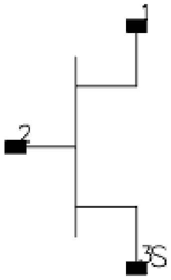
CGGI	Depleted capacitance scaling parameter	F / µm	1e-015
CGSS	Minimum gate-source capacitance	F / µm	3e-016
KGIL	Depleted capacitance low-side slope	1 / V	2e-016
KGIH	Depleted capacitance high-side slope	1 / V	2e-016
VTH	Depleted capacitance partition voltage	V	0.3
CGG0	Series capacitance scaling parameter	F / µm	1e-015
CGDS	Minimum gate-drain capacitance	F / µm	3e-016
KG01	Series capacitance first-order correction factor	1 / V	2e-016
KG02	Series capacitance second-order correction factor	1 / V	2e-016
PHI0	Junction capacitance offset voltage	V	0.2
KPHI	Offset voltage correction factor	1 / V	0
T_D	Gate diode diffusion time constant	sec	1e-006
ILK			3.8e-012
PLK			0.844
ALPHATCE	Temperature exponential coefficient for Alpha	1/°C	-0.4
GAMMATC	Temperature linear coefficient for Gamma	1/°C	0
CGSTCE		1/°C	0
CGDTCE		1/°C	0
MSTTC	Temperature linear coefficient for Mst	1/(V °C)	0
VSTTC	Temperature linear coefficient for Vst	V/°C	0
VTOTC	Temperature linear coefficient for Vto	V/°C	-0.00091
BETATCE	Temperature exponential coefficient for Beta	1/°C	0
Af	Flicker noise exponent	None	1
Kf	Flicker noise coefficient	None	3.86e-011
Ffe	Flicker noise frequency exponent	None	1
E_G	Energy gap for temperature effect on Is	eV	0.3
XTI	Temperature exponent for saturation current	None	2
CapMod	Capacitance model: 1=bias-dependent capacitances, 0=charge	None	1

Netlist syntax

model ModelName TOM4 ...

TOM (TriQuint Scalable Nonlinear GaAsFET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a TOM_Model	None	TOMM1
W	new unit gate width, in length units		1.0
N	new number of gate fingers	None	0
Temp	device operating temperature	°C	25
_M	number of devices in parallel	None	1

Range of Usage

W > 0
N > 0

Notes/Equations

1. W and N are used for scaling device instance as described in the TOM_Model information.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

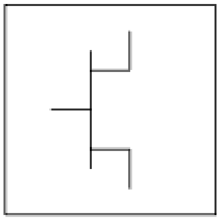
DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Ggs	Gate to source conductance	siemens
Ggd	Gate to drain conductance	siemens
dIgs_dVgd	(dIgs/dVgd)	siemens
dIgd_dVgs	(dIgd/dVgs)	siemens
dIds_dVgb	Backgate transconductance (dIds/dVgb)	siemens
Cgs	Gate-source capacitance	farads
Cgd	Gate-drain capacitance	farads
Cds	Drain-source capacitance	farads
dQgs_dVgd	(dQgs/dVgd)	farads
dQgd_dVgs	(dQgd/dVgs)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts

3. This device has no default artwork associated with it.

TOM_Model (TriQuint Scalable Nonlinear GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
Idsmod	Ids model: 1=CQ 2=CC 3=Statz 4=Materka 5=Tajima 6=symbolic 7=TOM 8=Modified Materka	None	7
Vto [†]	nonscalable portion of threshold voltage	V	-2.0
Alpha	saturation voltage coefficient	1/V	2.0
Beta [†, †††]	transconductance coefficient	A/V^Q	1.0e-4
Tqdelta [††]	output feedback coefficient	1/W	0.0
Tqgamma	DC drain pull coefficient	None	0.0
TggammaAc	AC pinchoff change with vds	None	0.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Q	power law exponent	None	2.0
Tau	gate transit time delay	sec	0.0
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	drain current exponential temperature coefficient	%/°C	0.0
Cgs [†, †††]	zero-bias gate-source capacitance	F	0.0
Cgd [†, †††]	zero-bias gate-drain capacitance	F	0.0
Vbi	gate diode built-in potential	V	0.85
Tqm	temperature coefficient for TriQuint junction capacitance	None	0.2
Vmax	maximum junction voltage before capacitance limiting		0.5
Fc	coefficient for forward bias depletion capacitance (diode model)	None	0.5
Delta1	capacitance saturation transition voltage	V	0.3
Delta2	capacitance threshold transition voltage	V	0.2
M	grading coefficient	None	0.5

Is †, †††	gate diode saturation current (diode model)	A	1.0e-14
N	gate diode emission coefficient (diode model)	None	1
Eg	energy gap for temperature effect on Is		1.11
Xti	temperature exponent for saturation current	None	3.0
Vbr	Gate diode breakdown voltage	V	1e100
Rg ‡‡	gate ohmic resistance	Ohm	fixed at 0
Rd ††	drain contact resistance	Ohm	fixed at 0
Rs ††	source contact resistance	Ohm	fixed at 0
Trg1	linear temperature coefficient for Rg	1/°C	0.0
Trd1	linear temperature coefficient for Rd	1/°C	0.0
Trs1	linear temperature coefficient for Rs	1/°C	0.0
Cds †††	drain source capacitance	F	0.0
Rdb	R for frequency-dependent output conductance	Ohm	0.0
Cbs	C for frequency-dependent output capacitance	F	0.0
Rgmet ‡‡	gate metal resistance	Ohm	0.0
Vtosc ††	scalable portion of threshold voltage	V	0
Ris ††	source end channel resistance	Ohm	0.0
Rid ††	drain end channel resistance	Ohm	0.0
Vgr	Vg(s,d)c includes voltage across Rg(s,d): yes or no	None	No
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 4)	A	defaults to Imax
Fnc	flicker noise corner frequency	Hz	0.0
R	gate noise coefficient	None	0.5
P	drain noise coefficient	None	1.0
C	gate drain noise correlation coefficient	None	0.9
Taumdl	Use 2nd order Bessel polynomial to model tau effect in transient: yes or no	None	no
Ugw	unit gate width of device	um	1e-6
Ngf	number of device gate fingers	None	1
wVgfwd	gate junction forward bias warning	V	None
wBvgs	gate-source reverse breakdown voltage warning	V	None
wBvgd	gate-drain reverse breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap	None	Statz
Gsfwd	0=none, 1=linear, 2=diode	None	diode
Gsrev	0=none, 1=linear, 2=diode	None	diode
Gdcap	0=None 1=Linear 2=Junction 3=Statz charge 5=Statz cap 6=Statz charge conserving	None	Statz
Gdfwd	0=none, 1=linear, 2=diode	None	diode
Gdrev	0=none, 1=linear, 2=diode	None	diode

Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
AllParams	Data Access Component (DAC) Based Parameters	None	None
† Parameter value varies with temperature based on model Tnom and device Temp.†† Parameter value scales inversely with Area.††† Parameter value scales with Area.‡ Value of 0.0 is interpreted as infinity.‡‡ Total gate resistance is Rg + Rgmet.			

Notes/Equations

1. This model supplies values for a TOM device.
2. Implementation of the TOM model is based on the work of McCaman et al, and includes some features not covered in McCaman's work. These enhancements include scaling with gate area and a seamless method for simulating with two different values for the parameters Tqgamma and TqgammaAc (one extracted at DC and the other adjusted to fit AC output conductance).
3. Model parameters such as Ls, Ld, Lg are not used by the TOM device in the simulator. Only those parameters in the parameters list are part of the TOM device. Extrinsic devices must be added externally by the user.
4. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
5. To prevent numerical problems, the setting of some model parameters to 0 is trapped by the simulator. The parameter values are changed internally:

   $Rd = 10^{-4}$
   $Rs = 10^{-4}$
   $Rg = 10^{-4}$
   $Ris = 10^{-4}$
   $Rid = 10^{-4}$
   $Rgmet = 10^{-4}$

   Other parameters are restricted to values > 0. If the user violates this restriction, the parameters will be internally fixed by the simulator:

   Vbi = 0.1
   N = 1.0
   Tqdelta= 0.0

Equations/Discussion

DC Drain-Source Current

The Tom DC drain-source current model is an enhanced version of the one published by McCamant et al. It includes the same features as the version implemented by TriQuint in PSPICE for their foundry customers (minus temperature effects). The TOM model DC drain-source current is given by the following expressions:

$$Ids = \frac{Idso}{1 + \delta \times Vds \times Idso}$$

where

$$Idso = \beta(V_{gs} - V_t)^Q \times \left[1 - \left[1 - \frac{\alpha Vds}{3}\right]^3\right]$$

for 0 < Vds < 3/α

$$Idso = \beta(V_{gs} - V_t)^Q$$

for Vds ≥ 3/α

The threshold voltage V_t is given by:

$Vt = (Vto + Vtosc) - Tqgamma \times Vds$

where δ is Tqdelta, α is Alpha, β is Beta, and Vtosc represents the scalable portion of the zero-bias threshold voltage.

The current is set to zero for Vgs < Vt.

Gate Capacitances

The gate capacitances in the TOM model come from Statz et al.

The gate-source capacitance:

$$\frac{Cgs}{\sqrt{1 - \frac{Vn}{Vbi}}} \times \frac{1}{2}\left[1 + \frac{Veff - Vto}{\sqrt{(Veff - Vto)^2 + Delta2^2}}\right] \times \frac{1}{2}\left[1 + \frac{Vgs - Vgd}{\sqrt{(Vgs - Vgd)^2 + Delta^2}}\right] + Cgd \times \frac{1}{2}$$
$$\left[1 - \frac{Vgs - Vgd}{\sqrt{(Vgs - Vgd)^2 + Delta^2}}\right]$$

The gate-drain capacitance:

$$\frac{Cgs}{\sqrt{1-\frac{Vn}{Vbi}}}\times\frac{1}{2}\left[1+\frac{Veff-Vto}{\sqrt{(Veff-Vto)^2+Delta2^2}}\right]\times\frac{1}{2}\left[1-\frac{Vgs-Vgd}{\sqrt{(Vgs-Vgd)^2+Delta^2}}\right]+Cgd\times\frac{1}{2}$$
$$\left[1+\frac{Vgs-Vgd}{\sqrt{(Vgs-Vgd)^2+Delta^2}}\right]$$

where

Delta = Delta1 if Delta1 is specified, otherwise Delta = $\frac{1}{Alpha}$

$$Veff = \frac{1}{2}(Vgs+Vgd+\sqrt{(Vgs-Vgd)^2+Delta^2})$$

$$Vnew = \frac{1}{2}(Veff+Vto+\sqrt{(Veff-Vto)^2+Delta2^2})$$

Vn = Vnew if Vnew < Min (Fc × Vbi, Vmax) otherwise Vn = Min (Fc × Vbi, Vmax)

High-Frequency Output Conductance

In their paper McCaman et al., discuss the effects of the parameter ccnld-4-20-532.gif! on the output conductance of the TOM model. Agilent's implementation permits the user to input both a DC (Tqgamma) and high frequency (TqgammaAc) value into the model. Given these two γ values, two separate values of the drain-source current function Ids can be calculated, one for DC and one for AC:

Ids^{DC} = Ids (Vgs (t-Tau), Vds, Tqgamma)
Ids^{AC} = Ids (Vgs (t-Tau), Vds, TqgammaAc)

These two current functions can be seamlessly integrated into the nonlinear model by setting the current source in the equivalent circuit to the difference of these two functions:
Idb (Vgs (t-Tau), Vds) = Ids^{AC} - Ids^{DC}
The circuit elements Rdb and Cbs are both linear elements that are used to control the frequency at which the current source Idb becomes a factor. Note that at DC the source Idb has no impact on the response and the drain-source current is just the DC value. At very high frequency and with Rdb set to a very large quantity, the sources Ids and Idb add, giving the AC value for the drain-source current. The frequency at which the current (conductance) is midway between its two transitional extremes is:

$$f_o = \frac{1}{2\pi\tau_{disp}}$$

where

$$\tau_{disp} = Rdb \times Cbs$$

The user may select this transition frequency by setting the parameters Rdb and Cbs. However, it is recommended that Rdb be kept at a large value so it remains an effective open to the circuit.

Parameters Rdb and Cbs should not be set to zero; they should either be set to non-zero values or left blank. When they are left blank, the drain-source current dispersion effect is not modeled.

Dimensional Scaling Relations

Scaling of TOM_Model parameters is accomplished through the use of the model parameters Ugw and Ngf and the device parameters Ugw (same name as the model parameter) and N. From these four parameters, the following scaling relations can be defined:

$$sf = \frac{W \times N}{Ugw \times Ngf}$$

$$sfg = \frac{Ugw \times N}{W \times Ngf}$$

where W represents the device parameter Ugw, the new unit gate width.
Scaling will be disabled if N is not specified. The new parameters are calculated internally by the simulator according to the following equations:

$$Beta^{new} = Beta \times sf$$

$$Tqdelta^{new} = \frac{Tqdelta}{sf}$$

$$Vtosc^{new} = \frac{Vtosc}{sf}$$

$$Is^{new} = Is \times sf$$

$$Ris^{new} = \frac{Ris}{sf}$$

$$Rid^{new} = \frac{Rid}{sf}$$

Temperature Scaling Relations

TOM_Model uses an extensive set of temperature scaling relations that permit the analysis of drain current, gate current, capacitances and even parasitic resistances over ambient temperature changes. The scaling relations assume the unscaled (nominal) parameters were extracted at Tnom. The parameters are scaled to an arbitrary operating ambient temperature (Temp) through the temperature scaling relations. Note that the user must specify the temperatures Temp and Tnom in °C; the program converts these temperatures to units of Kelvin. The equations that follow use temperature in Kelvin.

$$Vbi(Temp) = Vbi \times \left(\frac{Temp}{Tnom}\right) - 3V_t \log\left(\frac{Temp}{Tnom}\right)$$

$$-E_g(Tnom) \times \left(\frac{Temp}{Tnom}\right) + E_g(Temp)$$

$$Beta(Temp) = Beta \times 1.01^{Betatce \times (Temp - Tnon}$$

$$Vto(Temp) = Vto + Vtotc \times (Temp - Tnom)$$

$$Is(Temp) = exp\left[\left(\frac{Temp}{Tnom} - 1\right) \times \frac{Eg}{V_t}\right] \times Is\left(\frac{Temp}{Tnom}\right)^{\frac{Xti}{N}}$$

$$Rd(Temp) = Rd \times (1 + Trd1 \times (Temp - Tnom))$$

$$Rs(Temp) = Rs \times (1 + Trs1 \times (Temp - Tnom))$$

$$Cgs(Temp) = Cgs\left[1 + Tqm \times \left[4.0 \times 10^{-4}(Temp - Tnom) + 1 - \frac{Vbi(Temp)}{Vbi}\right]\right]$$

$$Cgd(Temp) = Cgd\left[1 + Tqm \times \left[4.0 \times 10^{-4} \times \left((Temp - Tnom) + 1 - \frac{Vbi(Temp)}{Vbi}\right)\right]\right]$$

where:

$$V_t = \frac{V \times Temp}{q}$$

$$E_g(T) = \frac{1.519 - 5.405 \times 10^{-4} T^2}{T + 204}$$

where:

K = Boltzmann's constant = $8.62 \times 10^{-5} eV\, K^{-1}$

q = electron charge = $1.602 \times 10^{-19} C$

.

Noise Model

Thermal noise generated by resistors Rg, Rs and Rd is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Parameters P, R, and C model drain and gate noise sources.

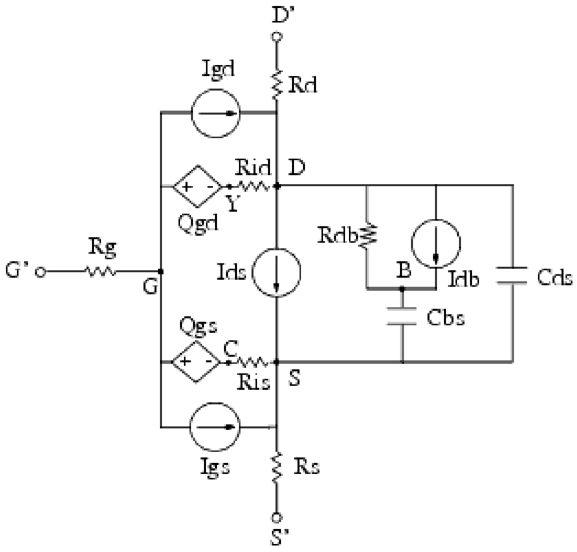
$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P + 4kTg_m\ PFnc\ /f + Kf\ Ids^{Af}\ /f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^{\ 2}\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega\sqrt{PR}\ C$$

For Series IV compatibility, set P=2/3, R=0, C=0, and Fnc=0; copy Kf, Af, and Ffe from the Series IV model.

Equivalent Circuit

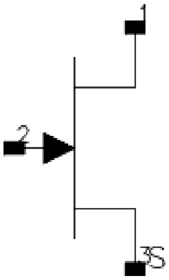


References

1. A. McCaman, G. McCormack and D. Smith. "An Improved GaAs MESFET Model for SPICE", *IEEE Trans. on Microwave Theory Tech* ., vol. MTT-38, pp. 822-824, June 1990.
2. H. Statz, P. Newman, I. Smith, R. Pucel and H. Haus. "GaAs FET Device and Circuit Simulation in SPICE", *IEEE Trans. on Electron Devices* , vol. ED-34, pp. 160-169, Feb. 1987.
3. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques* , Vol. 36, No. 1, pp. 1-10, Jan. 1988.

TriQuintMaterka (TriQuint-Materka Nonlinear FET)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a TriQuintMaterka_Model instance	None	MESFETM1
W	gate width	m	1.0
N	number of gate fingers	None	no scaling
Temp	device instance temperature	°C	25
Trise	device temperature relative to circuit ambient (if Temp not specified)	°C	0
Noise	noise generation option: yes or no	None	yes
_M	number of devices in parallel	None	1

Range of Usage

W > 0
N > 0 (if specified)

Notes/Equations/References

1. W and N are used for scaling the device instance. Refer to *TriQuintMaterka_Model (TriQuint-Materka Nonlinear FET Model)* (ccnld) for details.

   Note
   Area/finger scaling will be disabled if N is not specified.

   The default value for W is 1 m, while typical values are in the order of micrometers; so, the recommendation is to not rely on this default value.

2. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the corresponding TriQuintMaterka_Model) certain parameters and responses are scaled so that the device is simulated at its operating temperature. Refer to *TriQuintMaterka_Model*

(TriQuint-Materka Nonlinear FET Model) (ccnld) for details.

3. The following table lists the DC operating point parameters that can be sent to the dataset.

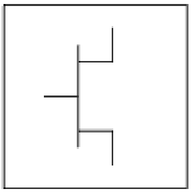
DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Ggs	Gate to source conductance	siemens
Ggd	Gate to drain conductance	siemens
dIgs_dVgd	(dIgs/dVgd)	siemens
dIgd_dVgs	(dIgd/dVgs)	siemens
dIds_dVgb	Backgate transconductance (dIds/dVgb)	siemens
Cgs	Gate-source capacitance	farads
Cgd	Gate-drain capacitance	farads
Cds	Drain-source capacitance	farads
dQgs_dVgd	(dQgs/dVgd)	farads
dQgd_dVgs	(dQgd/dVgs)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts

4. This device has no default artwork associated with it.

TriQuintMaterka_Model (TriQuint-Materka Nonlinear FET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	UCM/SDD Name	Description	Units	Default
Idsmod		Ids model (do not change the default value)	None	9
NFET		N-channel type: yes or no	None	yes
PFET		P-channel type: yes or no	None	no
Tnom		model temperature at which all parameters were derived	°C	25
Ugw		gate width to which model parameters are normalized	m	1e-6
Ngf		number of gate fingers to which model parameters are normalized	None	1
Idss	IDSS	saturation drain current	A	0
Vto	VPO	threshold voltage	V	-2.0
Beta2	GAMA	coefficient for pinch-off change with respect to Vds	None	0
Ee	E	exponent defining dependence of saturation current	None	2.0
Ke	KE	coefficient for exponent dependence on gate voltage	1/V	0
Kg	KG	drain current dependence on Vgs in linear region	1/V	0
Sl	SL	linear region slope of Vgs=0 drain characteristic	1/Ohm	1.0
Ss	SS	saturation region drain slope characteristic at Vgs=0	1/Ohm	0
Tau	TAU	transit time under gate	sec	0
Idstc		Ids temperature linear coefficient	1/°C	0
Vtotc		Vto temperature linear coefficient	V/°C	0
Gsfwd		gate-source forward model: 0=none 1=linear 2=diode	None	diode
Gdfwd		gate-drain forward model: 0=none 1=linear	None	None

		2=diode		
Is	IG0	gate junction saturation current	A	1.0e-14
Alfg	ALFG	Schottky current exponent multiplier	1/V	22
Eg		energy gap for temperature effect on Is	eV	1.11
Xti		temperature exponent for saturation current	None	3.0
Rf		gate forward resistance if Gsfwd or Gdfwd = linear	Ohm	open circuit
Gsrev		gate-source breakdown model: 0=none 1=linear 2=diode	None	None
Gdrev		gate-drain breakdown model: 0=none 1=linear 2=diode	None	diode
Ir	IGD0	gate reverse saturation current	A	1.0e-14
Vbr	VBR, refer to note 4	gate junction reverse bias breakdown voltage	V	1e100
Alpvb	ALPVB	breakdown exponent fitting factor	1/V	0.4
AlfdA	A	fitting factor in Igd current exponent	1/V	0
AlfdB	B	fitting factor in Igd current exponent	1/\(V^{2})	0
R1		breakdown resistance if Gsrev or Gdrev = linear	Ohm	open circuit
R2		resistance relating breakdown voltage to channel	Ohm	0
Gscap		mode: 0=none, 1=const, 2=junction, 3=Statz charge, 5=Statz cap	None	None
Cgs	CGS	zero bias gate-source junction capacitance	F	0
Gdcap		mode 0=none, 1=const, 2=junction, 3=Statz charge, 5=Statz cap	None	const
Cgd	CGD	zero bias gate-drain junction capacitance	F	0
Vbi		built-in gate potential \(junction capacitance models)	V	0.85
Fc		coefficient for forward bias depletion junction capacitance	None	0.5
Delta1		capacitance saturation transition voltage \(Statz models)	V	0.3
Delta2		capacitance threshold transition voltage \(Statz models)	V	0.2
Vmax		maximum voltage before capacitance limiting \(Statz models)	V	0.5
Rin	RI	channel resistance	Ohm	0
RLgs	RGS,refer to note 5	gate-source leakage resistance	Ohm	open circuit
RLgd	RGD,refer to note 5 and note 6	gate-drain leakage resistance	Ohm	open circuit
Rc	RRF, refer to note 7	dispersion model resistance	Ohm	0
Crf	CRF, refer to note 7	dispersion model capacitance	F	0
Cds	CDS	drain-source capacitance	F	0
Rd	RD	drain resistance	Ohm	0
Trd1		temperature linear coefficient for Rd	1/°C	0
Rg	RG	gate resistance	Ohm	0
Trg1		temperature linear coefficient for Rd	1/°C	0
Rs	RS	source resistance	Ohm	0
Trs1		temperature linear coefficient for Rd	1/°C	0

Ld	LD	drain inductance	H	0
Lg	LG	gate inductance	H	0
Ls	LS	source inductance	H	0
Taumdl		use 2nd order Bessel polynomial to model Tau effect in transient: yes or no	None	no
Imax		explosion current	A	1.6
Imelt		explosion current similar to Imax; defaults to Imax (refer to Note 12)	A	defaults to Imax
Fnc		flicker noise corner frequency	Hz	0
R		gate noise coefficient	None	0.5
P		drain noise coefficient	None	1.0
C		gate-drain noise correlation coefficient	None	0.9
wVgfwd		gate junction forward bias warning	V	
wBvgs		gate-source reverse breakdown voltage warning	V	
wBvgd		gate-drain reverse breakdown voltage warning	V	
wBvds		drain-source breakdown voltage warning	V	
wIdsmax		maximum drain-source current warning	A	
wPmax		maximum power dissipation warning	W	
AllParams		Data Access Component (DAC) Based Parameters	None	None

† A value of 0.0 is interpreted as infinity.

Notes/Equations

1. This model supplies values for a TriQuintMaterka device.
2. Implementation of the TriQuint-Materka model is based on [1-3].
3. The UCM/SDD column in the Parameters table shows the names of the parameters that were used either in the User Compiled Model implementation or in the SDD implementation of the TriQuint-modified Materka model. These names must be changed to the name given in the Name column. Note that the Name is case sensitive. Also, do not rely on the default values as, in general, they are different from those in the UCM or SDD.
   Parameters listed in the Name column that do not have corresponding UCM/SDD parameters are used for extended features of this model with respect to the UCM/SDD implementations. Refer to Notes 4 through 9 for specific translation issues.
4. The breakdown voltage parameter Vbr is internally converted to its absolute value at parsing. Thus, the negative values used in UCM/SDD do not need to be changed to conform to the ADS convention.
5. When using other than UI means of entering model parameters, (e.g., file-based, do not use the parameter names Rgs and Rgd). The correct translation of the UCM/SDD parameters RGS and RGD is RLgs and RLgd.
6. In the UCM implementation, the parameters RGS and RGD are not scaled with area. The corresponding leakage resistances RLgs and RLgd, however, are dimensionally scaled (inversely proportional to area). Therefore, they should be accordingly adjusted if the device instance scaling parameters call for dimensional scaling.
7. In SDD implementation, the parameters CRF and RRF are not scaled with the area. The corresponding parameters in the built-in model (capacitance/resistance Crf/Rc), however, are dimensionally scaled (directly/inversely proportional to the area). Therefore, they should be accordingly adjusted if the device instance scaling parameters call for dimensional scaling.

8. The functionality of the UCM/SDD scaling parameters is replaced by the use of two device parameters (W, N) and two model parameters (Ugw, Ngf). Refer to the section Dimensional Scaling Relations for details and translation rules.
9. For UCM/SDD compatibility use Temp = Tnom, Gsfwd=2, Gdrev=2, Imax=230, follow Notes 3 through 8, and use defaults for other parameters that were not present in UCM/SDD.
10. The standard emission coefficient N is implicitly defined by the parameter Alfg as N = 1 / (Alfg × V_{Tnom}), where V_{Tnom} is the thermal voltage corresponding to the value of the parameter Tnom. Refer to the section Forward Gate Diode Models (Gsfwd=2 and/or Gdfwd=2) for details.
11. To prevent numerical problems, the simulator maintains the following minimum parameter values:

    Rd = 1e-4
    Rs = 1e-4
    Rg = 1e-4

    If the user wants any of the extrinsic resistances Rd, Rg, and Rs to be exactly zero, their values should not be entered. The default is a short circuit. If a value is entered, it must be different from zero.
12. Imax and Imelt Parameters
    Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
    If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
    If Imelt is specified (in the model or in Options) then the junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
13. Several parameters are restricted to positive, non-zero, or non-negative values. If the user violates this restriction, an error message will be written in the status window, and the simulation will not proceed.

Drain-Source Current

The TriQuintMaterka_Model drain-source current is calculated using the same equation as the Modified_Materka_Model.
Let

$$VP = Vto + Beta2 \times V_{ds}$$

If

$$VP < 0 \quad \text{and} \quad V_{gs} > VP$$

then

$$I_{ds} = Idss \times \left(1 - \frac{V_{gs}}{VP}\right)^{(Ee + Ke \times V_{gs})} \times \tanh\left(\frac{Sl \times V_{ds}}{Idss \times (1 - Kg \times V_{gs})}\right) \times \left(1 + \frac{Ss \times V_{ds}}{Idss}\right)$$

otherwise

$$I_{ds} = 0$$

For time-varying drain-source current, the voltage V_{gs} is delayed by the transit time Tau. Idss, Vto, Beta2, Ee, Ke, Sl, Kg and Ss are model parameters.

Gate Capacitances

There are several options in modeling the junction capacitance of a device; these options are shared with other GaAs FET models. The first option is to model the junction as a linear component (a constant capacitance); the second option is to model the junction using a diode depletion capacitance model. If a non-zero value of Cgs is specified and Gscap=1 (linear), the gate-source junction capacitance will be modeled as a linear component. Similarly, specifying a non-zero value for Cgd and Gdcap=1 result in a linear gate-drain model. A non-zero value for either Cgs or Cgd together with Gscap=2 (junction) or Gdcap=2 will force the use of the diode depletion capacitance model for that particular junction. Refer to *Curtice2_Model (Curtice-Quadratic GaAsFET Model)* (ccnld) for details and equations.

The other options Gscap=3 or Gdcap=3 (Statz Charge) and Gscap=5 or Gdcap=5 (Statz Cap) correspond to the Statz-based models [4, 5]. Refer to *Statz_Model (Statz Raytheon GaAsFET Model)* (ccnld) for details and equations.

Note that each junction is modeled independent of the other; hence, it is possible to model one junction as a linear component while the other is treated nonlinearly.

Gate Conduction Currents

The gate conduction currents are controlled by four flags: Gsfwd, Gsrev, Gdfwd, and Gdrev. Each of them can be set to 0, 1, or 2. Setting any of these flags to 0 results in a corresponding open circuit. For non-zero settings, the following sections describe the respective behaviors.

Linear Gate Conduction Models (flag=1)

The simplest models assume an effective value of forward bias resistance Rf and an approximate breakdown resistance R1 (refer to *Curtice3_Model (Curtice-Cubic GaAsFET Model)* (ccnld)). The linear model of the forward conduction current is used when Rf is specified (must be different from zero) and Gsfwd=1 and/or Gdfwd=1. For example, if Gsfwd=1 then the gate-source forward conduction current is given by:

If $V_{gs} > Vbi$

$$I_{gs} = (V_{gs} - Vbi)/ Rf$$

otherwise:

$$I_{gs} = 0$$

Vbi and Rf are model parameters. A similar expression defines I_{gd}.

The linear model of the reverse breakdown current is used when R1 is set and Gsrev=1 and/or Gdrev=1. For example, if Gdrev = 1
If $V_{gd} < - Vb$

$$I_{gd} = (V_{gd} + Vb)/ R1$$

otherwise:

$$I_{gd} = 0$$

In the above equation, Vb is a modified breakdown voltage defined as:

$$Vb = Vbr + R2 \times I_{ds}$$

Vbr, R1 and R2 are model parameters. Note that Vbr is assumed to be positive (the actual breakdown voltage in terms of Vgd would be negative for an n-channel device). A similar expression defines I_{gs}.

Forward Gate Diode Models (Gsfwd=2 and/or Gdfwd=2)

This model is controlled by the model parameters Is and Alfg, and is similar for both Igs and Igd. For example, the Igs current is determined as

$$I_{gs} = Is \times [\exp(Alfg \times V_{gs}) - 1]$$

The parameter Alfg must be positive. It is converted to the standard emission coefficient N (see note 10) and the following equation is used instead.

$$I_{gs} = Is \times \left[\exp\left(\frac{V_{gs}}{N \times V_T}\right) - 1\right]$$

where VT is the thermal voltage:

$$V_T = \frac{k \times Temp}{q}$$

$k = 1.38 \times 10^{-23}$ (Boltzmann's constant)
$q = 1.602 \times 10^{-19}$ (electron charge)

This facilitates temperature dependence of the exponent on *Temp* , which is either equal to the device instance parameter Temp, or if Temp is not specified, to *Temp* =

ambient_circuit_temperature + Trise.

Large negative and large positive exponent values are handled similarly to other GaAs FET models. Refer to (for example) *Statz_Model (Statz Raytheon GaAsFET Model)* (ccnld) information for details.

Reverse Breakdown Gate-Drain Diode Model (Gdrev=2)

The diode model of the reverse gate-drain breakdown has been modified by TriQuint to include its dependence on the gate-source voltage Vgs. Following [2]|TriQuintMaterka Model (TriQuint-Materka Nonlinear FET Model)#reference1], the Igd current is calculated as:

$$I_{gd} = -Ir \times \exp(AlfdA \times V_{gs} + AlfdB \times V_{gs} \times V_{gs} - Alpvb \times (Vb + V_{gd}))$$

In the above equation, Vb is a modified breakdown voltage defined as:

$$Vb = Vbr + R2 \times I_{ds}$$

Ir, AlfdA, AlfdB, Alpvb, R2, and Vbr are model parameters. Note that Vbr is assumed to be positive (the actual breakdown voltage in terms of Vgd would be negative for an n-channel device).

Reverse Breakdown Gate-Source Diode Model (Gsrev=2)

The gate-source breakdown diode model, if used, takes the standard exponential form:

$$I_{gs} = -Ir \times [\exp(-Alpvb \times (Vb + V_{gs})) - 1]$$

In the above equation, Vb is a modified breakdown voltage defined as:

$$Vb = Vbr + R2 \times I_{ds}$$

Time Delay

Like other GaAs FET models, TriQuintMaterka_Model uses an ideal time delay to model transit time effects under the gate. In the time domain, the drain source current for the ideal delay is given by:

$$I_{ds}(t) = I_{ds}(V_j(t - Tau), V_{ds}(t))$$

where Vj = Vgs or Vj = Vgd (depending on whether Vds is positive or negative). Tau is a model parameter. In the frequency domain, only the transconductance is impacted by this delay and the familiar expression for transadmittance is obtained:

$$y_m = g_m \times \exp(-j\omega Tau)$$

High-Frequency Output Conductance

A series-RC network comprised of the parameters Crf and Rc is included to provide a correction to the AC output conductance. At a frequency high enough such that Crf is an effective short, the output conductance of the device can be increased by the factor 1/Rc.

Dimensional Scaling Relations

For each device instance, area/finger scaling is performed only if the device parameter N is specified, and its value is positive. The width scaling factor is determined as:

width_scale = W / Ugw

where W is the actual device gate width and Ugw is a model parameter whose meaning is the gate width to which all the model parameters have been normalized (or Ugw is the actual gate width of the measured device if the extracted model parameters have not been normalized).

Similarly, the finger scaling factor is determined as:

finger_scale = N / Ngf

where N is the actual device number of fingers and Ngf is a model parameter whose meaning is the number of gate fingers to which all the model parameters have been normalized (or Ngf is the actual number of gate fingers of the measured device if the extracted model parameters have not been normalized).

It is strongly recommended that the model parameters Ugw and Ngf are always specified without relying on their default values.

The following model parameters are scaled with area = width_scale * finger_scale:

Idss, Sl, Ss, Is, Ir, Cgs, Cgd, Cds, Crf

The following model parameters are scaled inversely with area:

Rd, Rs, RLgs, RLgd, Rc, Rin

The following model parameters are scaled with width_scale / finger_scale:

Rg, Lg

The inductances Ld and Ls are not scaled.

For compatibility with the UCM or SDD implementation, the values of device/model scaling parameters W, N, Ugw and Ngf must be determined from the UCM/SDD scaling parameters (see Note 8). In terms of the parameters W, N, Ugw and Ngf, the UCM parameters AREA and SFING can be expressed as:

AREA = (W / Ugw) * (N / Ngf)
SFING = Ngf / N

If the actual values of Ugw and Ngf are not known, they can be set arbitrarily. Then, given the values of AREA, SFING, Ugw and Ngf, the device parameters W and N must be set as:

W = Ugw × AREA × SFING
N = Ngf / SFING

Similarly, in terms of W, N, Ugw and Ngf parameters, the SDD Size and Original Size parameters can be expressed as:

Size = W × N
OriginalSize = Ugw × Ngf

SDD Finger and OriginalFinger parameters mean the same as N and Ngf parameters, respectively. Therefore, the translation rules for SDD scaling parameters are:

Ugw = OriginalSize / OriginalFinger
Ngf = OriginalFinger
W = Size/Finger
N = Finger

Temperature Scaling Relations

The TriQuintMaterka_Model model uses several temperature scaling relations which modify the model behavior when the ambient temperature changes. The scaling relations assume the unscaled (nominal) parameters were extracted at Tnom.
It is strongly recommended that the model parameter Tnom is always specified without relying on its default value.

The parameters are scaled to an arbitrary operating temperature through the temperature scaling relations. Note that the user specifies the temperatures in °C and the program converts them to units of Kelvin. The value of *Temp* is either the device instance parameter Temp, or if Temp is not specified then it is evaluated as
Temp = ambient_circuit_temperature + Trise.

The emission coefficient *N* used in the equations is evaluated from the parameter Alfg (see Note 10), or it assumes the default value of 1 if Alfg=0. In addition to the thermal voltage in the forward diode equations, the following temperature scaling is used.

The saturation current Is scales as:

$$Is^{NEW} = Is \times \exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times \ln\left(\frac{Temp}{Tnom}\right)\right]$$

The gate depletion capacitances Cgs and Cgd vary as:

$$Cgs^{NEW} = Cgs\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

$$Cgd^{NEW} = Cgd\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.

The gate junction potential Vbi varies as:

$$Vbi^{NEW} = \frac{Temp}{Tnom} \times Vbi + \frac{2k \times Temp}{q} \times \ln\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

where n_i is the intrinsic carrier concentration for silicon, calculated at the appropriate temperature.

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

The Ids current, after being evaluated, is scaled linearly using the model parameter Idstc, as:

$$I_{ds}^{NEW} = I_{ds} \times (1 + Idstc \times (Temp - Tnom))$$

The extrinsic resistances are also scaled linearly as:

$$Rx^{NEW} = Rx \times (1 + Trx1 \times (Temp - Tnom))$$

where x stands for d, g, or s, and correspondingly, Rd, Rg, Rs, Trd1, Trg1 and Trs1 are model parameters.

Noise Model

The resistors Rg, Rs and Rd generate thermal noise, which is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

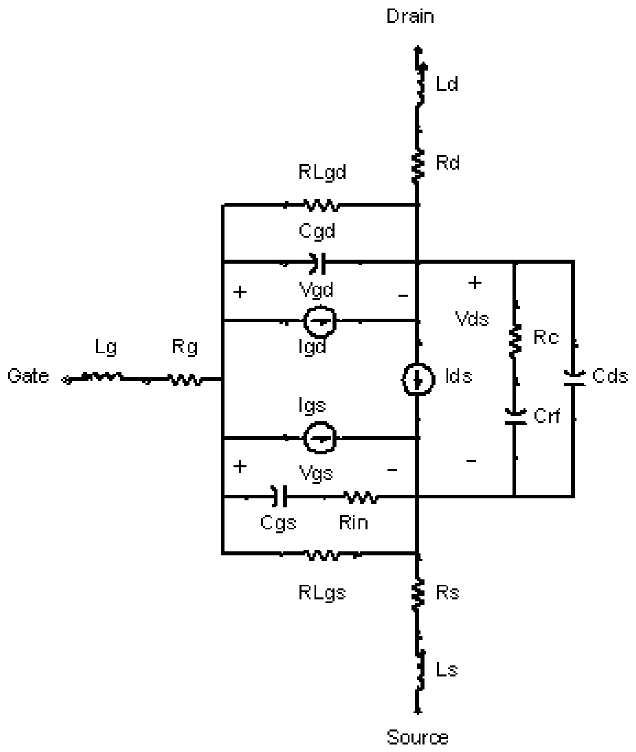
The P, R, and C parameters model drain and gate noise sources [6].

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\, P(1 + f_{NC}/f)$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\, C_{gs}^2\, \omega^2\, R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\, C_{gs}\, \omega \sqrt{PR}\, C$$

Equivalent Circuit



References

1. A. Materka and T. Kacprzak "Computer Calculation of Large-Signal GaAs FET Amplifier Characteristics," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-33, No. 2, February 1985.
2. An internal document describing model parameters and equations, Private communication from TriQuint.
3. Igd "Breakdown Equation" developed by D. R. Bridges and W. Anholt, Private communication from TriQuint.
4. H. Statz, P. Newman, I. Smith, R. Pucel and H. Haus. "GaAs FET device and circuit simulation in SPICE," IEEE Trans. Electron Devices, vol. ED-34, pp. 160-169, Feb. 1987.
5. D. Divekar, Comments on "GaAs FET device and circuit simulation in SPICE," IEEE Trans. Electron Devices, Vol. ED-34, pp. 2564-2565, Dec. 1987.
6. A. Cappy, "Noise Modeling and Measurement Techniques," IEEE Transactions on Microwave Theory and Techniques, Vol. 36, No. 1, pp. 1-10, Jan. 1988.

Devices and Models, JFET

- *JFET Model (Junction FET Model)* (ccnld)
- *JFET NFET, JFET PFET (Nonlinear Junction FETs, P-Channel, N-Channel)* (ccnld)
- *r3 (Three-Terminal Nonlinear Diffused and Poly-Silicon Resistor and JFET Model and Instance)* (ccnld)

Bin Model

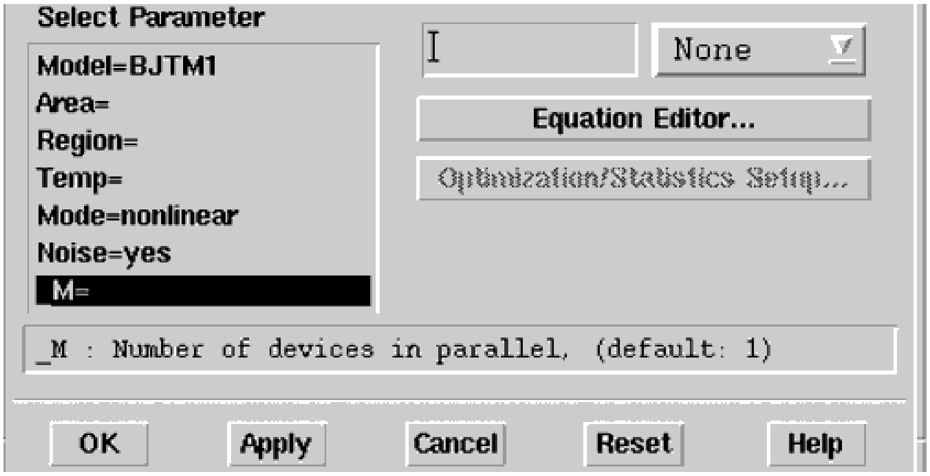
The BinModel in the JFET library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to *BinModel* (ccsim).

Multiplicity Parameter _M

The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M* , the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

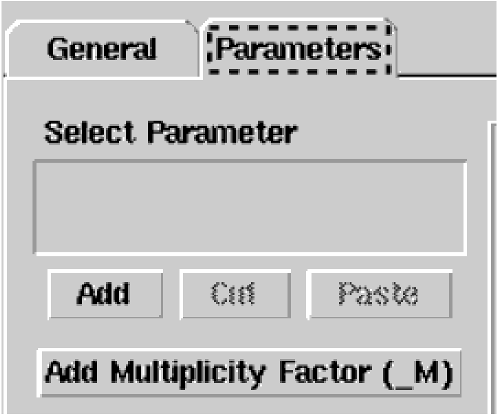
The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



Model=BJTM1
Area=
Region=
Temp=
Mode=nonlinear
Noise=yes
_M=

_M : Number of devices in parallel, (default: 1)

For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor_M**.



Netlist Syntax

Models for the ADS circuit simulator have the following syntax:

```
model modelname modeltype [param=value]*
```

where `model` is a keyword, `modelname` is the user-defined name for the model and `modeltype` is one of the predefined model types (e.g., Diode, BJT, MOSFET). After these three required fields comes zero or more `param=value` pairs.

`param` is a model keyword and value is its user-assigned value. There is no required order for the `param=value` pairs. Model keywords that are not specified take on their default values. Refer to documentation for each model type to see the list of model parameters, their meanings and default values.

The model statement must be on a single line. Use the backslash "\" as a line continuation character. Instance and model parameter names are case sensitive; most (not all) model parameters have their first character capitalized and the rest are lower case. Scale factors (e.g., p=10^{-12}, n=10^{-9}, u=10^{-6}, m=10^{-3}, k=10^{+3}, M=10^{+6}) can be used with numbers for numeric values. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

A netlist translator is available for translating models and subcircuits from Pspice, Hspice, and Spectre syntax to the form used by the ADS Circuit Simulator. Refer to the *Netlist Translator for SPICE and Spectre* (netlist) for more information.

Parameter Aliases

For compatibility with other simulators, some models accept two or more different keywords for the same parameter. For example, the Diode model accepts both model keywords Is and Js for the saturation current. In the documentation, the parameter Name column lists the aliases in parentheses after the main parameter name. The main parameter name is the one that appears in the ADS dialog box for the model.

Tnom

All nonlinear device models have a parameter that specifies the temperature at which the model parameters were extracted. Normally called Tnom, some models may use Tref, Tr, or Tmeas. The default value for Tnom is specified on the Options item in the Tnom field. If Options.Tnom is not specified it defaults to 25°C. This is true for all nonlinear devices.

It is strongly suggested that the user explicitly set Tnom in each model and not depend on its default value. First, this provides a self-documenting model; other users of the device will not have to guess at what Tnom should be. Second, different users of the same model would get different results for the same circuit if they simulate with different values of Options.Tnom.

Temp and Trise

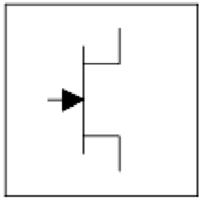
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with *Options.Temp*, which defaults to 25° C.

For compatibility with other simulators, many of the nonlinear devices allow the user to specify Trise for each device instance, which specifies actual device temperature as an increase from ambient. It defaults to zero. The Trise instance value is used only if the Temp instance value is not specified. If the user does not specify Trise on the instance, a default value for Trise can also be specified in the model. It defaults to zero. The following shows the logic of how the instance temperature is calculated if it is not explicitly specified.

```
if Instance.Temp is not specified
 if instance.Trise is not specified
   Instance.Temp = Options.Temp \+ Model.Trise
 else
   Instance.Temp = Options.Temp \+ Instance.Trise
```

JFET_Model (Junction FET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	**Description**	**Units**	**Default**
NFET	N-channel model: yes or no	None	yes
PFET	P-channel model: yes or no	None	no
Vto [†]	zero-bias threshold voltage	V	-2.0
Beta [†] , [††]	transconductance parameter	$A/(V\times m)^2$	1.0e-4
Lambda	channel-length modulation	1/V	0.0
Rd [††]	drain ohmic resistance	Ohm	fixed at 0
Rs [††]	source ohmic resistance	Ohm	fixed at 0
Is [†] , [††]	gate-junction saturation current	A	1.0e-14
Cgs [†]	zero-bias gate-source junction capacitance	F	0.0
Cgd [†]	zero-bias gate-drain junction capacitance	F	0.0
Pb [†]	gate-junction potential	V	1.0
Fc	forward-bias junction capacitance coefficient	None	0.5
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0
Kf	flicker-noise coefficient	None	0.0
Af	flicker-noise exponent	None	1.0
Imax	explosion current	A	1.6
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 5)	A	defaults to Imax
N	gate P-N emission coefficient	None	1.0
Isr [†]	gate P-N recombination current parameter	A	0.0
Nr	Isr emission coefficient	None	2.0
Alpha	ionization coefficient	1/V	0.0
Vk	ionization knee voltage	V	0.0
M	gate P-N grading coefficient	None	0.5
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	Beta exponential temperature coefficient	1/°C	0.0
Xti	temperature coefficient	None	3.0
Ffe	flicker noise frequency exponent	None	1.0
Gdsnoise	generate noise from gds as well as gm: yes=1, no=0	None	no
wBvgs	gate-source reverse breakdown voltage (warning)	V	None
wBvgd	gate-drain reverse breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	DataAccessComponent-based parameters	None	None

[†] Parameter value varies with temperature based on model Tnom and device Temp. [††] Parameter value is scaled with Area specified with the JFET device.

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to the *Design Kit Development* (dkarch).

```
model modelname JFET [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by JFET components to refer to the model. The third parameter indicates the type of model; for this model it is *JFET* . Use either parameter NFET=yes or PFET=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  U310  JFET \
 Vto=-3 Beta=3e-4 NFET=yes
```

Notes

1. This model supplies values for a JFET device.
2. JFET_Model equations are based on the FET model of Shichman and Hodges. For more information on JFET_Model, its parameters and equations, see [1].
3. The DC characteristics of a JFET_Model are defined by:
    - Vto and Beta: determine variation in drain current with respect to gate voltage.
    - Lambda: determines the output conductances
    - Is: saturation current of the two gate junctions.
4. Charge storage is modeled by nonlinear depletion layer capacitance for both gate junctions. These capacitances vary as 1/Sqrt (Junction Voltage) and are defined by Cgs, Cgd and Pb.
5. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
6. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent (Data Access Component)* (ccsim)). Note that model parameters that are explicitly specified take precedence over those specified via AllParams.

Equations/Discussions

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The saturation currents Is and Isr scale as:

$$Is^{NEW} = Is \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times N \times Temp} + \frac{Xti}{N} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Isr^{NEW} = Isr \times exp\left[\left(\frac{Temp}{Tnom} - 1\right)\frac{q \times Eg}{k \times Nr \times Temp} + \frac{Xti}{Nr} \times ln\left(\frac{Temp}{Tnom}\right)\right]$$

The depletion capacitances Cgs and Cgd vary as:

$$Cgs^{NEW} = Cgs\left[\frac{1 + M[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + M[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cgd^{NEW} = Cgd\left[\frac{1 + M[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + M[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.

The gate junction potential Pb varies as:

$$Pb^{NEW} = \frac{Temp}{Tnom} \times Pb + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

where n_i is the intrinsic carrier concentration for silicon, calculated at the appropriate temperature.

The threshold voltage Vto varies as:

$$Vto^{NEW} = Vto + Vtotc(Temp - Tnom)$$

The transconductance Beta varies as:

$$Beta^{NEW} = Beta \times 1.01^{Betatce(Temp - Tnom)}$$

Noise Model

Thermal noise generated by resistors Rs and Rd is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Channel noise and flicker noise (Kf, Af, Ffe) generated by the DC transconductance g_m and current flow from drain to source is characterized by the following spectral density:

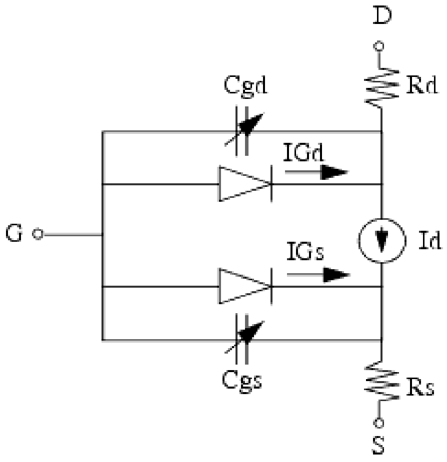
$$\frac{\langle i_{DS}^2 \rangle}{\Delta f} = \frac{8kTg_m}{3} + Kf\frac{I_{DS}^{Af}}{f^{Ffe}}$$

If the model parameter *Gdsnoise=yes*, the channel noise is instead characterized by the following:

$$\frac{\langle i_{DS}^2 \rangle}{\Delta f} = \frac{8}{3}kT(g_m + g_{DS})\left[\frac{3}{2} - \frac{min(Vds, Vdsat)}{2Vdsat}\right] + K_f\frac{I_{DS}^{Af}}{f^{Ffe}}$$

In the above expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, *Kf*, *Af*, and *Ffe* are model parameters, *f* is the simulation frequency, and Δ *f* is the noise bandwidth.

Equivalent Circuit

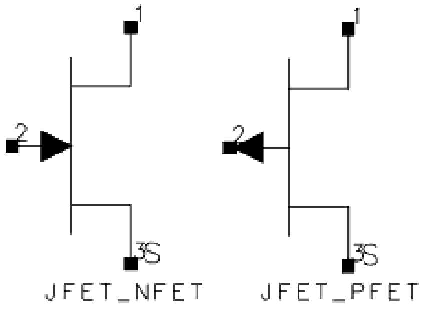


References

1. P. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE*, New York: McGraw-Hill, Second Edition 1993.

JFET_NFET, JFET_PFET (Nonlinear Junction FETs, P-Channel, N-Channel)

Symbol



Parameters

Name	Description	Units	Default
Model	name of a JFET_Model	None	JFETM1
Area	scaling factor that scales certain parameter values of the JFET_Model	None	1.0
Region	DC operating region, 0=off, 1=on, 2=rev, 3=ohmic	None	on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 2)	None	Nonlinear
Noise	Noise generation option; yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

1. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated JFET_Model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to *JFET_Model (Junction FET Model)* (ccnld) to see which parameter values are scaled.
2. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
3. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Cgs	Gate-source capacitance	farads
Cgd	Gate-drain capacitance	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts

4. This device has no default artwork associated with it.

References

1. *SPICE2: A Computer Program to Simulate Semiconductor Circuits,* University of California, Berkeley.
2. P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE,* Second Edition, McGraw-Hill, Inc., 1993.

r3 (Three-Terminal Nonlinear Diffused and Poly-Silicon Resistor and JFET Model and Instance)

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

model modelName r3 [parm=value]*

Example:

model Nch r3 rsh=100

Model Parameters

Name (Alias)	Description	Units	Default
Gender	+1=N-type, -1=P-type		1(n),-1(p)
Tnom	Parameter measurement temperature	deg C	27
Secured	Secured model parameters		0
version	model version		1
subversion	model subversion		0
revision	model revision		0
level	model level		1003
type	resistor type: -1=n-body and +1=p-body		-1
scale	scale factor for instance geometries		1
shrink	shrink percentage for instance geometries		0
tmin	minimum ambient temperature		-100
tmax	maximum ambient temperature		500
rthresh	threshold to switch end resistance to V=I*R form		0.001
gmin	minimum conductance		1e-12
imax	current at which to linearize diode currents		1
lmin	minimum allowed drawn length		0
lmax	maximum allowed drawn length		9.9e+09
wmin	minimum allowed drawn width		0
wmax	maximum allowed drawn width		9.9e+09
jmax	maximum current density		100
vmax	maximum voltage w.r.t. control node nc		9.9e+09
tminclip	clip minimum temperature		-100
tmaxclip	clip maximum temperature		500
rsh	sheet resistance		100
xw	width offset (total)		0
nwxw	narrow width width offset correction coefficient		0
wexw	webbing effect width offset correction coefficient (for dogboned devices)		0
fdrw	finite doping width offset reference width		1
fdxwinf	finite doping width offset width value for wide devices		0
xl	length offset (total)		0

xlw	width dependence of length offset		0
dxlsat	additional length offset for velocity saturation calculation		0
nst	subthreshold slope parameter		1
ats	saturation smoothing parameter		0
dfinf	depletion factor for wide/long device		0.01
dfw	depletion factor 1/w coefficient		0
dfl	depletion factor 1/l coefficient		0
dfwl	depletion factor 1/(w*l) coefficient		0
sw_dfgeo	switch for depletion factor geometry dependence: 0=drawn and 1=effective		1
dp	depletion potential		2
ecrit	velocity saturation critical field		4
ecorn	velocity saturation corner field		0.4
du	mobility reduction at ecorn		0.02
rc	resistance per contact		0
rcw	width adjustment for contact resistance		0
fc	depletion capacitance linearization factor		0.9
isa	diode saturation current per unit area		0
na	ideality factor for isa		1
ca	fixed capacitance per unit area		0
cja	depletion capacitance per unit area		0
pa	built-in potential for cja		0.75
ma	grading coefficient for cja		0.33
aja	smoothing parameter for cja		-0.5
isp	diode saturation current per unit perimeter		0
np	ideality factor for isp		1
cp	fixed capacitance per unit perimeter		0
cjp	depletion capacitance per unit perimeter		0
pp	built-in potential for cjp		0.75
mp	grading coefficient for cjp		0.33
ajp	smoothing parameter for cjp		-0.5
vbv	breakdown voltage		0
ibv	current at breakdown		1e-06
nbv	ideality factor for breakdown current		1
kfn	flicker noise coefficient (unit depends on afn)		0
afn	flicker noise current exponent		2
bfn	flicker noise 1/f exponent		1
sw_fngeo	switch for flicker noise geometry calculation: 0=drawn and 1=effective		0
ea	activation voltage for diode temperature dependence		1.12
xis	exponent for diode temperature dependence		3
tc1	resistance linear TC		0
tc2	resistance quadratic TC		0
tc1l	resistance linear TC length coefficient		0
tc2l	resistance quadratic TC length coefficient		0
tc1w	resistance linear TC width coefficient		0
tc2w	resistance quadratic TC width coefficient		0
tc1rc	contact resistance linear TC		0
tc2rc	contact resistance quadratic TC		0

tc1kfn	flicker noise coefficient linear TC		0
tc1vbv	breakdown voltage linear TC		0
tc2vbv	breakdown voltage quadratic TC		0
tc1nbv	breakdown ideality factor linear TC		0
gth0	thermal conductance fixed component		1e+06
gthp	thermal conductance perimeter component		0
gtha	thermal conductance area component		0
gthc	thermal conductance contact component		0
cth0	thermal capacitance fixed component		0
cthp	thermal capacitance perimeter component		0
ctha	thermal capacitance area component		0
cthc	thermal capacitance contact component		0
nsig_rsh	number of standard deviations of global variation for rsh		0
nsig_w	number of standard deviations of global variation for w		0
nsig_l	number of standard deviations of global variation for l		0
sig_rsh	global variation standard deviation for rsh (relative)		0
sig_w	global variation standard deviation for w (absolute)		0
sig_l	global variation standard deviation for l (absolute)		0
smm_rsh	local variation standard deviation for rsh (relative)		0
smm_w	local variation standard deviation for w (absolute)		0
smm_l	local variation standard deviation for l (absolute)		0
sw_mmgeo	switch for flicker noise geometry calculation: 0=drawn and 1=effective		0

Instance Netlist Format

```
modelName [:Name] d g s b
```

Example

```
Nch:M1 2 1 0 w=10u l=0.9u
```

Instance Parameters

Name (Alias)	Description	Units	Default
Temp	Device operating temperature	deg C	25
Trise (dtemp)	Temperature rise over ambient	deg C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
M	multiplicity factor		1
w	design width of resistor body		1e-06
l	design length of resistor body		1e-06
wd	dogbone width (total; not per side)		0
a1	area of node n1 partition		0
p1	perimeter of node n1 partition		0
c1	# contacts at node n1 terminal		0
a2	area of node n2 partition		0
p2	perimeter of node n2 partition		0
c2	# contacts at node n2 terminal		0
sw_noise	switch for including noise: 0=no and 1=yes		1
sw_et	switch for self-heating: 0=no and 1=yes		1
sw_mman	switch for mismatch analysis: 0=no and 1=yes		0
nsmm_rsh	number of standard deviations of local variation for rsh		0
nsmm_w	number of standard deviations of local variation for w		0
nsmm_l	number of standard deviations of local variation for l		0

Devices and Models, MOS

- *ADS MOS (ADS Root MOS Transistor)* (ccnld)
- *ADS MOS Model (ADS Root MOS Transistor Model)* (ccnld)
- *BSIM1 Model (BSIM1 MOSFET Model)* (ccnld)
- *BSIM2 Model (BSIM2 MOSFET Model)* (ccnld)
- *BSIM3 Model (BSIM3 MOSFET Model)* (ccnld)
- *BSIM3SOI5 NMOS, BSIM3SOI5 PMOS (BSIM3 SOI Transistor with 5th Terminal, ExtBody Contact, NMOS, PMOS)* (ccnld)
- *BSIM3SOI Model (BSIM3 Silicon On Insulator MOSFET Model)* (ccnld)
- *BSIM3SOI NMOS, BSIM3SOI PMOS (BSIM3 SOI Transistor, Floating Body, NMOS, PMOS)* (ccnld)
- *BSIM4 Model (BSIM4 MOSFET Model)* (ccnld)
- *BSIM4 NMOS, BSIM4 PMOS (BSIM4 Transistor, NMOS, PMOS)* (ccnld)
- *bsimsoi (bsimsoi MOSFET Model and Instance)* (ccnld)
- *EE MOS1, EE MOS1P (EEsof Nonlinear MOSFETs, N-Channel, P-Channel)* (ccnld)
- *EE MOS1 (EEsof Nonlinear MOSFET, N-Channel)* (ccnld)
- *EE MOS1 Model (EEsof Nonlinear MOSFET Model)* (ccnld)
- *hisim2 (HiSIM 2 MOSFET Model and Instance)* (ccnld)
- *HiSIM_HV* (ccnld)
- *HiSIM_HV_1_2* (ccnld)
- *hisim (HiSIM MOSFET Model and Instance)* (ccnld)
- *LEVEL1 Model (MOSFET Level-1 Model)* (ccnld)
- *LEVEL2 Model (MOSFET Level-2 Model)* (ccnld)
- *LEVEL3 Model (MOSFET Level-3 Model)* (ccnld)
- *LEVEL3 MOD Model (Level-3 NMOD MOSFET Model)* (ccnld)
- *MM9 NMOS, MM9 PMOS (Philips MOS Model 9, NMOS, PMOS)* (ccnld)
- *MM11 NMOS, MM11 PMOS (Philips MOS Model 11 NMOS, PMOS)* (ccnld)
- *MM30 Model (Philips MOS Model 30)* (ccnld)
- *MM30 NMOS, MM30 PMOS (Philips MOS Model 30, NMOS, PMOS)* (ccnld)
- *MOSFET NMOS, MOSFET PMOS (Nonlinear MOSFETs, NMOS, PMOS)* (ccnld)
- *MOS Model9 Process (Philips MOS Model 9, Process Based)* (ccnld)
- *MOS Model9 Single (Philips MOS Model 9, Single Device)* (ccnld)
- *MOS Model11 Binned (Philips MOS Model 11, Binned)* (ccnld)
- *MOS Model11 Electrical (Philips MOS Model 11, Electrical)* (ccnld)
- *MOS Model11 Physical (Philips MOS Model 11, Physical)* (ccnld)
- *MOSVAR_1_1 (PSP-Based MOS Varactor Version 1.1 Model and Instance)* (ccnld)
- *MOSVAR (PSP-Based MOS Varactor Model)* (ccnld)

Bin Model

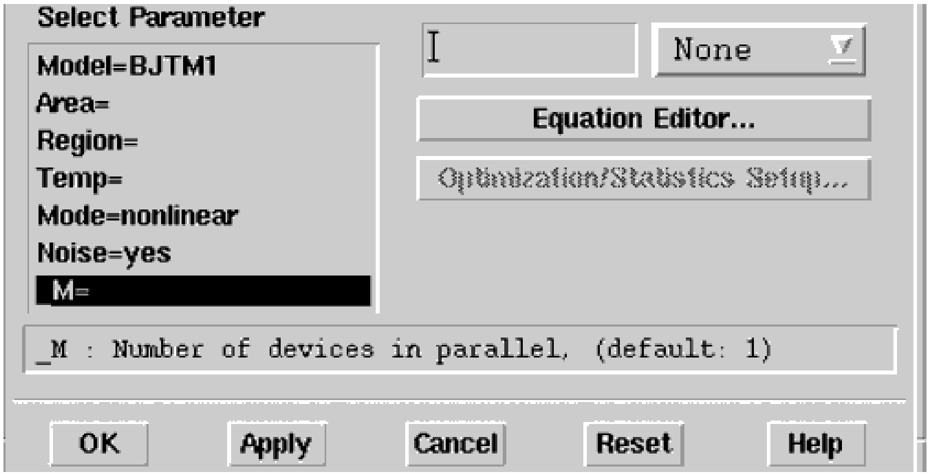
The BinModel in the MOS library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to *BinModel* (ccsim) in *Introduction to Circuit Components*.

Multiplicity Parameter _M

The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M* , the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

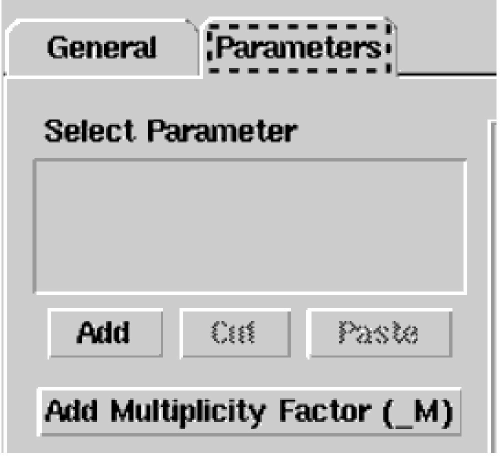
The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



Model=BJTM1
Area=
Region=
Temp=
Mode=nonlinear
Noise=yes
_M=

_M : Number of devices in parallel, (default: 1)

For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor (_M)**.



Netlist Syntax

Models for the ADS circuit simulator have the following syntax:

```
model modelname modeltype [param=value]*
```

where `model` is a keyword, `modelname` is the user-defined name for the model and `modeltype` is one of the predefined model types (e.g., Diode, BJT, MOSFET). After these three required fields comes zero or more `param=value` pairs. `param` is a model keyword and value is its user-assigned value. There is no required order for the `param=value` pairs. Model keywords that are not specified take on their default values. Refer to documentation for each model type to see the list of model parameters, their meanings and default values.

The model statement must be on a single line. Use the backslash "\" as a line continuation character. The instance and model parameter names are case sensitive. Most, but not all, model parameters have their first character capitalized and the rest are lower case. Scale factors (e.g., p=10 $^{-12}$, n=10 $^{-9}$, u=10 $^{-6}$, m=10 $^{-3}$, k=10 $^{+3}$, M=10 $^{+6}$) can be used with numbers for numeric values. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

A netlist translator is available for translating models and subcircuits from Pspice, Hspice, and Spectre syntax to the form used by the ADS Circuit Simulator. Refer to *Netlist Translator for SPICE and Spectre* (netlist) for more information.

Parameter Aliases

For compatibility with other simulators, some models accept two or more different keywords for the same parameter. For example, the Diode model accepts both model keywords Is and Js for the saturation current. In the documentation, the parameter Name column lists the aliases in parentheses after the main parameter name. The main parameter name is the one that appears in the ADS dialog box for the model.

Tnom

All nonlinear device models have a parameter that specifies the temperature at which the model parameters were extracted. Normally called Tnom, some models may use Tref, Tr, or Tmeas. The default value for Tnom is specified on the Options item in the Tnom field. If Options.Tnom is not specified it defaults to 25° C. This is true for all nonlinear devices.

It is strongly suggested that the user explicitly set Tnom in each model and not depend on its default value. First, this provides a self-documenting model; other users of the device will not have to guess at what Tnom should be. Second, different users of the same model would get different results for the same circuit if they simulate with different values of Options.Tnom.

Temp and Trise

The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp, which defaults to 25° C.

For compatibility with other simulators, many of the nonlinear devices allow the user to specify Trise for each device instance, which specifies actual device temperature as an increase from ambient. It defaults to zero. The Trise instance value is used only if the Temp instance value is not specified. If the user does not specify Trise on the instance, a default value for Trise can also be specified in the model. It defaults to zero. The following shows the logic of how the instance temperature is calculated if it is not explicitly specified.

```
if Instance.Temp is not specified
 if instance.Trise is not specified
   Instance.Temp = Options.Temp \+ Model.Trise
 else
   Instance.Temp = Options.Temp \+ Instance.Trise
```

MOSFET Parameter Nlev

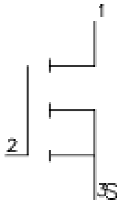
The MOSFET noise model is controlled by the model parameter Nlev. The following table shows which noise equations are used for each value of Nlev. These equations are always used for the BSIM1, BSIM2, LEVEL1, LEVEL2, LEVEL3 and LEVEL3_MOD models. For a BSIM3, these equations can be used to override the standard BSIM3v3 noise equations only when Nlev ≥ 1.

Equations Used for Nlev parameter

Nlev Value	**Channel Noise**	**Flicker Noise**	**Default**
-1	8/3k T g_m	$\frac{Kf\vert I_{DS}\vert^{Af}}{f^{Ffc}}$	ADS default (not usable with BSIM3v3)
0	8/3k T g_m	$\frac{Kf\vert I_{DS}\vert^{Af}}{f^{Ffc}C_{OX}L^2Eff}$	Spice2G6
1	8/3k T g_m	$\frac{Kf\vert I_{DS}\vert^{Af}}{f^{Ffc}C_{OX}W_{Eff\,LEff}}$	Hspice Nlev=1
2	8/3k T g_m	$\frac{Kfg_m{}^2}{f^{Ffc}C_{OX}W_{Eff\,L_{Eff}}}$	Hspice Nlev=2
3	$\frac{8}{3}kTB\langle V_{GS}-V_T\rangle\frac{1+a+a^2}{1+a}Gdsnoi$ 1 (pinchoff) a=1 - V_{DS}/V_{DSAT} (linear) 0 (saturation)	$\frac{Kfg_m{}^2}{f^{Ffc}C_{OX}W_{Eff\,L_{Eff}}}$	Hspice Nlev=3

ADS_MOS (ADS_Root MOS Transistor)

Symbol



Parameters

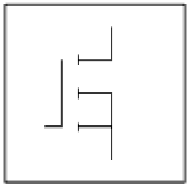
Name	Description	Units	Default
Model	Model instance name	None	ADSMOSM1
Wtot	Total gate width		1.0e-4
N	number of gate fingers	None	1
_M	number of devices in parallel	None	1

Notes/Equations

1. Wtot and N are optional scaling parameters that make it possible to scale the extracted model for different geometries.
2. Wtot is the *total* gate width-not the width per finger; N is the number of fingers. Therefore, the width per finger is Wtot / N. The scaling remains valid for ratios up to 5:1.
3. The parameters Ggs, Gds, Gmr, dQg_dVgs, and the rest are the small-signal parameters of the device evaluated at the DC operating point. To be displayed, they must be listed among the OUTPUT_VARS in the analysis component.

ADS_MOS_Model (ADS_Root MOS Transistor Model)

Symbol



Parameters

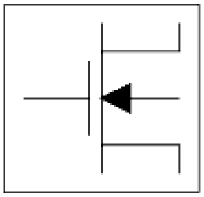
Name	Description	Units	Default
File	name of rawfile	None	None
Rs	source resistance	None	None
Rg	gate resistance	None	None
Rd	drain resistance	None	None
Ls	source inductance	None	None
Lg	gate inductance	None	None
Ld	drain inductance	None	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Notes/Equations

1. The values of Rs, Rg, Rd, Ls, Lg, and Ld are meant to override the extracted values stored in the data file named in the File parameter. Generally, these parameters should not be used.
2. Because this model is measurement-based, extrapolation warning messages may occur if the Newton iteration exceeds the measurement range. If these messages occur frequently, check that the measurement data is within the simulation range.
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via *AllParams*. Set *AllParams* to the DataAccessComponent instance name.
4. For a list of ADS Root Model references, refer to *ADS_Diode_Model (ADS_Root Diode Model)* (ccnld).

BSIM1_Model (BSIM1 MOSFET Model)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	Ids model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	4
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Js	Gate Saturation Current	A	0.0
Temp	parameter measurement temperature	°C	25
Trise	Temperature rise over ambient	°C	None
Muz	Surface Mobility at VDS=0 VGS=VTH	$cm^2/(V\times s)$	600
Dl	shortening of channel	um	0.0
Dw	narrowing of channel	um	0.0
Vdd	measurement drain bias range	V	5.0
Vfb	flat-band voltage	V	-0.3
Lvfb	Length Dependence of Vfb	um×V	0.0
Wvfb	Width Dependence of Vfb	um×V	0.0
Phi	surface potential at strong inversion	V	0.6
Lphi	Length Dependence of Phi	um×V	0.0
Wphi	Width Dependence of Phi	um×V	0.0
K1	body effect coefficient	$V^{(1/2)}$	0.5
Lk1	Length Dependence of K1	$um\times V^{(1/2)}$	0.0
Wk1	Width Dependence of K1	$um\times V^{(1/2)}$	0.0
K2	drain-source depletion charge sharing coefficient	None	0.0
Lk2	Length Dependence of K2	um	0.0
Wk2	Width Dependence of K2	um	0.0
Eta	Zero-Bias Drain-Induced Barrier Lowering Coefficient	None	0.0
Leta	Length Dependence of Eta	um	0.0
Weta	Width Dependence of Eta	um	0.0
U0	transverse field mobility degradation coefficient	1/V	670.0
Lu0	Length Dependence of U0	um/V	0.0

Wu0	Width Dependence of U0	um/V	0.0
U1	zero-bias velocity saturation coefficient	um/V	0.0
Lu1	Length Dependence of U1	um^2 /V	0.0
Wu1	Width Dependence of U1	um^2/V	0.0
X2mz	sensitivity of mobility to substrate bias	cm^2/(V^2×s)	0.0
Lx2mz	Length Dependence of X2mz	um×cm^2/(V^2 ×s)	0.0
Wx2mz	Width Dependence of X2mz	um×cm^2/(V^2 ×s)	0.0
X2e	Sensitivity of of Eta to Substrate Bias	1/V	-0.07
Lx2e	Length Dependence of X2e	um/V	0.0
Wx2e	Width Dependence of X2e	um/V	0.0
X3e	Sensitivity of of Eta to Drain Bias	1/V	0.0
Lx3e	Length Dependence of X3e	um/V	0.0
Wx3e	Width Dependence of X3e	um/V	0.0
X2u0	Sensitivity of U0 to Substrate Bias	1/V^2	0.0
Lx2u0	Length Dependence of X2u0	um/V^2	0.0
Wx2u0	Width Dependence of X2u0	um/V^2	0.0
X2u1	Sensitivity of U1 to Substrate Bias	um/V^2	0.0
Lx2u1	Length Dependence of X2u1	um^2/V^2	0.0
Wx2u1	Width Dependence of X2u1	um^2/V^2	0.0
X3u1	Sensitivity of U1 to Drain Bias	um/V^2	0.0
Lx3u1	Length Dependence of X3u1	um^2/V^2	0.0
Wx3u1	Width Dependence of X3u1	um^2/V^2	0.0
Mus	Mobility at VDS=VDD VGS=VTH	cm^2/(V×s)	600.0
Lmus	Length Dependence of Mus	um×cm^2 /(V×s)	0.0
Wmus	Width Dependence of Mus	um×cm^2 /(V×s)	0.0
X2ms	Sensitivity of Mus to Substrate Bias	cm^2/(V^2×s)	0.0
Lx2ms	Length Dependence of X2ms	um×cm^2/(V^2 ×s)	0.0
Wx2ms	Width Dependence of X2ms	um×cm^2/(V^2 ×s)	0.0
X3ms	Sensitivity of Mus to Drain Bias	cm^2/(V^2×s)	0.0
Lx3ms	Length Dependence of X3ms	um×cm^2/(V^2 ×s)	0.0
Wx3ms	Width Dependence of X3ms	um×cm^2/(V^2 ×s)	0.0
N0	Zero-Bias Subthreshold Slope Coefficient	None	None
Ln0	Length Dependence of N0	um	0.0
Wn0	Width Dependence of N0	um	0.0
Nb	Sens. of N0 to Substrate Bias	1/V	0.0
Lnb	Length Dependence of N0	um/V	0.0
Wnb	Width Dependence of N0	um/V	0.0
Nd	Sens. of N0 to Drain Bias	1/V	0.0

Lnd	Length Dependence of N0	um/V	0.0
Wnd	Width Dependence of N0	um/V	0.0
Tox	oxide thickness	um	0.02
Cj	Zero-bias Bulk Junction Capacitance	F/m	0.0
Mj	Junction grading coefficient	None	0.5
Cjsw	Zero-bias Bulk Junction Sidewall Cap	F/m	0.0
Mjsw	Junction Sidewall grading coefficient	None	1/3
Pb	Bulk Junction Potential	V	0.8
Pbsw	Bulk Side Junction Potential	V	1.0
Cgso	gate-source overlap capacitance, per channel width	F/m	0.0
Cgdo	gate-drain overlap capacitance, per channel width	F/m	0.0
Cgbo	gate-bulk overlap capacitance, per channel width	F/m	0.0
Xpart	coefficient of channel charge share	None	1.0
Nlev	Noise model level	None	-1
Gdwnoi	Drain noise parameters for Nlev=3	None	1
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
Rg	gate resistance	Ohm	fixed at 0
N	bulk P-N emission coefficient	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 3)	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	Area Calculation Method	None	0
Hdif	Length of heavily doped diffusion (ACM=2,3 only)	m	0.0
Ldif	Length of lightly doped diffusion adjacent to gate (ACM=1,2 only)	m	0.0
Wmlt	Width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	Accounts for masking and etching effects	m	0.0
Rdc	Additional drain resistance due to contact resistance	Ohm	0.0
Rsc	Additional source resistance due to contact resistance	Ohm	0.0
AllParams	DataAccessComponent-based parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=4 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the

modelname that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET*. Idsmod=4 is a required parameter that is used to tell the simulator to use the BSIM1 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

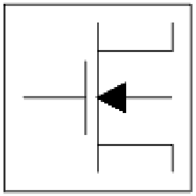
```
model Nch4 MOSFET Idsmod=4 \
Vfb=-0.9 Muz=500 NMOS=yes
```

Notes/Equations

1. This model supplies values for a MOSFET device.
2. BSIM1, BSIM2, and BSIM3 MOSFET models use the same parameters and parameter definitions as the BSIM models in SPICE3 (University of California-Berkeley).
3. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
4. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

BSIM2_Model (BSIM2 MOSFET Model)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	Ids model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	5
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Js	Gate Saturation Current	A/m^2	0.0
Mu0	Surface Mobility at VDS=0 VGS=VTH	cm^2 /(V×s)	600
Dl	shortening of channel	um	0.0
Dw	narrowing of channel	um	0.0
Vdd	Measurement Drain Bias Range	V	5.0
Vgg	Measurement Gate Bias Range	V	5.0
Vbb	Measurement Bulk Bias Range	V	-5.0
Temp	parameter measurement temperature	°C	25
Trise	Temperature rise over ambient	°C	None
Tox	oxide thickness	um	0.02
Cj	Zero-bias Bulk Junction Capacitance	F/m^2	0.0
Mj	Junction grading coefficient	None	0.5
Cjsw	Zero-bias Bulk Junction Sidewall Cap	F/m	0.0
Mjsw	Junction Sidewall grading coefficient	None	1/3
Pb	Bulk Junction Potential	V	0.8
Pbsw	Bulk Side Junction Potential	V	1.0
Cgso	gate-source overlap capacitance, per channel width	F/m	0.0
Cgdo	gate-drain overlap capacitance, per channel width	F/m	0.0
Cgbo	gate-bulk overlap capacitance, per channel width	F/m	0.0
Xpart	coefficient of channel charge share	None	1.0
Vfb	flat-band voltage	V	-0.3
Lvfb	Length Dependence of Vfb	um×V	0.0
Wvfb	Width Dependence of Vfb	um×V	0.0
Phi	surface potential at strong inversion	V	0.6

Lphi	Length Dependence of Phi	um×V	0.0
Wphi	Width Dependence of Phi	um×V	0.0
K1	body effect coefficient	$V^{(1/2)}$	0.5
Lk1	Length Dependence of K1	$um \times V^{(1/2)}$	0.0
Wk1	Width Dependence of K1	$um \times V^{(1/2)}$	0.0
K2	drain-source depletion charge sharing coefficient	None	0.0
Lk2	Length Dependence of K2	um	0.0
Wk2	Width Dependence of K2	um	0.0
Eta0	Zero-Bias Drain-Induced Barrier Lowering Coefficient	None	0.08
Leta0	Length Dependence of Eta	um	0.0
Weta0	Width Dependence of Eta	um	0.0
Ua0	transverse field mobility degradation coefficient	1/V	670.0
Lua0	Length Dependence of Ua0	um/V	0.0
Wua0	Width Dependence of Ua0	um/V	0.0
U10	zero-bias velocity saturation coefficient	um/V	0.0
Lu10	Length Dependence of U10	um^2/V	0.0
Wu10	Width Dependence of U10	um^2/V	0.0
Mu0b	sensitivity of mobility to substrate bias	$cm^2/(V^2 \times s)$	0.0
Lmu0b	Length Dependence of X2mz	$um \times cm^2/(V^2 \times s)$	0.0
Wmu0b	Width Dependence of X2mz	$um \times cm^2/(V^2 \times s)$	0.0
Etab	Sensitivity of of Eta to Substrate Bias	1/V	-0.07
Letab	Length Dependence of X2e	um/V	0.0
Wetab	Width Dependence of X2e	um/V	0.0
Uab	Sensitivity of Ua0 to Substrate Bias	$1/V^2$	0.0
Luab	Length Dependence of Uab	um/V^2	0.0
Wuab	Width Dependence of Uab	um/V^2	0.0
U1b	Sensitivity of U1 to Substrate Bias	um/V^2	0.0
Lu1b	Length Dependence of U1b	um^2/V^2	0.0
Wu1b	Width Dependence of U1b	um^2/V^2	0.0
U1d	Sensitivity of U1 to Drain Bias	um/V^2	0.0
Lu1d	Length Dependence of U1d	um^2/V^2	0.0
Wu1d	Width Dependence of U1d	um^2/V^2	0.0
Mus0	Mobility at VDS=VDD VGS=VTH	$cm^2/(V \times s)$	600.0
Lmus0	Length Dependence of Mus0	$um \times cm^2/(V \times s)$	0.0
Wmus0	Width Dependence of Mus0	$um \times cm^2/(V \times s)$	0.0
Musb	Sensitivity of Mus to Substrate Bias	$cm^2/(V^2 \times s)$	0.0
Lmusb	Length Dependence of Musb	$um \times cm^2/(V^2 \times s)$	0.0
Wmusb	Width Dependence of Musb	$um \times cm^2/(V^2 \times s)$	0.0
N0	Zero-Bias Subthreshold Slope Coefficient	None	None

Ln0	Length Dependence of N0	um	0.0
Wn0	Width Dependence of N0	um	0.0
Nb	Sens. of N0 to Substrate Bias	1/V	None
Lnb	Length Dependence of N0	um/V	0.0
Wnb	Width Dependence of N0	um/V	0.0
Nd	Sens. of N0 to Drain Bias	1/V	None
Lnd	Length Dependence of N0	um/V	0.0
Wnd	Width Dependence of N0	um/V	0.0
Mu20	Empirical Parameter in Beta0 Expression	None	None
Lmu20	Length Dependence of Mu20	um	0.0
Wmu20	Width Dependence of Mu20	um	0.0
Mu2b	Sens. of Mu20 to Substrate Bias	1/V	None
Lmu2b	Length Dependence of Mu2b	um/V	0.0
Wmu2b	Width Dependence of Mu2b	um/V	0.0
Mu2g	Sens. of Mu20 to Gate Bias	1/V	None
Lmu2g	Length Dependence of Mu2g	um/V	0.0
Wmu2g	Width Dependence of Mu2g	um/V	0.0
Mu30	Linear Empirical Parameter in Beta0 Expression	$cm^2/(V^2 \times s)$	None
Lmu30	Length Dependence of Mu30	$um \times cm^2/(V^2 \times s)$	0.0
Wmu30	Width Dependence of Mu30	$um \times cm^2/(V^2 \times s)$	0.0
Mu3g	Sens. of Mu3 to Gate Bias	$cm^2/(V^3 \times s)$	0.0
Lmu3g	Length Dependence of Mu3g	$um \times cm^2/(V^3 \times s)$	0.0
Wmu3g	Width Dependence of Mu3g	$um \times cm^2/(V^3 \times s)$	0.0
Mu40	Quadratic Empirical Parameter in Beta0 Expression	$cm^2/(V^3 \times s)$	0.0
Lmu40	Length Dependence of Mu40	$um \times cm^2/(V^3 \times s)$	0.0
Wmu40	Width Dependence of Mu40	$um \times cm^2/(V^3 \times s)$	0.0
Mu4b	Sens. of Mu4 to Substrate Bias	$cm^2/(V^4 \times s)$	0.0
Lmu4b	Length Dependence of Mu4b	$um \times cm^2/(V^4 \times s)$	0.0
Wmu4b	Width Dependence of Mu4b	$um \times cm^2/(V^4 \times s)$	0.0
Mu4g	Sens. of Mu4 to Gate Bias	$cm^2/(V^4 \times s)$	0.0
Lmu4g	Length Dependence of Mu4g	$um \times cm^2/(V^4 \times s)$	0.0
Wmu4g	Width Dependence of Mu4g	$um \times cm^2/(V^4 \times s)$	0.0
Ub0	Mobility Reduction to Vertical Field at Vbs=0	$1/V^2$	None
Lub0	Length Dependence of Ub0	um/V^2	0.0
Wub0	Width Dependence of Ub0	um/V^2	0.0
Ubb	Sens. of Ub to Substrate Bias	$1/V^3$	None
Lubb	Length Dependence of Ubb	um/V^3	0.0

Wubb	Width Dependence of Ubb	um/V^{3}	0.0
Vof0	Threshold Voltage Offset in the Subthreshold Region	V	0.0
Lvof0	Length Dependence of Vof0	um×V	0.0
Wvof0	Width Dependence ofVof0	um×V	0.0
Vob	Sens. of Vof to Substrate Bias	None	0.0
Lvob	Length Dependence of Vob	um	0.0
Wvob	Width Dependence of Vob	um	0.0
Vofd	Sens. of Vof to Substrate Bias	None	0.0
Lvofd	Length Dependence of Vofd	um	0.0
Wvofd	Width Dependence of Vofd	um	0.0
Ai0	Hot-Electron-Induced Rout Degradation Coeff.	None	0.0
Lai0	Length Dependence of Ai0	um	0.0
Wai0	Width Dependence of Ai0	um	0.0
Aib	Sens. of Ai to Substrate Bias	1/V	0.0
Laib	Length Dependence of Aib	um/V	0.0
Waib	Width Dependence of Aib	um/V	0.0
Bi0	Exponential Parameter of Rout Degradation	V	0.0
Lbi0	Length Dependence of Bi0	um×V	0.0
Wbi0	Width Dependence of Bi0	um×V	0.0
Bib	Sens. of Bi to Substrate Bias	None	0.0
Lbib	Length Dependence of Bib	um	0.0
Wbib	Width Dependence of Bib	um	0.0
Vghigh	Upper Bound for the Transition Region	V	0.15
Lvghigh	Length Dependence of Vghigh	um×V	0.0
Wvghigh	Width Dependence of Vghigh	um×V	0.0
Vglow	Upper Bound for the Transition Region	V	-0.15
Lvglow	Length Dependence of Vglow	um×V	0.0
Wvglow	Width Dependence of Vglow	um×V	0.0
Nlev	Noise model level	None	-1
Gdwnoi	Drain noise parameters for Nlev=3	None	1
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Ffe	flicker noise frequency exponent	None	1.0
Rg	gate resistance	Ohm	fixed at 0
N	bulk P-N emission coefficient	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 3)	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	Area Calculation Method	None	0
Hdif	Length of heavily doped diffusion (ACM=2,3 only)	m	0.0
Ldif	Length of lightly doped diffusion adjacent to gate (ACM=1,2 only)	m	0.0

Wmlt	Width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	Accounts for masking and etching effects	m	0.0
Rdc	Additional drain resistance due to contact resistance	Ohm	0.0
Rsc	Additional source resistance due to contact resistance	Ohm	0.0
AllParams	DataAccessComponent-based parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=5 [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET* . Idsmod=5 is a required parameter that is used to tell the simulator to use the BSIM2 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch5 MOSFET Idsmod=5 \
Vfb=-0.9 Mu0=500 NMOS=yes
```

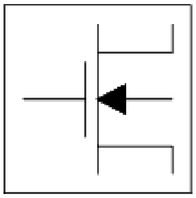
Notes/Equations

1. This model supplies values for a MOSFET device.
2. BSIM1, BSIM2, and BSIM3 MOSFET models use the same parameters and parameter definitions as the BSIM models in SPICE3 (University of California-Berkeley).
3. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
4. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *ataAccessComponent (Data Access Component)* (ccsim)). Note that model

parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

BSIM3_Model (BSIM3 MOSFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	Ids model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	8
Version	model version	None	3.30
Mobmod	mobility model selector	None	1
Capmod	capacitance model selector	None	3 (v3.2+), 2 (v3.1)
Noimod	noise model selector	None	1
Paramchk	model parameter checking selector	None	0
Binunit	bin unit selector	None	1
Rg	gate resistance	Ohm	fixed at 0
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Nj	bulk P-N emission coefficient	None	1.0
Xti	junction current temp. exponent	None	3.0
Js	gate saturation current	A/m^2	1.0e-4
Jsw	sidewall junction reverse saturation current; defaults to Js	A/m^2	defaults to Js
Lintnoi	Lint offset for noise calculation	m	0.0
Lint †	length offset fitting parameter	m	0.0
Ll	Length Reduction Parameter	None	0.0
Lln	Length Reduction Parameter	None	1.0
Lw	Length Reduction Parameter	None	0.0
Lwn	Length Reduction Parameter	None	1.0
Lwl	Length Reduction Parameter	None	0.0
Wint	Width Reduction Parameter	None	0.0
Wl	Width Reduction Parameter	None	0.0

Wln	Width Reduction Parameter	None	1.0
Ww	Width Reduction Parameter	None	0.0
Wwn	Width Reduction Parameter	None	1.0
Wwl	Width Reduction Parameter	None	0.0
Tnom	parameter measurement temp.	°C	25
Trise	temperature rise above ambient	°C	None
Tox	oxide thickness	m	1.5e-8
Cj	zero-bias bulk junction bottom capacitance	F/m^2	5.0e-4
Mj	bulk junction bottom grading coefficient	None	0.5
Cjsw	zero-bias bulk junction sidewall capacitance	F/m	5.0e-10
Mjsw	bulk junction sidewall grading coefficient	None	1/3
Pb	bulk junction potential	V	1.0
Pbsw	bulk sidewall junction potential	V	1.0
Cjswg	S/D (gate side) sidewall junction capacitance; defaults to Cjsw	F/m	defaults to Cjsw
Mjswg	S/D (gate side) sidewall junction grading coefficient; defaults to Mjsw	None	defaults to Mjsw
Pbswg	S/D (gate side) sidewall junction built-in potential; defaults to Pbsw	V	defaults to Pbsw
Cgso	gate-source overlap capacitance, per channel width	F/m	Calculated
Cgdo	gate-drain overlap capacitance, per channel width	F/m	Calculated
Cgbo	gate-bulk overlap capacitance, per channel length	F/m	Calculated
Xpart	Coefficient of Channel Charge Share	None	0.0
Dwg †	coefficient of Weff's gate dependence	m/V	0.0
Ldwg	Length Dependence of Dwg	None	0.0
Wdwg	Width Dependence of Dwg	None	0.0
Pdwg	Cross Dependence of Dwg	None	0.0
Dwb †	coefficient of Weff's body dependence	$m/V^{(1/2)}$	0.0
Ldwb	Length Dependence of Dwb	None	0.0
Wdwb	Width Dependence of Dwb	None	0.0
Pdwb	Cross Dependence of Dwb	None	0.0
Nch	channel doping concentration	$1/cm^3$	1.7e17
Lnch	Length Dependence of Nch	None	0.0
Wnch	Width Dependence of Nch	None	0.0
Pnch	Cross Dependence of Nch	None	0.0
Nsub	substrate doping concentration	$1/cm^3$	6.0e+16
Lnsub	Length Dependence of Nsub	None	0.0
Wnsub	Width Dependence of Nsub	None	0.0
Pnsub	Cross Dependence of Nsub	None	0.0
Ngate	Gate Doping Concentration	$1/cm^3$	Calculated
Lngate	Length Dependence of Ngate	None	0.0
Wngate	Width Dependence of Ngate	None	0.0
Pngate	Cross Dependence of Ngate	None	0.0

Gamma1	body effect coefficient near interface	$V^{(1/2)}$	Calculated
Lgamma1	Length Dependence of Gamma1	None	0.0
Wgamma1	Width Dependence of Gamma1	None	0.0
Pgamma1	Cross Dependence of Gamma1	None	0.0
Gamma2	body effect coefficient in the bulk	$V^{(1/2)}$	Calculated
Lgamma2	Length Dependence of Gamma2	None	0.0
Wgamma2	Width Dependence of Gamma2	None	0.0
Pgamma2	Cross Dependence of Gamma2	None	0.0
Xt	doping depth	m	1.55e-7
Lxt	Length Dependence of Xt	None	0.0
Wxt	Width Dependence of Xt	None	0.0
Pxt	Cross Dependence of Xt	None	0.0
Vbm	Maximum Body Voltage	V	3.0
Lbm	Length Dependence of Vbm	None	0.0
Wbm	Width Dependence of Vbm	None	0.0
Pbm	Cross Dependence of Vbm	None	0.0
Vbx	Vth transition body voltage	V	calculated
Lbx	Length Dependence of Vbx	None	0.0
Wbx	Width Dependence of Vbx	None	0.0
Pbx	Cross Dependence of Vbx	None	0.0
Xj	metallurgical junction depth	m	0.15e-6
Lxj	Length Dependence of Xj	None	0.0
Wxj	Width Dependence of Xj	None	0.0
Pxj	Cross Dependence of Xj	None	0.0
U0 †	low-field mobility at T=Tnom	cm^2 /V×s	670.0 (NMOS) 250.0 (PMOS)
L	Length Dependence of U0	None	0.0
W	Width Dependence of U0	None	0.0
P	Cross Dependence of U0	None	0.0
Vth0 †	zero-bias threshold voltage	V	0.7 (NMOS) -0.7 (PMOS)
Lvth0	Length Dependence of Vth0	None	0.0
Wvth0	Width Dependence of Vth0	None	0.0
Pvth0	Cross Dependence of Vth0	None	0.0
K1	first order body effect coefficient †	$V^{(1/2)}$	0.5
Lk1	Length Dependence of K1	None	0.0
Wk1	Width Dependence of K1	None	0.0
Pk1	Cross Dependence of K1	None	0.0
K2	second order body effect coefficient †	None	-0.0186
Lk2	Length Dependence of K2	None	0.0
Wk2	Width Dependence of K2	None	0.0
Pk2	Cross Dependence of K2	None	0.0
K3	narrow width effect coefficient †	None	80.0
Lk3	Length Dependence of K3	None	0.0

Wk3	Width Dependence of K3	None	0.0
Pk3	Cross Dependence of K3	None	0.0
K3b	Narrow Width Effect Coefficient †	1/V	0.0
Lk3b	Length Dependence of K3b	None	0.0
Wk3b	Width Dependence of K3b	None	0.0
Pk3b	Cross Dependence of K3b	None	0.0
W0 †	narrow width effect W offset	m	2.5e-6
Lw0	Length Dependence of W0	None	0.0
Ww0	Width Dependence of W0	None	0.0
Pw0	Cross Dependence of W0	None	0.0
Nlx	Lateral Non-Uniform Doping Coeff.	m	1.74e-7
Lnlx	Length Dependence of Nlx	None	0.0
Wnlx	Width Dependence of Nlx	None	0.0
Pnlx	Cross Dependence of Nlx	None	0.0
Dvt0 †	First Coeff. of Short-Channel Effect on Vth	None	2.2
Ldvt0	Length Dependence of Dvt0	None	0.0
Wdvt0	Width Dependence of Dvt0	None	0.0
Pdvt0	Cross Dependence of Dvt0	None	0.0
Dvt1 †	Second Coeff. of Short-Channel Effect on Vth	None	0.53
Ldvt1	Length Dependence of Dvt1	None	0.0
Wdvt1	Width Dependence of Dvt1	None	0.0
Pdvt1	Cross Dependence of Dvt1	None	0.0
Dvt2 †	Body-Bias Coeff. of Short-Channel Effect on Vth	1/V	-0.032
Ldvt2	Length Dependence of Dvt2	None	0.0
Wdvt2	Width Dependence of Dvt2	None	0.0
Pdvt2	Cross Dependence of Dvt2	None	0.0
Dvt0w †	First Coeff. of Narrow-Width Effect on Vth	None	0.0
Ldvt0w	Length Dependence of Dvt0w	None	0.0
Wdvt0w	Width Dependence of Dvt0w	None	0.0
Pdvt0w	Cross Dependence of Dvt0w	None	0.0
Dvt1w †	Second Coeff. of Narrow-Width Effect on Vth	None	5.3e6
Ldvt1w	Length Dependence of Dvt1w	None	0.0
Wdvt1w	Width Dependence of Dvt1w	None	0.0
Pdvt1w	Cross Dependence of Dvt1w	None	0.0
Dvt2w †	Body-Bias Coeff. of Narrow-Width Effect on Vth	1/V	-0.032
Ldvt2w	Length Dependence of Dvt2w	None	0.0
Wdvt2w	Width Dependence of Dvt2w	None	0.0
Pdvt2w	Cross Dependence of Dvt2w	None	0.0
Ua †	First Order Mobility Degradation Coeff.	m/V	2.25e-9
Lua	Length Dependence of Ua	None	0.0
Wua	Width Dependence of Ua	None	0.0
Pua	Cross Dependence of Ua	None	0.0

Ub †	Second Order Mobility Degradation Coeff.	$(m/V)^2$	5.87e-19
Lub	Length Dependence of Ub	None	0.0
Wub	Width Dependence of Ub	None	0.0
Pub	Cross Dependence of Ub	None	0.0
Uc †	Body-Bias Mobility Degradation Coeff.	m/V^2 (1/V)	-0.0465 (Modmod=3), -0.0465e-9 (Mobmod=1,2)
Luc	Length Dependence of Uc	None	0.0
Wuc	Width Dependence of Uc	None	0.0
Puc	Cross Dependence of Uc	None	0.0
Delta †	effective Vds parameter	V	0.01
Ldelta	Length Dependence of Delta	None	0.0
Wdelta	Width Dependence of Delta	None	0.0
Pdelta	Cross Dependence of Delta	None	0.0
Rdsw †	Parasitic Resistance per Unit Width	Ohm×um	0.0
Lrdsw	Length Dependence of Rdsw	None	0.0
Wrdsw	Width Dependence of Rdsw	None	0.0
Prdsw	Cross Dependence of Rdsw	None	0.0
Prwg †	Gate-Bias Effect on Parasitic Resistance	1/V	0.0
Lprwg	Length Dependence of Prwg	None	0.0
Wprwg	Width Dependence of Prwg	None	0.0
Pprwg	Cross Dependence of Prwg	None	0.0
Prwb †	Body Effect on Parasitic Resistance	$1/V^{(1/2)}$	0.0
Lprwb	Length Dependence of Prwb	None	0.0
Wprwb	Width Dependence of Prwb	None	0.0
Pprwb	Cross Dependence of Prwb	None	0.0
Wr †	width dependence of Rds	None	1.0
Lwr	Length Dependence of Wr	None	0.0
Wwr	Width Dependence of Wr	None	0.0
Pwr	Cross Dependence of Wr	None	0.0
Vsat †	Saturation Velocity at Tnom	m/s	8.0e4
Lvsat	Length Dependence of Vsat	None	0.0
Wvsat	Width Dependence of Vsat	None	0.0
Pvsat	Cross Dependence of Vsat	None	0.0
A0 †	Bulk Charge Effect Coeff.	None	1.0
La0	Length Dependence of A0	None	0.0
Wa0	Width Dependence of A0	None	0.0
Pa0	Cross Dependence of A0	None	0.0
Keta †	Body-Bias Coeff. of the Bulk Charge Effect	1/V	-0.047
Lketa	Length Dependence of Keta	None	0.0
Wketa	Width Dependence of Keta	None	0.0
Pketa	Cross Dependence of Keta	None	0.0
Ags †	Gate Bias Coeff. of Abulk	1/V	0.0

Lags	Length Dependence of Ags	None	0.0
Wags	Width Dependence of Ags	None	0.0
Pags	Cross Dependence of Ags	None	0.0
A1 †	First Non-Saturation Factor	1/V	0.0
La1	Length Dependence of A1	None	0.0
Wa1	Width Dependence of A1	None	0.0
Pa1	Cross Dependence of A1	None	0.0
A2 †	Second Non-Saturation Factor	None	1.0
La2	Length Dependence of A2	None	0.0
Wa2	Width Dependence of A2	None	0.0
Pa2	Cross Dependence of A2	None	0.0
B0 †	Bulk Charge Effect Coeff. for Channel Width	m	0.0
Lb0	Length Dependence of B0	None	0.0
Wb0	Width Dependence of B0	None	0.0
Pb0	Cross Dependence of B0	None	0.0
B1 †	Bulk Charge Effect Width Offset	m	0.0
Lb1	Length Dependence of B1	None	0.0
Wb1	Width Dependence of B1	None	0.0
Pb1	Cross Dependence of B1	None	0.0
Alpha0 †	First Parameter of Impact Ionization Current	m/V	0.0
Lalpha0	Length Dependence of Alpha0	None	0.0
Walpha0	Width Dependence of Alpha0	None	0.0
Palpha0	Cross Dependence of Alpha0	None	0.0
Beta0 †	First Parameter of Impact Ionization Current	m/V	30.0
Lbeta0	Length Dependence of Beta0	None	0.0
Wbeta0	Width Dependence of Beta0	None	0.0
Pbeta0	Cross Dependence of Beta0	None	0.0
Voff †	Offset Voltage in Subthreshold Region	V	-0.08
Lvoff	Length Dependence of Voff	None	0.0
Wvoff	Width Dependence of Voff	None	0.0
Pvoff	Cross Dependence of Voff	None	0.0
Nfactor †	Subthreshold Swing Factor	None	1.0
Lnfactor	Length Dependence of Nfactor	None	0.0
Wnfactor	Width Dependence of Nfactor	None	0.0
Pnfactor	Cross Dependence of Nfactor	None	0.0
Cdsc †	Drain/Source and Channel Coupling Capacitance	F/m^2	2.4e-4
Lcdsc	Length Dependence of Cdsc	None	0.0
Wcdsc	Width Dependence of Cdsc	None	0.0
Pcdsc	Cross Dependence of Cdsc	None	0.0
Cdscb †	Body-Bias Dependence of Cdsc	F/(V×m^2)	0.0
Lcdscb	Length Dependence of Cdscb	None	0.0

Wcdscb	Width Dependence of Cdscb	None	0.0
Pcdscb	Cross Dependence of Cdscb	None	0.0
Cdscd †	Drain-Bias Dependence of Cdsc	F/(V×m^2)	0.0
Lcdscd	Length Dependence of Cdscd	None	0.0
Wcdscd	Width Dependence of Cdscd	None	0.0
Pcdscd	Cross Dependence of Cdscd	None	0.0
Cit †	Capacitance due to Interface Charge	F/m^2	0.0
Lcit	Length Dependence of Cit	None	0.0
Wcit	Width Dependence of Cit	None	0.0
Pcit	Cross Dependence of Cit	None	0.0
Eta0 †	Subthreshold Region DIBL Coeff.	None	0.08
Leta0	Length Dependence of Eta0	None	0.0
Weta0	Width Dependence of Eta0	None	0.0
Peta0	Cross Dependence of Eta0	None	0.0
Etab †	Subthreshold Region DIBL Coeff.	None	-0.07
Letab	Length Dependence of Peta0	None	0.0
Wetab	Width Dependence of Peta0	None	0.0
Petab	Cross Dependence of Peta0	None	0.0
Dsub †	DIBL Coeff. in Subthreshold Region; defaults to Drout	None	defaults to Drout
Ldsub	Length Dependence of Dsub	None	0.0
Wdsub	Width Dependence of Dsub	None	0.0
Pdsub	Cross Dependence of Dsub	None	0.0
Drout †	DIBL Coeff. of Output Resistance	None	0.56
Ldrout	Length Dependence of Drout	None	0.0
Wdrout	Width Dependence of Drout	None	0.0
Pdrout	Cross Dependence of Drout	None	0.0
Pclm †	Channel Length Modulation Coeff.	None	1.3
Lpclm	Length Dependence of Pclm	None	0.0
Wpclm	Width Dependence of Pclm	None	0.0
Ppclm	Cross Dependence of Pclm	None	0.0
Pdiblc1	Drain Induced Barrier Lowering Effect Coeff. 1	None	0.39
Lpdiblc1	Length Dependence of Pdiblc1	None	0.0
Wpdiblc1	Width Dependence of Pdiblc1	None	0.0
Ppdiblc1	Cross Dependence of Pdiblc1	None	0.0
Pdiblc2	Drain Induced Barrier Lowering Effect Coeff. 2	None	0.0086
Lpdiblc2	Length Dependence of Pdiblc2	None	0.0
Wpdiblc2	Width Dependence of Pdiblc2	None	0.0
Ppdiblc2	Cross Dependence of Pdiblc2	None	0.0
Pdiblcb	Body-Effect on Drain Induced Barrier Lowering	1/V	0.0
Lpdiblcb	Length Dependence of Pdiblcb	None	0.0
Wpdiblcb	Width Dependence of Pdiblcb	None	0.0
Ppdiblcb	Cross Dependence of Pdiblcb	None	0.0

Pscbe1	Substrate Current Body-Effect Coeff. 1	V/m	4.24e8
Lpscbe1	Length Dependence of Pscbe1	None	0.0
Wpscbe1	Width Dependence of Pscbe1	None	0.0
Ppscbe1	Cross Dependence of Pscbe1	None	0.0
Pscbe2	Substrate Current Body-Effect Coeff. 2	m/V	1.0e-5
Lpscbe2	Length Dependence of Pscbe2	None	0.0
Wpscbe2	Width Dependence of Pscbe2	None	0.0
Ppscbe2	Cross Dependence of Pscbe2	None	0.0
Pvag	Gate voltage dependence of Rout	None	0.0
Lpvag	Length Dependence of Pvag	None	0.0
Wpvag	Width Dependence of Pvag	None	0.0
Ppvag	Cross Dependence of Pvag	None	0.0
Ute	Mobility Temperature Exponent	None	-1.5
Lute	Length Dependence of Ute	None	0.0
Wute	Width Dependence of Ute	None	0.0
Pute	Cross Dependence of Ute	None	0.0
At	Temperature Coefficient of Vsat	m/s	3.3e4
Lat	Length Dependence of At	None	0.0
Wat	Width Dependence of At	None	0.0
Pat	Cross Dependence of At	None	0.0
Ua1	Temperature Coefficient of Ua	m/V	4.31e-9
Lua1	Length Dependence of Ua1	None	0.0
Wua1	Width Dependence of Ua1	None	0.0
Pua1	Cross Dependence of Ua1	None	0.0
Ub1	Temperature Coefficient of Ub	$(m/V)^2$	-7.61e-18
Lub1	Length Dependence of Ub1	None	0.0
Wub1	Width Dependence of Ub1	None	0.0
Pub1	Cross Dependence of Ub1	None	0.0
Uc1	Temperature Coefficient of Uc	1/V	-0.056 (Mobmod=3), -0.056e-9 (Mobmod=1,2)
Luc1	Length Dependence of Uc1	None	0.0
Wuc1	Width Dependence of Uc1	None	0.0
Puc1	Cross Dependence of Uc1	None	0.0
Kt1	Temperature Coefficient of Vth	V	-0.11
Lkt1	Length Dependence of Kt1	None	0.0
Wkt1	Width Dependence of Kt1	None	0.0
Pkt1	Cross Dependence of Kt1	None	0.0
Kt1l	Channel Length Sensitivity of Kt1	V×m	0.0
Lkt1l	Length Dependence oKt1l 1	None	0.0
Wkt1l	Width Dependence of Kt1l	None	0.0
Pkt1l	Cross Dependence of Kt1l	None	0.0
Kt2	Body Coefficient of Kt1	None	0.022
Lkt2	Length Dependence of Kt2	None	0.0

Wkt2	Width Dependence of Kt2	None	0.0
Pkt2	Cross Dependence of Kt2	None	0.0
Prt	Temperature Coefficient of Rdsw	Ohm × um	0.0
Lprt	Length Dependence of Prt	None	0.0
Wprt	Width Dependence of Prt	None	0.0
Pprt	Cross Dependence of Prt	None	0.0
Cgsl	Light Doped Source-Gate Overlap Capacitance	F/m	0.0
Lcgsl	Length Dependence of Cgsl	None	0.0
Wcgsl	Width Dependence of Cgsl	None	0.0
Pcgsl	Cross Dependence of Cgsl	None	0.0
Cgdl	Light Doped Drain-Gate Overlap Capacitance	F/m	0.0
Lcgdl	Length Dependence of Cgdl	None	0.0
Wcgdl	Width Dependence of Cgdl	None	0.0
Pcgdl	Cross Dependence of Cgdl	None	0.0
Ckappa	Coeff. for Light Doped Overlap Capacitance	F/m	0.6
Lckappa	Length Dependence of Ckappa	None	0.0
Wckappa	Width Dependence of Ckappa	None	0.0
Pckappa	Cross Dependence of Ckappa	None	0.0
Cf	Fringing Field Capacitance	F/m	calculated
Lcf	Length Dependence of Cf	None	0.0
Wcf	Width Dependence of Cf	None	0.0
Pcf	Cross Dependence of Cf	None	0.0
Clc	Constant Term for the Short Channel C-V Model	m	0.1e-6
Lclc	Length Dependence of Clc	None	0.0
Wclc	Width Dependence of Clc	None	0.0
Pclc	Cross Dependence of Clc	None	0.0
Cle	Exponential Term for the Short Channel C-V Model	None	0.6
Lcle	Length Dependence of Cle	None	0.0
Wcle	Width Dependence of Cle	None	0.0
Pcle	Cross Dependence of Cle	None	0.0
Dlc	Length Offset Fitting Parameter from C-V Model; defaults to Lint	m	defaults to Lint
Dwc	Width Offset Fitting Parameter from C-V Model; defaults to Wint	m	defaults to Wint
Vfbcv	flat-band voltage parameter for capmod=0 only	V	-1.0
Lvfbcv	Length Dependence of Vfbcv	None	0.0
Wvfbcv	Width Dependence of Vfbcv	None	0.0
Pvfbcv	Cross Dependence of Vfbcv	None	0.0
Toxm	gate oxide thickness tox value at which parameters are extracted; defaults to tox	m	defaults to tox
Vfb	DC flat-band voltage	V	calculated
Lvfb	Length Dependence of Vfb	None	0.0
Wvfb	Width Dependence of Vfb	None	0.0

Pvfb	Cross Dependence of Vfb	None	0.0
Noff	CV Turn on/off	None	1.0
Lnoff	Length Dependence of Noff	None	0.0
Wnoff	Width Dependence of Noff	None	0.0
Pnoff	Cross Dependence of Noff	None	0.0
Voffcv	CV Lateral Shift Parameter	V	0.0
Lvoffcv	Length Dependence of Voffcv	None	0.0
Wvoffcv	Width Dependence of Voffcv	None	0.0
Pvoffcv	Cross Dependence of Voffcv	None	0.0
Ijth	diode limiting current	None	0.1
Alpha1	substrate current	1/V	0.0
Lalpha1	Length Dependence of Alpha1	None	0.0
Walpha1	Width Dependence of Alpha1	None	0.0
Palpha1	Cross Dependence of Alpha1	None	0.0
Acde †	Exponential Coefficient for Finite Charge Thickness	m/V	1.0
Lacde	Length Dependence of Acde	None	0.0
Wacde	Width Dependence of Acde	None	0.0
Pacde	Cross Dependence of Acde	None	0.0
Moin †	coefficient for the gate-bias dependent surface potential	$V^{(1/2)}$	15.0
Lmoin	Length Dependence of Moin	None	0.0
Wmoin	Width Dependence of Moin	None	0.0
Pmoin	Cross Dependence of Moin	None	0.0
Tpb	Temperature Coefficient of Pb	V/K	0.0
Tpbsw	Temperature Coefficient of Pbsw	V/K	0.0
Tpbswg	Temperature Coefficient of Pbswg	V/K	0.0
Tcj	Temperature Coefficient of Cj	1/K	0.0
Tcjsw	Temperature Coefficient of Cjsw	1/K	0.0
Tcjswg	Temperature Coefficient of Cjswg	1/K	0.0
Llc	Length Reduction Parameter for CV; defaults to LI	None	defaults to LI
Lwc	Length Reduction Parameter for CV; defaults to Lw	None	defaults to Lw
Lwlc	Length Reduction Parameter for CV; defaults to Lwl	None	defaults to Lwl
Wlc	Width Reduction Parameter for CVt; defaults to WI	None	defaults to Wl
Wwc	Width Reduction Parameter for CV; defaults to Ww	None	defaults to Ww
Wwlc	Width Reduction Parameter for CV; defaults to Wwl	None	defaults to Wwl
Elm	Non-Quasi Static Elmore Constant	None	5.0
Lelm	Length Dependence of Elm	None	0.0
Welm	Width Dependence of Elm	None	0.0
Pelm	Cross Dependence of Elm	None	0.0
Nlev	Noise model level	None	-1
Gdwnoi	Drain noise parameters for Nlev=3	None	1
Kf	Flicker Noise Coefficient	None	0.0
Af	Flicker Noise Coefficient	None	1.0

Ef	Flicker Noise Frequency Exponent	None	1.0
Em	Flicker Noise	V/m	4.1e7
Noia	noise parameter A	None	1.0e20 (NMOS), 9.9e18 (PMOS)
Noib	noise parameter B	None	5.0e4 (NMOS), 2.4e3 (PMOS)
Noic	noise parameter C	None	-1.4e-12 (NMOS), 1.4e-12 (PMOS)
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	area calculation method	None	-1
Hdif	length of heavily doped diffusion (ACM=2,3 only)	m	0.0
Ldif	length of lightly doped diffusion adjacent to gate (ACM=1,2)	m	0.0
Wmlt	width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	Ohm	0.0
Rsc	additional source resistance due to contact resistance	Ohm	0.0
AllParams	DataAccessComponent-based parameters	None	None
B3qmod	BSIM3 charge model (0 for Berkeley, 1 for Hspice Capmod=0)	None	0
Calcacm	flag to use Acm when Acm=12	None	0
Xl	accounts for masking and etching effects	m	0.0
Is	bulk junction saturation current	A	1.0e-14
Rd	drain resistance	Ohm	0.0
Rs	source resistance	Ohm	0.0
Flkmod	flicker noise model selector	None	0
Tlev	temperature equation selector (0/1/2/3)	None	0
Tlevc	temperature equation selector for capacitance (0/1/2/3)	None	0
Eg	band gap	eV	1.16
Gap1	energy gap temperature coefficient alpha	V/°C	7.04e-4
Gap2	energy gap temperature coefficient beta	K	1108
Cta	Cj linear temperature coefficient	1/°C	0
Ctp	Cjsw linear temperature coefficient	1/°C	0
Pta	Vj linear temperature coefficnet	1/°C	0
Ptp	Vjsw linear temperature coefficient	1/°C	0
Trd	Rd linear temperature coefficient	1/°C	0

Trs	Rs linear temperature coefficient	1/°C	0
Wmin	binning minimum width (not used for binning; use BinModel)	m	0.0
Wmax	binning maximum width (not used for binning; use BinModel)	m	1.0
Lmin	binning minimum length (not used for binning; use BinModel)	m	0.0
Lmax	binning maximum length (not used for binning; use BinModel)	m	1.0
Lgcd	Gate-to-contact length of drain side	m	0.0
Lgcs	Gate-to-contact length of source side	m	0.0
Rdd	Scalable drain resistance,	Ohm × m	0.0
Rss	Scalable source resistance	Ohm × m	0.0
Sc	Spacing between contacts	m	infinity
W	Channel width	m	None
L	Channel length	m	None
Ad	Drain Area	m^2	None
As	Source Area	m^2	None
Pd	Drain Perimeter	m	None
Ps	Source Perimeter	m	None
Nrd	Drain Squares	None	None
Nrs	Source Squares	None	None
Dtoxcv	Delta oxide thickness	m	0.0
Vfbflag	Select Vfb for Capmod=0	None	0
Stimod	LOD stress effect model selector	None	0
Sa0	Reference distance between OD edge to poly of one side	m	1.0e-6
Sb0	Reference distance between OD edge to poly of the other side	m	1.0e-6
Wlod	Length parameter for stress effect	None	0.0
Ku0	Mobility degradation/enhancement coefficient for LOD	None	0.0
Kvsat	Saturation velocity degradation/enhancement coefficient for LOD	None	0.0
Kvth0	Threshold degradation/enhancement parameter for LOD	None	0.0
Tku0	Temperature coefficient of Ku0	None	0.0
Llodku0	Length parameter for U0 LOD effect	None	0.0
Wlodku0	Width parameter for U0 LOD effect	None	0.0
Llodvth	Length parameter for Vth LOD effect	None	0.0
Wlodvth	Width parameter for Vth LOD effect	None	0.0
Lku0	Length dependence of Ku0	None	0.0
Wku0	Width dependence of Ku0	None	0.0
Pku0	Cross-term dependence of Ku0	None	0.0
Lkvth0	Length dependence of Kvth0	None	0.0
Wkvth0	Width dependence of Kvth0	None	0.0

Pkvth0	Cross-term dependence of Kvth0	None	0.0
Stk2	K2 shift factor related to stress effect on Vth	None	0.0
Lodk2	K2 shift modification factor for stress effect	None	1.0
Steta0	Eta0 shift factor related to stress effect on Vth	None	0.0
Lodeta0	Eta0 shift modification factor for stress effect	None	1.0
Nqsmod	non-quasi-static model selector	None	0
Acnqsmod	AC non-quasi static model option: 1=on or 0=off	None	0
† binning parameter; see Note 5			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=8 [parm=value]*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET* . Idsmod=8 is a required parameter that tells the simulator to use the BSIM3v3 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch6 MOSFET Idsmod=8 \
Vtho=0.7 Cj=3e-4 NMOS=yes
```

Notes/Equations

1. This model supplies values for a MOSFET device. The default Version is 3.24; previous versions can be used by setting the Version parameter to 3.0, 3.1, 3.2, 3.21, 3.22, or 3.23.
2. More information about this model is available at: http://www-device.eecs.berkeley.edu/bsim3
3. BSIM1, BSIM2, and BSIM3 MOSFET models use the same parameters and parameter definitions as the BSIM models in SPICE3 (University of California-Berkeley).
4. The K1 parameter's default value is calculated except when K2 is present. When K2 is present, 0.5 is used as the default value of K1.
5. Several DC, AC, and capacitance parameters can be binned; these parameters follow this implementation:

$$P = P_0 + \frac{P_L}{L_{eff}} + \frac{P_w}{W_{eff}} + \frac{P_p}{L_{eff} \times W_{eff}}$$

For example, for the K1 parameter, the following relationships exist: P_0=k1, P_L=lk1, P_W=wk1, P_P=pk1. The Binunit parameter is a binning unit selector. If Binunit=1, the units of L_{eff} and W_{eff} used in the preceding binning equation have the units of microns, otherwise in meters. For example, for a device with L_{eff}=0.5mm and W_{eff} =10mm, if Binunit=1, parameter values are le5, le4, 2e4, and 3e4 for Vsat, Lvsat, Wvsat, and Pvsat, respectively, Therefore, the effective value of Vsat for this device is:

Vsat = 1e5 + 1e4/0.5 + 2e4/10 + 3e4/(0.5 × 10) = 1.28e5

To get the same effective value of Vsat for Binunit=0, values of Vsat, Lvsat, Wvsat, and Pvsat would be 1e5, le2, 2e2, 3e8, respectively. Thus:

Vsat = 1e5 + 1e-2/0.5e6 + 2e2/10e6 + 3e 8/(0.5e-6 × 10e6) = 1.28e5

6. The nonquasi-static (NQS) charge model is supported in versions 3.2 and later.
7. Model parameter U0 can be entered in meters or centimeters. U0 is converted to m2/V sec as follows: if U0 > 1, it is multiplied by 10^{-4}.
8. Nqsmod is also supported as an instance parameter. For simulation, only the Nqsmod instance parameter is used (the Nqsmod model parameter is not used). This is the way Berkeley defined Nqsmod in BSIM3v3.2. Hspice supports Nqsmod only as a model parameter.
9. Imelt and Ijth Parameters
   Imelt and Ijth specify the diode limiting current (also known as P-N junction explosion current). Imelt and Ijth can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Ijth value, the Imelt value is increased to the Ijth value.
   If Imelt is specified (in the model or in Options) diode limiting current = Imelt; otherwise, if Ijth is specified (in the model or in Options) diode limiting current = Ijth; otherwise, diode limiting current = model Imelt default value (which is the same as the model Ijth default value).
10. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.
11. DC operating point data is generated for this model. If a DC simulation is performed, device operating point data can be viewed for a component. The procedure for viewing device operating point data for a component is in *Using Circuit Simulators* (cktsim). The device operating point information displayed for the BSIM3 model is:

    Gmb: small-signal Vbs to Ids transconductance, in Siemens
    Gds: small-signal drain source conductance, in Siemens
    Vdsat: saturation voltage, in volts
    Capbd: small-signal bulk drain capacitance, in farads
    Capbs: small-signal bulk source capacitance, in farads
    CgdM: small-signal gate drain Meyer capacitance, in farads
    CgbM: small-signal gate bulk Meyer capacitance, in farads

CgsM: small-signal gate source Meyer capacitance, in farads
DqgDvgb: small-signal transcapacitance dQg/dVg, in farads
DqgDvdb: small-signal transcapacitance dQg/dVd, in farads
DqgDvsb: small-signal transcapacitance dQg/dVs, in farads
DqbDvgb: small-signal transcapacitance dQb/dVg, in farads
DqbDvdb: small-signal transcapacitance dQb/dVd, in farads
DqbDvsb: small-signal transcapacitance dQb/dVs, in farads
DqdDvgb: small-signal transcapacitance dQd/dVg, in farads
DqdDvdb: small-signal transcapacitance dQd/dVd, in farads
DqdDvsb: small-signal transcapacitance dQd/dVs, in farads

12. The model parameter Dtoxcv has been added to the BSIM3 model for Version ≥ 3.2. The implementation is taken from a recent enhancement to the B3soiPD made by U. C. Berkeley. This parameter allows a different effective gate oxide thickness to be used in the I-V and C-V calculations. The value Tox-Dtoxcv is used in the calculation of Vfbzb instead of Tox. In the Capmod=3 code, the effective oxide thickness is now Tox-Dtoxcv instead of Tox.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device Temp parameter. (Temperatures in the following equations are in Kelvin.)

The energy bandgap E_G varies as:

$$E_G(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108} \quad Tlev = 0, 1, 3$$

$$E_G(T) = Eg - \frac{Gap1 T^2}{T + Gap2} \quad Tlev = 2$$

The intrinsic carrier concentration n_i for silicon varies as:

$$n_i(T) = 1.45 \times 10^{10} \left(\frac{T}{300.15}\right)^{3/2} \exp\left(\frac{E_G(300.15)}{2k 300.15/q} - \frac{E_G(T)}{2kT/q}\right)$$

The saturation currents Js and Jsw scale as:

$$Js^{NEW} = Js \exp\left[\frac{E_G(Tnom)}{NkTnom/q} - \frac{E_G(Temp)}{NkTemp/q} + \frac{Xti}{N} \ln\left(\frac{Temp}{Tnom}\right)\right]$$

$$Jsw^{NEW} = Jsw \exp\left[\frac{E_G(Tnom)}{NkTnom/q} - \frac{E_G(Temp)}{NkTemp/q} + \frac{Xti}{N} \ln\left(\frac{Temp}{Tnom}\right)\right]$$

The series resistances Rs and Rd scale as:

$$Rs^{NEW} = Rs[1 + Trs(Temp - Tnom)]$$

$$Rd^{NEW} = Rd[1 + Trd(Temp - Tnom)]$$

The junction potentials Pb, Pbsw, and Pbswg and the junction capacitances Cj, Cjsw, and Cjswg scale as:

if Version ≥ 3.2 and ACM ≥ 10

$$Pb^{NEW} = Pb - Tpb(Temp - Tnom)$$

$$Pbsw^{NEW} = Pbsw - Tpbsw(Temp - Tnom)$$

$$Pbswg^{NEW} = Pbswg - Tpbswg(Temp - Tnom)$$

$$Cj^{NEW} = Cj(1 + Tcj(Temp - Tnom))$$

$$Cjsw^{NEW} = Cjsw(1 + Tcjsw(Temp - Tnom))$$

$$Cjswg^{NEW} = Cjswg(1 + Tcjswg(Temp - Tnom))$$

else if ACM <10

if Tlevc = 0

$$Pb^{NEW} = Pb\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Pbsw^{NEW} = Pbsw\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Pbswg^{NEW} = Pbswg\frac{Temp}{Tnom} + \frac{2kTemp}{q}\ln\left(\frac{n_i(Tnom)}{n_i(Temp)}\right)$$

$$Cj^{NEW} = Cj\left(1 + Mj\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Pb^{NEW}}{Pb}\right]\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 + Mjsw\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Pbsw^{NEW}}{Pbsw}\right]\right)$$

$$Cjswg^{NEW} = Cjswg\left(1 + Mjswg\left[1 + 4 \times 10^{-4}(Temp - Tnom) - \frac{Pbswg^{NEW}}{Pbswg}\right]\right)$$

if Tlevc = 1

$$Pb^{NEW} = Pb - Pta(Temp - Tnom)$$

$$Pbsw^{NEW} = Pbsw - Ptp(Temp - Tnom)$$

$$Pbswg^{NEW} = Pbswg - Ptp(Temp - Tnom)$$

$$Cj^{NEW} = Cj[1 + Cta(Temp - Tnom)]$$

$$Cjsw^{NEW} = Cjsw[1 + Ctp(Temp - Tnom)]$$

$$Cjswg^{NEW} = Cjswg[1 + Ctp(Temp - Tnom)]$$

if Tlevc = 2

$$Pb^{NEW} = Pb - Pta(Temp - Tnom)$$

$$Pbsw^{NEW} = Pbsw - Ptp(Temp - Tnom)$$

$$Pbswg^{NEW} = Pbswg - Ptp(Temp - Tnom)$$

$$Cj^{NEW} = Cj\left(\frac{Pb}{Pb^{NEW}}\right)^{Mj}$$

$$Cjsw^{NEW} = Cjsw\left(\frac{Pbsw}{Pbsw^{NEW}}\right)^{Mjsw}$$

$$Cjswg^{NEW} = Cjswg\left(\frac{Pbswg}{Pbswg^{NEW}}\right)^{Mjswg}$$

if Tlevc = 3

if Tlev = 0, 1, 3

$$dPbdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Pb\right)\frac{1}{Tnom}$$

$$dPbswdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Pbsw\right)\frac{1}{Tnom}$$

$$dPbswdgdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (1.16 - E_G(Tnom))\frac{Tnom + 2 \times 1108}{Tnom + 1108} - Pbswg\right)\frac{1}{Tnom}$$

if Tlev = 2

$$dPbdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pb\right)\frac{1}{Tnom}$$

$$dPbswdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pbsw\right)\frac{1}{Tnom}$$

$$dPbswdgT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pbswg\right)\frac{1}{Tnom}$$

$$Pb^{NEW} = Pb + dPbdT(Temp - Tnom)$$

$$Pbsw^{NEW} = Pbsw + dPbswdT(Temp - Tnom)$$

$$Pbswg^{NEW} = Pbswg + dPbswgT(Temp - Tnom)$$

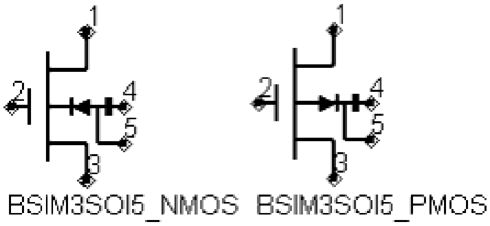
$$Cj^{NEW} = Ce\left(1 - \frac{dPbdT(Temp - Tnom)}{2Pb}\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 - \frac{dPbswdT(Temp - Tnom)}{2Pbsw}\right)$$

$$Cjswg^{NEW} = Cjswg\left(1 - \frac{dPbswgdT(Temp - Tnom)}{2Pbswg}\right)$$

BSIM3SOI5_NMOS, BSIM3SOI5_PMOS (BSIM3 SOI Transistor with 5th Terminal, Ext. Body Contact, NMOS, PMOS)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
Model	model instance name	None	BSIM3SOIM1
Length †	channel length	m	5.0e-6
Width †	channel width	m	5.0e-6
Ad †	area of drain diffusion	m^2	0.0
As †	area of source diffusion	m^2	0.0
Pd †	perimeter of the drain junction	m	0.0
Ps †	perimeter of the drain junction	m	0.0
Nrd	number of squares of the drain diffusion	None	1.0
Nrs	number of squares of the source diffusion	None	1.0
Nrb	number of squares in body	None	1.0
Bjtoff	BJT on/off flag: yes=1, no=0	None	no
Rth0	instance thermal resistance; defaults to Rth0	(Ohm)	defaults to Rth0
Cth0	instance thermal capacitance; defaults to Cth0	(F)	defaults to Cth0
Nbc	number of body contact insulation edge	None	0.0
Nseg	number segments for width partitioning	None	1.0
Pdbcp †	perimter length for bc parasitics at drain side	m	0.0
Psbcp †	perimter length for bc parasitics at source side	m	0.0
Agbc †	gate to body overlap area for bc parasitics	m^2	0.0
Aebcp †	substrate to body overlap area for bc parasitics	m^2	0.0
Vbsusr	Vbs specified by the user; defaults to Vbs	V	defaults to Vbs
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 1)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1
† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by *scale* ^{1} and a parameter with a dimension of m^2 will be multiplied by *scale*^{2}. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.			

Notes/Equations

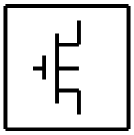
1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gmb	Backgate transconductance (dIds/dVbs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Vth	Threshold voltage	volts
Vdsat	Drain-source saturation voltage	volts
DqgDvgb	(dQg/dVgb)	farads
DqgDvdb	(dQg/dVdb)	farads
DqgDvsb	(dQg/dVsb)	farads
DqgDveb	(dQg/dVeb)	farads
DqbDvgb	(dQb/dVgb)	farads
DqbDvdb	(dQb/dVdb)	farads
DqbDvsb	(dQb/dVsb)	farads
DqbDveb	(dQb/dVeb)	farads
DqdDvgb	(dQd/dVgb)	farads
DqdDvdb	(dQd/dVdb)	farads
DqdDvsb	(dQd/dVsb)	farads
DqdDveb	(dQd/dVeb)	farads
DqeDvgb	(dQe/dVgb)	farads
DqeDvdb	(dQe/dVdb)	farads
DqeDvsb	(dQe/dVsb)	farads
DqeDveb	(dQe/dVeb)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts
Ves	Substrate-source voltage	volts
Vps	Body-source voltage	volts

BSIM3SOI_Model (BSIM3 Silicon On Insulator MOSFET Model)

Symbol



Parameters

Model parameters must be specified in SI units. In some cases, parameters that are simply geometric variations of a listed parameter, such as L, W, or P, are not listed.

Parameter	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Capmod	short-channel capacitance model selector	None	2
Mobmod	mobility model selector	None	1
Noimod	noise model selector	None	1
Shmod	self-heating mode selector; 0=no self-heating, 1= self-heating	None	0
Ddmod	dynamic depletion mode selector	None	0
Igmod	gate current model selector	None	0
Paramchk	model parameter checking selector	None	0
Binunit	Bin unit selector	None	1
Version	model version	None	2.0
Tox	gate oxide thickness	m	1.0e-8
Cdsc	Drain/Source and channel coupling capacitance	F/m^2	2.4e-4
Cdscb	body effect coefficient of Cdsc	F/(V×m^2)	0.0
Cdscd	drain bias dependence of Cdsc	F/(V×m^2	0.0
Cit	capacitance due to interface change	F/m^2	1.0
Nfactor †	subthreshold swing factor	None	0.0
Vsat †	saturation velocity at Temp	m/s	8.0e4
At †	temperature coefficient for saturation velocity	m/s	3.3e4
A0 †	bulk charge effect coefficient	None	1.0
Ags †	gate bulk coefficient of Abulk	V^{-1}	0.0
A1	first saturation factor	V^{-1}	0.0

A2 †	second non-saturation factor	None	1.0
Keta †	body-bias coefficient of the bulk charge effect	V^{-1}	-0.6
Nsub	substrate doping concentration with polarity	cm^{-3}	6.0e16
Nch	Channel doping concentration	cm^{-3}	1.7e17
Ngate	poly-gate doping concentration	cm^{-3}	0.0
Gamma1	body-effect coefficient near the interface	V$^{(1/2)}$	calculated
Gamma2	body-effect coefficient in the bulk	V$^{(1/2)}$	calculated
Vbx	Vth transition body voltage	V	calculated
Vbm	maximum body voltage	V	-3.0
Xt	doping depth	m	1.55e-7
K1 †	body-effect coefficient	V$^{(1/2)}$	0.5
Kt1	temperature coefficient for threshold voltage	V	-0.11
Kt1l	channel length sensitivity of kt1	V×m	0.0
Kt2	body-bias coefficient	None	0.022
K2 †	bulk effect coefficient 2	None	0.0
K3 †	narrow width coefficient	None	0.0
K3b †	body effect coefficient of K3	V^{-1}	0.0
W0 †	narrow width	m	2.5e6
Nlx †	lateral non-uniform doping coefficient	m	1.74e-7
Dvt0 †	first coefficient of short-channel effect on Vth	None	2.2
Dvt1 †	first coefficient of short-channel effect on Vth	None	0.53
Dvt2 †	body-bias coefficient of short-channel effect on Vth	V^{-1}	-0.032
Dvt0w †	first coefficient of narrow-width effect on Vth	None	0.0
Dvt1w †	Second Coefficient of narrow-width effect on Vth	m^{-1}	5.3e6
Dvt2w †	Body-bias Coefficient of narrow-width effect on Vth	V^{-1}	0.032
Drout †	L depend	None	0.56
Dsub †	DIBL coefficient in sub-threshold region; defaults to Drout	None	defaults to Drout
Vth0 †	zero-bias threshold voltage	V	0.7 (NMOS)-0.7 (PMOS)
Ua †	first-order mobility degradation coefficient	m/V	2.25e-9
Ua1	temperature coefficient of Ua	m/V	4.31e-9
Ub †	second-order mobility degradation coefficient	(m/V)^2	5.87e-19
Ub1	temperature coefficient of Ub	(m/V)^2	−7.61e-18
Uc †	body-bias mobility degradation coefficient	V^{-1}	-0.0465
Uc1	temperature coefficient of Uc	V^{-1}	-0.056
U0 †	low-field mobility at T=Tnom	m^2/(V×s)	0.067 NMOS0.025 PMOS
Ute	Mobility temperature exponent	None	-1.5
Voff †	Offset voltage in sub-threshold region	V	-0.08
Tnom	measurement temperature	°C	25

Trise	temperature rise above ambient	°C	None
Cgso	G-S overlap capacitance per meter channel width	F/m	calculated
Cgdo	G-D overlap capacitance per meter channel width	F/m	calculated
Xpart	coefficient of channel charge share	None	0.0
Delta †	effective Vds	V	0.01
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Rdsw †	parasitic resistance per unit width	Ohm × um^{Wr}	0.0
Prwg †	gate bias effect on parasitic resistance	V^{-1}	0.0
Prwb †	body effect on parasitic resistance	$V^{-1/2}$	0.0
Prt	temperature coefficient of parasitic resistance	Ohm × um	0.0
Eta0	Sub-threshold region DIBL coefficient	None	0.08
Etab	Sub-threshold region DIBL coefficient	V^{-1}	-0.07
Pclm	channel-length modulation effect coefficient	None	1.3
Pdiblc1	drain induced barrier lowering effect coefficient 1	None	0.39
Pdiblc2	drain induced barrier lowering effect coefficient 2	None	0.086
Pdiblcb	body effect on drain induced barrier lowering	V^{-1}	0.0
Pvag †	gate voltage dependence of Rout coefficient	None	0.0
Tbox	back gate oxide thickness	m	3.0e-7
Tsi	silicon-on-insulator thickness	m	1.0e-7
Xj	metallurgical junction depth; defaults to Tsi	m	defaults to Tsi
Rth0	self-heating thermal resistance	Ohm	0.0
Cth0	self-heating thermal capacitance	F	0.0
Ngidi	GIDL first parameter	V	1.2
Agidl	GIDL second parameter	Ohm^{-1}	0.0
Bgidl	GIDL third parameter	V/m	0.0
Ndiode †	diode non-ideality factor	None	1.0
Xbjt	temperature coefficient for Isbjt	None	1.0
Xdif	temperature coefficient for Isdif	None	1.0
Xrec	temperature coefficient for Isrec	None	1.0
Xtun	temperature coefficient for Istun	None	0.0
Pbswg	S/D (gate side) sidewall junction built-in potential	V	0.7
Mjswg	S/D (gate side) sidewall junction grading coefficient	None	0.5
Cjswg	S/D (gate side) sidewall junction capacitance	F/m	1.0e-10
Lint †	length reduction parameter	m	0.0
Ll	coefficient of length dependence for length offset	m	0.0
Lln	power of length dependence of length offset	None	1.0
Lw	coefficient of width dependence for length offset	m	0.0
Lwn	power of width dependence for length offset	None	1.0
Lwl	coefficient of lenth and width cross term length offset	m	0.0
Wr †	width dependence of Rds	None	1.0
Wint †	width reduction parameter	m	0.0

Dwg †	coefficient of Weff's gate dependence	m/V	0.0
Dwb †	coefficient of Weff's substrate body bias dependence	$m/V^{(1/2)}$	0.0
Wl	coefficient of length dependence for width offset	m	0.0
Wln	power of length dependence for width offset	None	1.0
Ww	coefficient of width dependence for width offset	m	0.0
Wwn	power of width dependence for width offset	None	1.0
Wwl	coefficient of length and width cross term width of offset	m	0.0
B0 †	Bulk charge effect coefficient for channel width	m	0.0
B1 †	Bulk charge effect width offset	m	0.0
Cgsl	light doped source-gate region overlap capacitance	F/m	0.0
Cgdl	Light doped drain-gate region overlap capacitance	F/m	0.0
Ckappa	coefficient for light doped source-gate region overlap capacitance	F/m	0.6
Cf	fringing field capacitance	F/m	calculated
Clc	constant term for the short channel model	m	0.1e-7
Cle	exponential term for the short channel model	None	0.0
Dwc	width offset fitting parameter from C-V; defaults to Wint	m	defaults to Wint
Dlc	length offset fitting parameter from C-V; defaults to Lint	m	defaults to Lint
Alpha0 †	first parameter of impact ionization current	m/V	0.0
Noia	noise parameter A	None	1.0e20 (NMOS)9.9e18 (PMOS)
Noib	noise parameter B	None	5.0e4(NMOS),2.4e3 (PMOS)
Noic	noise parameter C	None	-1,4e-12 (NMOS)1.4e-12 (PMOS)
Em	flicker (1/f) noise parameter	V/m	4.1e-7
Ef	flicker (1/f) noise frequency exponent	None	1.0
Af	flicker (1/f) noise exponent	None	1.0
Kf	flicker (1/f) noise coefficient	None	0.0
Noif	floating body noise ideality factor	None	1.0
K1w1 †	first body effect width dependent parameter	m	0.0
K1w2 †	second body effect width dependent parameter	m	0.0
Ketas †	surface potential adjustment for bulk charge effect	V	0.0
Dwbc	width offset for body contact isolation edge	m	0.0
Beta0 †	first Vds parameter of impact isolation current	V^{-1}	0.0
Beta1 †	second Vds parameter of impact isolation current	None	0.0
Beta2 †	third Vds parameter of impact isolation current	V	0.1
Vdsatii0	nominal drain saturation voltage at threshold for impact ionization current	V	0.9
Tii †	temperature dependent parameter for impact ionization	None	0.0
Lii †	channel length dependent parameter threshold for impact ionization	None	0.0

Sii0 †	first Vgs dependent parameter for impact ionization current	V^{-1}	0.5
Sii1 †	second Vgs dependent parameter for impact ionization current	V^{-1}	0.1
Sii2 †	third Vgs dependent parameter for impact ionization current	V^{-1}	0.1
Siid †	Vgs dependent parameter for impact ionization current	V^{-1}	0.1
Fbjtii	fraction of bipolar current affecting the impact ionization	None	0.0
Esatii †	saturation electric field for impact ionization	V /m	1.0e7
Ntun †	reverse tunneling new-ideality factor	None	10.0
Nrecf0 †	recombination non-ideality factor at forward bias	None	2.0
Nrecr0 †	recombination non-ideality factor at reversed bias	None	10.0
lsbjt †	BJT injection saturation current	A/m^2	1.0e-6
lsdif †	Body to source/drain injection saturation current	A/m^2	0.0
lsrec †	recombination in depletion saturation current	A/m^2	1.0e-5
lstun †	reverse tunneling saturation current	A/m^2	0.0
Ln	electron/hole diffusion length	m	2.0e-6
Vrec0 †	voltage dependent parameter for recombination current	V	0.0
Vtun0 †	voltage dependent parameter for tunneling current	V	0.0
Nbjt †	power coefficient of channel length dependency for bipolar current	None	1.0
Lbjt0 †	Reference channel length for bipolar current	m	0.2e-6
Ldif0	channel length dependency coefficient of diffusion capacitance	None	1.0
Vabjt †	early voltage for bipolar current	V	10.0
Aely †	channel length dependency of early voltage for bipolar current	V/m	0.0
Ahli †	high level injection parameter for bipolar current	None	0.0
Rbody	intrinsic body sheet resistance	Ohm/m^2	0.0
Rbsh	extrinsic body sheet resistance	Ohm/m^2	0.0
Cgeo	Gate substrate overlap capacitance per unit channel length	F/m	0.0
Tt	diffusion capacitance transit time coefficient	sec	1.0e-12
Ndif	power coefficient of channel length dependency for diffusion capacitance	None	-1.0
Vsdfb †	Source/drain bottom diffusion capacitance flatband voltage	V	calculated
Vsdth †	Source/drain bottom diffusion capacitance threshold voltage	V	calculated
Csdmin	Source/drain bottom diffusion minimum capacitance	F	calculated
Asd	source/drain bottom diffusion smoothing parameter	None	0.3
Csdesw	source/drain sidewall fringing capacitance per unit channel length	F/m	0/0

Ntrecf	temperature coefficient for Ncref	None	0.0
Ntrecr	temperature coefficient for Ncrer	None	0.0
Dlcb	length offset fitting parameter for body charge; defaults to Lint	m	defaults to Lint
Fbody	scaling factor for body charge	None	1.0
Tcjswg	temperature coefficient of Cjswg	K^{-1}	0.0
Tpbswg	temperature coefficient of Pbswg	V/K	0.0
Acde †	exponential coefficient for finite charge thickness	m/V	1.0
Moin †	coefficient for gate-bias dependent surface potential	$V^{(1/2)}$	15.0
Delvt †	threshold voltage adjust for CV	V	0.0
Kb1 †	coefficient of Vbs0 dependency on Ves	None	1.0
Dlbg	length offset fitting parameter for backgate charge	m	0.0
Toxqm	effective oxide thickness considering quantum effect; defaults toTox	m	defaults toTox
Wth0	minimum width for thermal resistance calculation	m	0.0
Rhalo	Body halo sheet resistance	Ohm	1.0e15
Ntox	power term of gate current	None	1.0
Toxref	target oxide thickness	m	2.5e-9
Ebg	effective bandgap in gate current calculation	V	1.2
Nevb	valence-band electron non-ideality factor	V	3.0
Alphagb1	first Vox dependent parameter for gate current in inversion	None	0.35
Betagb1	second Vox dependent parameter for gate current in inversion	None	0.03
Vgb1	third Vox dependent parameter for gate current in inversion	None	300.0
Necb	condition-band electron non-ideality factor	None	1.0
Alphagb2	first Vox dependent parameter for gate current in accumulation	None	0.43
Betagb2	second Vox dependent parameter for gate current in accumulation	None	0.05
Vgb2	third Vox dependent parameter for gate current in accumulation	None	17.0
Voxh	limit of Vox in gate current calculation	V	5.0
Deltavox	Smoothing parameter in the Vox smoothing function	V	0.005
Lnch	Length dependence of nch	None	0.0
Lnsub	Length dependence of nsub	None	0.0
Lngate	Length dependence of ngate	None	0.0
Lvth0	Length dependence of vth0	None	0.0
Lk1	Length dependence of body effect coefficient	$um \times V^{(1/2)}$	0.0
Lk1w1	Length dependence of K1w1	None	0.0
Lk1w2	Length dependence of K1w2	None	0.0
Lk2	Length dependence of charge sharing coefficient	um	0.0
Lk3	Length dependence of k3	None	0.0
Lk3b	Length dependence of k3b	None	0.0

Lkb1	Length dependence of kb1	None	0.0
Lw0	Length dependence of w0	None	0.0
Lnlx	Length dependence of nlx	None	0.0
Ldvt0	Length dependence of dvt0	None	0.0
Ldvt1	Length dependence of dvt1	None	0.0
Ldvt2	Length dependence of dvt2	None	0.0
Ldvt0w	Length dependence of dvt0w	None	0.0
Ldvt1w	Length dependence of dvt1w	None	0.0
Ldvt2w	Length dependence of dvt2w	None	0.0
Lu0	Length dependence of u0	None	0.0
Lua	Length dependence of ua	None	0.0
Lub	Length dependence of ub	None	0.0
Luc	Length dependence of uc	None	0.0
Lvsat	Length dependence of vsat	None	0.0
La0	Length dependence of a0	None	0.0
Lags	Length dependence of ags	None	0.0
Lb0	Length dependence of b0	None	0.0
Lb1	Length dependence of b1	None	0.0
Lketa	Length dependence of keta	None	0.0
Lketas	Length dependence of ketas	None	0.0
La1	Length dependence of a1	None	0.0
La2	Length dependence of a2	None	0.0
Lrdsw	Length dependence of rdsw	None	0.0
Lprwb	Length dependence of prwb	None	0.0
Lprwg	Length dependence of prwg	None	0.0
Lwr	Length dependence of wr	None	0.0
Lnfactor	Length dependence of nfactor	None	0.0
Ldwg	Length dependence of dwg	None	0.0
Ldwb	Length dependence of dwb	None	0.0
Lvoff	Length dependence of voff	None	0.0
Leta0	Length dependence of barrier lowering coefficient,	um	0.0
Letab	Length dependence of sens	um/V	0.0
Ldsub	Length dependence of dsub	None	0.0
Lcit	Length dependence of cit	None	0.0
Lcdsc	Length dependence of cdsc	None	0.0
Lcdscb	Length dependence of cdscb	None	0.0
Lcdscd	Length dependence of cdscd	None	0.0
Lpclm	Length dependence of pclm	None	0.0
Lpdiblc1	Length dependence of pdiblc1	None	0.0
Lpdiblc2	Length dependence of pdiblc2	None	0.0
Lpdiblcb	Length dependence of pdiblcb	None	0.0
Ldrout	Length dependence of drout	None	0.0
Lpvag	Length dependence of pvag	None	0.0

Ldelta	Length dependence of delta	None	0.0
Lalpha0	Length dependence of alpha0	None	0.0
Lfbjtii	Length dependence of fbjtii	None	0.0
Lbeta0	Length dependence of beta0	None	0.0
Lbeta1	Length dependence of beta1	None	0.0
Lbeta2	Length dependence of beta2	None	0.0
Lvdsatii0	Length dependence of vdsatii0	None	0.0
Llii	Length dependence of lii	None	0.0
Lesatii	Length dependence of esatii	None	0.0
Lsii0	Length dependence of sii0	None	0.0
Lsii1	Length dependence of sii1	None	0.0
Lsii2	Length dependence of sii2	None	0.0
Lsiid	Length dependence of siid	None	0.0
Lagidl	Length dependence of agidl	None	0.0
Lbgidl	Length dependence of bgidl	None	0.0
Lngidl	Length dependence of ngidl	None	0.0
Lntun	Length dependence of ntun	None	0.0
Lndiode	Length dependence of ndiode	None	0.0
Lnrecf0	Length dependence of nrecf0	None	0.0
Lnrecr0	Length dependence of nrecr0	None	0.0
Lisbjt	Length dependence of isbjt	None	0.0
Lisdif	Length dependence of isdif	None	0.0
Listun	Length dependence of istun	None	0.0
Lvrec0	Length dependence of vrec0	None	0.0
Lvtun0	Length dependence of vtun0	None	0.0
Lnbjt	Length dependence of nbjt	None	0.0
Lnbjt0	Length dependence of lbjt0	None	0.0
Lvabjt	Length dependence of vabjt	None	0.0
Laely	Length dependence of aely	None	0.0
Lahli	Length dependence of ahli	None	0.0
Lvsdfb	Length dependence of vsdfb	None	0.0
Lvsdth	Length dependence of vsdth	None	0.0
Ldelvt	Length dependence of delvt	None	0.0
Lacde	Length dependence of Acde	None	0.0
Lmoin	Length dependence of Moin	um×$V^{(1/2)}$	0.0
Wnch	Width dependence of nch	None	0.0
Wnsub	Width dependence of nsub	None	0.0
Wngate	Width dependence of ngate	None	0.0
Wvth0	Width dependence of vth0	None	0.0
Wk1	Width dependence of body effect coefficient	um×$V^{(1/2)}$	0.0
Wk1w1	Width dependence of K1w1	None	0.0
Wk1w2	Width dependence of K1w2	None	0.0
Wk2	Width dependence of charge sharing coefficient	um	0.0

Wk3	Width dependence of k3	None	0.0
Wk3b	Width dependence of k3b	None	0.0
Wkb1	Width dependence of kb1	None	0.0
Ww0	Width dependence of w0	None	0.0
Wnlx	Width dependence of nlx	None	0.0
Wdvt0	Width dependence of dvt0	None	0.0
Wdvt1	Width dependence of dvt1	None	0.0
Wdvt2	Width dependence of dvt2	None	0.0
Wdvt0w	Width dependence of dvt0w	None	0.0
Wdvt1w	Width dependence of dvt1w	None	0.0
Wdvt2w	Width dependence of dvt2w	None	0.0
Wu0	Width dependence of mobility degradation coefficient	None	0.0
Wua	Width dependence of ua	None	0.0
Wub	Width dependence of ub	None	0.0
Wuc	Width dependence of uc	None	0.0
Wvsat	Width dependence of vsat	None	0.0
Wa0	Width dependence of a0	None	0.0
Wags	Width dependence of ags	None	0.0
Wb0	Width dependence of b0	None	0.0
Wb1	Width dependence of b1	None	0.0
Wketa	Width dependence of keta	None	0.0
Wketas	Width dependence of ketas	None	0.0
Wa1	Width dependence of a1	None	0.0
Wa2	Width dependence of a2	None	0.0
Wrdsw	Width dependence of rdsw	None	0.0
Wprwb	Width dependence of prwb	None	0.0
Wprwg	Width dependence of prwg	None	0.0
Wwr	Width dependence of wr	None	0.0
Wnfactor	Width dependence of nfactor	None	0.0
Wdwg	Width dependence of dwg	None	0.0
Wdwb	Width dependence of dwb	None	0.0
Wvoff	Width dependence of voff	None	0.0
Weta0	Width dependence of barrier lowering coefficient	um	0.0
Wetab	Width dependence of sens	um/V	0.0
Wdsub	Width dependence of dsub	None	0.0
Wcit	Width dependence of cit	None	0.0
Wcdsc	Width dependence of cdsc	None	0.0
Wcdscb	Width dependence of cdscb	None	0.0
Wcdscd	Width dependence of cdscd	None	0.0
Wpclm	Width dependence of pclm	None	0.0
Wpdiblc1	Width dependence of pdiblc1	None	0.0
Wpdiblc2	Width dependence of pdiblc2	None	0.0
Wpdiblcb	Width dependence of pdiblcb	None	0.0

Wdrout	Width dependence of drout	None	0.0
Wpvag	Width dependence of pvag	None	0.0
Wdelta	Width dependence of delta	None	0.0
Walpha0	Width dependence of alpha0	None	0.0
Wfbjtii	Width dependence of fbjtii	None	0.0
Wbeta0	Width dependence of beta	None	0.0
Wbeta1	Width dependence of beta1	None	0.0
Wbeta2	Width dependence of beta2	None	0.0
Wvdsatii0	Width dependence of vdsatii0	None	0.0
Wlii	Width dependence of lii	None	0.0
Wesatii	Width dependence of esatii	None	0.0
Wsii0	Width dependence of sii0	None	0.0
Wsii1	Width dependence of sii1	None	0.0
Wsii2	Width dependence of sii2	None	0.0
Wsiid	Width dependence of siid	None	0.0
Wagidl	Width dependence of agidl	None	0.0
Wbgidl	Width dependence of bgidl	None	0.0
Wngidl	Width dependence of ngidl	None	0.0
Wntun	Width dependence of ntun	None	0.0
Wndiode	Width dependence of ndiode	None	0.0
Wnrecf0	Width dependence of nrecf0	None	0.0
Wnrecr0	Width dependence of nrecr0	None	0.0
Wisbjt	Width dependence of isbjt	None	0.0
Wisdif	Width dependence of isdif	None	0.0
Wistun	Width dependence of istun	None	0.0
Wvrec0	Width dependence of vrec0	None	0.0
Wvtun0	Width dependence of vtun0	None	0.0
Wnbjt	Width dependence of nbjt	None	0.0
Wlbjt0	Width dependence of lbjt0	None	0.0
Wvabjt	Width dependence of vabjt	None	0.0
Waely	Width dependence of aely	None	0.0
Wahli	Width dependence of ahli	None	0.0
Wvsdfb	Width dependence of vsdfb	None	0.0
Wvsdth	Width dependence of vsdth	None	0.0
Wdelvt	Width dependence of delvt	None	0.0
Wacde	Width dependence of Acde	None	0.0
Wmoin	Width dependence of Moin	um×V$^{(1/2)}$	0.0
Pnch	Cross-term dependence of nch	None	0.0
Pnsub	Cross-term dependence of nsub	None	0.0
Pngate	Cross-term dependence of ngate	None	0.0
Pvth0	Cross-term dependence of vth0	None	0.0
Pk1	Cross-term dependence of k1	None	0.0
Pk1w1	Cross-term dependence of K1w1	None	0.0

Pk1w2	Cross-term dependence of K1w2	None	0.0
Pk2	Cross-term dependence of k2	None	0.0
Pk3	Cross-term dependence of k3	None	0.0
Pk3b	Cross-term dependence of k3b	None	0.0
Pkb1	Cross-term dependence of kb1	None	0.0
Pw0	Cross-term dependence of w	None	0.0
Pnlx	Cross-term dependence of nlx	None	0.0
Pdvt0	Cross-term dependence of dvt0	None	0.0
Pdvt1	Cross-term dependence of dvt1	None	0.0
Pdvt2	Cross-term dependence of dvt2	None	0.0
Pdvt0w	Cross-term dependence of dvt0w	None	0.0
Pdvt1w	Cross-term dependence of dvt1w	None	0.0
Pdvt2w	Cross-term dependence of dvt2w	None	0.0
Pu0	Cross-term dependence of u0	None	0.0
Pua	Cross-term dependence of ua	None	0.0
Pub	Cross-term dependence of ub	None	0.0
Puc	Cross-term dependence of uc	None	0.0
Pvsat	Cross-term dependence of vsat	None	0.0
Pa0	Cross-term dependence of a0	None	0.0
Pags	Cross-term dependence of ags	None	0.0
Pb0	Cross-term dependence of b0	None	0.0
Pb1	Cross-term dependence of b1	None	0.0
Pketa	Cross-term dependence of keta	None	0.0
Pketas	Cross-term dependence of ketas	None	0.0
Pa1	Cross-term dependence of a1	None	0.0
Pa2	Cross-term dependence of a2	None	0.0
Prdsw	Cross-term dependence of rdsw	None	0.0
Pprwb	Cross-term dependence of prwb	None	0.0
Pprwg	Cross-term dependence of prwg	None	0.0
Pwr	Cross-term dependence of wr	None	0.0
Pnfactor	Cross-term dependence of nfactor	None	0.0
Pdwg	Cross-term dependence of dwg	None	0.0
Pdwb	Cross-term dependence of dwb	None	0.0
Pvoff	Cross-term dependence of voff	None	0.0
Peta0	Cross-term dependence of eta0	None	0.0
Petab	Cross-term dependence of etab	None	0.0
Pdsub	Cross-term dependence of dsub	None	0.0
Pcit	Cross-term dependence of cit	None	0.0
Pcdsc	Cross-term dependence of cdsc	None	0.0
Pcdscb	Cross-term dependence of cdscb	None	0.0
Pcdscd	Cross-term dependence of cdscd	None	0.0
Ppclm	Cross-term dependence of pclm	None	0.0
Ppdiblc1	Cross-term dependence of pdiblc1	None	0.0

Ppdiblc2	Cross-term dependence of pdiblc2	None	0.0
Ppdiblcb	Cross-term dependence of pdiblcb	None	0.0
Pdrout	Cross-term dependence of drout	None	0.0
Ppvag	Cross-term dependence of pvag	None	0.0
Pdelta	Cross-term dependence of delta	None	0.0
Palpha0	Cross-term dependence of alpha0	None	0.0
Pfbjtii	Cross-term dependence of fbjtii	None	0.0
Pbeta0	Cross-term dependence of beta0	None	0.0
Pbeta1	Cross-term dependence of beta1	None	0.0
Pbeta2	Cross-term dependence of beta2	None	0.0
Pvdsatii0	Cross-term dependence of vdsatii0	None	0.0
Plii	Cross-term dependence of lii	None	0.0
Pesatii	Cross-term dependence of esatii	None	0.0
Psii0	Cross-term dependence of sii0	None	0.0
Psii1	Cross-term dependence of sii1	None	0.0
Psii2	Cross-term dependence of sii2	None	0.0
Psiid	Cross-term dependence of siid	None	0.0
Pagidl	Cross-term dependence of agidl	None	0.0
Pbgidl	Cross-term dependence of bgidl	None	0.0
Pngidl	Cross-term dependence of ngidl	None	0.0
Pntun	Cross-term dependence of ntun	None	0.0
Pndiode	Cross-term dependence of ndiode	None	0.0
Pnrecf0	Cross-term dependence of nrecf0	None	0.0
Pnrecr0	Cross-term dependence of nrecr0	None	0.0
Pisbjt	Cross-term dependence of isbjt	None	0.0
Pisdif	Cross-term dependence of isdif	None	0.0
Pistun	Cross-term dependence of istun	None	0.0
Pvrec0	Cross-term dependence of vrec0	None	0.0
Pvtun0	Cross-term dependence of vtun0	None	0.0
Pnbjt0	Cross-term dependence of nbjt	None	0.0
Plbjt0	Cross-term dependence of lbjt0	None	0.0
Pvabjt	Cross-term dependence of vabjt	None	0.0
Paely	Cross-term dependence of aely	None	0.0
Pahli	Cross-term dependence of ahli	None	0.0
Pvsdfb	Cross-term dependence of vsdfb	None	0.0
Pvsdth	Cross-term dependence of vsdth	None	0.0
Pdelvt	Cross-term dependence of delvt	None	0.0
Pacde	Cross-term dependence of Acde	None	0.0
Gmin	P-N junction parallel conductance	None	1e-20
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None

wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None
† binning factor (see Note 3)			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname B3SOI [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *B3SOI*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Nch8 B3SOI \
 Vtho=0.7 Cj=3e-4 NMOS=yes
```

Notes/Equations

1. In ADS, this BSIM3SOI model is equivalent to the Berkeley model named BSIMSOI, a deep submicron, silicon-on-insulator MOSFET device model for SPICE engines; it was developed by the BSIM Group under the direction of Professor Chenming Hu in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley. BSIMSOI is closely related to the industry standard bulk MOSFET model, BSIM.
2. BSIMPD2.2, used for this ADS release, is the new version of the Partial Depletion SOI MOSFET model, BSIMPD SOI. The gate-body tunneling (substrate current) is added in this release to enhance the model accuracy. BSIMPD2.2 information can be found on the BSIMSOI website "http://www-device.eecs.berkeley.edu/~bsimsoi" .
3. Several DC, AC, and capacitance parameters can be binned; these parameters follow this implementation:

$$P = P_0 + \frac{P_L}{L_{eff}} + \frac{P_w}{W_{eff}} + \frac{P_p}{L_{eff} \times W_{eff}}$$

For example, for the parameter K1, the following relationships exist: P_0 = k1, P_L = lk1, P_W = wk1, P_P=pk1. The Binunit parameter is a binning unit selector. If Binunit=1, the units of L_{eff} and W_{eff} used in the preceding binning equation have the units of microns, otherwise in meters. For example, for a device with L_{eff}=0.5mm and W_{eff}=10mm, if Binunit=1, parameter values are le5, le4, 2e4, and 3e4 for Vsat, Lvsat, Wvsat, and Pvsat, respectively, Therefore, the effective value of Vsat for this device is:

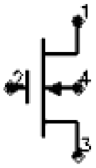
$$Vsat = 1e5 + 1e4/0.5 + 2e4/10 + 3e4/(0.5 \times 10) = 1.28e5$$

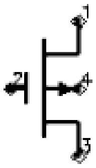
To get the same effective value of Vsat for Binunit=0, values of Vsat, Lvsat, Wvsat, and Pvsat would be 1e5, le−2, 2e−2, 3e−8, respectively. Thus:

$$Vsat = 1e5 + 1e-2/0.5e6 + 2e-2/10e-6 + 3e-8/(0.5e-6 \times 10e-6) = 1.28e5$$

BSIM3SOI_NMOS, BSIM3SOI_PMOS (BSIM3 SOI Transistor, Floating Body, NMOS, PMOS)

Symbol





Parameters

Model parameters must be specified in SI units.

Name	**Description**	**Units**	**Default**
Model	model instance name	None	None
Length[†]	channel length	m	5.0e-6
Width[†]	channel width	m	5.0e-6
Ad[†]	area of drain diffusion	m^2	0.0
As[†]	area of source diffusion	m^2	0.0
Pd[†]	perimeter of drain junction	m	0.0
Ps[†]	perimeter of source junction	m	0.0
Nrd	number of squares of drain diffusion	None	1.0
Nrs	number of squares of source diffusion	None	1.0
Nrb	number of squares in body	None	1.0
Bjtoff	BJT on/off flag: yes=1, no=0	None	no
Rth0	instance thermal resistance; defaults to Rth0	Ohm	
Cth0	instance thermal capacitance; defaults to Cth0	F	
Nbc	number of body contact insulation edge	None	0.0
Nseg	number of segments for width partitioning	None	1.0
Pdbcp[†]	perimter length for bc parasitics at drain side	None	0.0
Psbcp[†]	perimter length for bc parasitics at source side	None	0.0
Agbcp[†]	gate to body overlap area for bc parasitics	m^2	0.0
Aebcp[†]	substrate to body overlap area for bc parasitics	m^2	
Vbsusr	Vbs specified by the user; defaults to Vbs	V	None
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note for the Mode parameter)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

[†] Each instance parameter whose dimension contains a power of meter will be multiplied

by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.

DC Operating Point Information

The following table lists the DC operating point parameters that can be sent to the dataset.

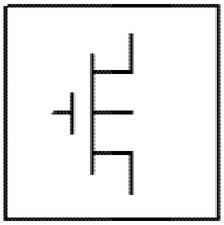
Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gmb	Backgate transconductance (dIds/dVbs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Vth	Threshold voltage	volts
Vdsat	Drain-source saturation voltage	volts
DqgDvgb	(dQg/dVgb)	farads
DqgDvdb	(dQg/dVdb)	farads
DqgDvsb	(dQg/dVsb)	farads
DqgDveb	(dQg/dVeb)	farads
DqbDvgb	(dQb/dVgb)	farads
DqbDvdb	(dQb/dVdb)	farads
DqbDvsb	(dQb/dVsb)	farads
DqbDveb	(dQb/dVeb)	farads
DqdDvgb	(dQd/dVgb)	farads
DqdDvdb	(dQd/dVdb)	farads
DqdDvsb	(dQd/dVsb)	farads
DqdDveb	(dQd/dVeb)	farads
DqeDvgb	(dQe/dVgb)	farads
DqeDvdb	(dQe/dVdb)	farads
DqeDvsb	(dQe/dVsb)	farads
DqeDveb	(dQe/dVeb)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts
Ves	Substrate-source voltage	volts
Vps	Body-source voltage	volts

Notes/Equations

1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.

BSIM4_Model (BSIM4 MOSFET Model)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Capmod	Capacitance model selector	None	2
Diomod	Diode IV model selector	None	1
Rdsmod	Bias-dependent S/D resistance model selector	None	0
Trnqsmod	Transient NQS model selector	None	0
Acnqsmod	AC NQS model selector	None	0
Mobmod	Mobility model selector	None	0
Rbodymod	Distributed body R model selector	None	0
Rgatemod	Gate R model selector	None	0
Permod	Pd and Ps model selector	None	1
Geomod	Geometry dependent parasitics model selector	None	0
Rgeomod	S/D resistance and contact model selector	None	0
Fnoimod	Flicker noise model selector	None	1
Tnoimod	Thermal noise model selector	None	0
Igcmod	Gate-to-channel Ig model selector	None	0
Igbmod	Gate-to-body Ig model selector	None	0
Tempmod	Temperature model selector	None	0
Paramchk	Model parameter checking selector	None	1
Nf	Number of fingers	None	1.0
Binunit	Bin unit selector	None	1
Version	Parameter for model version	None	4.65
Toxe	Electrical gate oxide thickness in meters	None	30.0e-10
Toxp	Physical gate oxide thickness in meters; defaults to Toxe	None	defaults to Toxe
Toxm	Gate oxide thickness at which parameters are extracted; defaults to Toxe	None	defaults to Toxe
Toxref	Target Tox value	None	30.0e-10
Dtox	Defined as (Toxe - Toxp)	None	0.0

Epsrox	Dielectric constant of the gate oxide relative to vacuum	None	3.9
Cdsc	Drain/Source and channel coupling capacitance	F/(V×m^2)	2.4e-4
Cdscb	Body-bias dependence of Cdsc	F/(V×m^2)	0.0
Cdscd	Drain-bias dependence of Cdsc	F/(V×m^2)	0.0
Cit	Interface state capacitance	F/(V×m^2)	0.0
Nfactor	Subthreshold swing coefficient	None	1.0
Xj	Junction depth in meters	m	1.5e-7
Vsat	Saturation velocity at Tnom	m/s	8.0e4
At	Temperature coefficient of Vsat	m/s	3.3e4
A0	Non-uniform depletion width effect coefficient	None	1.0
Ags	Gate bias coefficient of Abulk	V^{-1}	0.0
A1	First non-saturation effect coefficient	V^{-1}	0.0
A2	Second non-saturation effect coefficient	None	1.0
Keta	Body-bias coefficient of non-uniform depletion width effect	V^{-1}	-0.047
Nsub	Substrate doping concentration	cm^{-3}	6.0e16
Ndep	Channel doping concentration at the depletion edge	cm^{-3}	1.7e17
Nsd	S/D doping concentration	cm^{-3}	1.0e20
Phin	Adjusting parameter for surface potential due to non-uniform vertical doping	V	0.0
Ngate	Poly-gate doping concentration	cm^{-3}	0.0
Gamma1	Vth body coefficient	V$^{(1/2)}$	calculated
Gamma2	Vth body coefficient	V$^{(1/2)}$	calculated
Vbx	Vth transition body voltage	V	calculated
Vbm	Maximum body voltage	V	-3.0
Xt	Doping depth	m	1.55e-7
K1	Bulk effect coefficient 1	V$^{(1/2)}$	0.53
Kt1	Temperature coefficient of Vth	V	-0.11
Kt1l	Temperature coefficient of Vth	V×m	0.0
Kt2	Body coefficient of Kt1	None	0.022
K2	Bulk effect coefficient 2	None	-0.0186
K3	Narrow width effect coefficient	None	80.0
K3b	Body effect coefficient of K3	V^{-1}	0.0
W0	Narrow width effect parameter	m	2.5e-6
Dvtp0	First parameter for Vth shift due to pocket	m	0.0
Dvtp1	Second parameter for Vth shift due to pocket	V^{-1}	0.0
Lpe0	Equivalent length of pocket region at zero bias	m	1.74e-7
Lpeb	Equivalent length of pocket region accounting for body bias	m	0.0
Dvt0	Short channel effect coefficient 0	None	2.2
Dvt1	Short channel effect coefficient 1	None	0.53
Dvt2	Short channel effect coefficient 2	V^{-1}	-0.032

Dvt0w	Narrow Width coefficient 0	None	0.0
Dvt1w	Narrow Width effect coefficient 1	m^{-1}	5.3e6
Dvt2w	Narrow Width effect coefficient 2	V^{-1}	-0.032
Drout	DIBL coefficient of output resistance	None	0.56
Dsub	DIBL coefficient in the subthreshold region	None	fixed by Drout
Vth0	Threshold voltage	V	0.7 (NMOS)
Ua	Linear gate dependence of mobility	None	1.0e-15 (Mobmod=2),
Ua1	Temperature coefficient of Ua	m/V	1.0e-9
Ub	Quadratic gate dependence of mobility	(m/V^2)	1.0e-19
Ub1	Temperature coefficient of Ub	(m/V^2)	-1.0e-18
Uc	Body-bias dependence of mobility	V^{-1}	-0.0465 (Mobmod=1), -0.0465e-9 (Mobmod=0,2)
Uc1	Temperature coefficient of Uc	V^{-1}	-0.056 (Mobmod=1), -0.056e-9 (Mobmod=0,2)
U0	Low-field mobility at Tnom	$m^2/(V \times s)$	0.067 (NMOS),
Eu	Mobility exponent	None	1.67 (NMOS)
Ute	Temperature coefficient of mobility	None	-1.5
Voff	Threshold voltage offset	V	-0.08
Minv	Fitting parameter for moderate inversion in Vgsteff	None	0.0
Voffl	Length dependence parameter for Vth offset	V×m	0.0
Tnom	Parameter measurement temperature	°C	25
Trise	temperature rise above ambient	°C	0
Cgso	Gate-source overlap capacitance per width	F/m	calculated
Cgdo	Gate-drain overlap capacitance per width	F/m	calculated
Cgbo	Gate-bulk overlap capacitance per length	F/m	0.0
Xpart	Channel charge partitioning	None	0.0
Delta	Effective Vds parameter	V	0.01
Rsh	Source-drain sheet resistance	Ohm/sq	0.0
Rdsw	Source-drain resistance per width	Ohm×um	200.0
Rdswmin	Source-drain resistance per width at high Vg	Ohm×um	0.0
Rsw	Source resistance per width	Ohm×um	100.0
Rdw	Drain resistance per width	Ohm×um	100.0
Rdwmin	Drain resistance per width at high Vg	Ohm×um	0.0
Rswmin	Source resistance per width at high Vg	Ohm×um	0.0
Prwg	Gate-bias effect on parasitic resistance	V^{-1}	1.0
Prwb	Body-effect on parasitic resistance	$V^{(-1/2)}$	0.0
Prt	Temperature coefficient of parasitic resistance	Ohm×um	0.0
Eta0	Subthreshold region DIBL coefficient	None	0.08
Etab	Subthreshold region DIBL coefficient	V^{-1}	-0.07
Pclm	Channel length modulation coefficient	None	1.3
Pdiblc1	Drain-induced barrier lowering coefficient	None	0.39
Pdiblc2	Drain-induced barrier lowering coefficient	None	0.0086
Pdiblcb	Body-effect on drain-induced barrier lowering	V^{-1}	0.0
Fprout	Rout degradation coefficient for pocket devices	$V/m^{(1/2)}$	0.0
Pdits	Coefficient for drain-induced Vth shifts	V^{-1}	0.0

Pditsl	Length dependence of drain-induced Vth shifts	m^{-1}	0.0
Pditsd	Vds dependence of drain-induced Vth shifts	V^{-1}	0.0
Pscbe1	Substrate current body-effect coefficient	V/m	4.24e8
Pscbe2	Substrate current body-effect coefficient	m/V	1.0e-5
Pvag	Gate dependence of output resistance parameter	None	0.0
Jss	Bottom source junction reverse saturation current density	A/m^2	1.0e-4
Jsws	Isolation edge sidewall source junction reverse saturation current density	A/m	0.0
Jswgs	Gate edge source junction reverse saturation current density	A/m	0.0
Pbs	Source junction built-in potential	V	1.0
Njs	Source junction emission coefficient	None	1.0
Xtis	Source junction current temperature exponent	None	3.0
Mjs	Source bottom junction capacitance grading coefficient	None	0.5
Pbsws	Source sidewall junction capacitance built-in potential	V	1.0
Mjsws	Source sidewall junction capacitance grading coefficient	None	0.33
Pbswgs	Source gate side sidewall junction capacitance built-in potential; defaults to Pbsws	V	defaults to Pbsws
Mjswgs	Source gate side sidewall junction capacitance grading coefficient; defaults to Mjsws	None	defaults to Mjsws
Cjs	Source bottom junction capacitance per unit area	F/m^2	5.0e-4
Cjsws	Source sidewall junction capacitance per unit periphery	F/m	5.0e-10
Cjswgs	Source gate side sidewall junction capacitance per unit width; defaults to Cjsws	F/m	defaults to Cjsws
Jsd	Bottom drain junction reverse saturation current density; defaults to Jss	A/m^2	defaults to Jss
Jswd	Isolation edge sidewall drain junction reverse saturation current density; defaults to Jsws	A/m	defaults to Jsws
Jswgd	Gate edge drain junction reverse saturation current density; defaults to Jswgs	None	defaults to Jswgs
Pbd	Drain junction built-in potential; defaults to Pbs	V	None
Njd	Drain junction emission coefficient; defaults to Njs	None	defaults to Njs
Xtid	Drain junction current temperature exponent; defaults to Xtis	None	defaults to Xtis
Mjd	Drain bottom junction capacitance grading coefficient; defaults to Mjs	None	defaults to Mjs
Pbswd	Drain sidewall junction capacitance built-in potential; defaults to Pbsws	V	defaults to Pbsws
Mjswd	Drain sidewall junction capacitance grading coefficient; defaults to Mjsws	None	None
Pbswgd	Drain gate side sidewall junction capacitance built-in potential; defaults to Pbswgs	V	None
Mjswgd	Drain gate side sidewall junction capacitance grading coefficient; defaults to Mjswgs	None	None
Cjd	Drain bottom junction capacitance per unit area; defaults to Cjs	F/m^2	None
Cjswd	Drain sidewall junction capacitance per unit periphery; defaults to Cjsws	F/m	None

Cjswgd	Drain gate side sidewall junction capacitance per unit width; defaults to Cjswg	F/m	None
Vfbcv	Flat Band Voltage parameter for capmod	V	-1.0
Vfb	Flat Band Voltage	V	-1.0
Tpb	Temperature coefficient of pb	V/K	0.0
Tcj	Temperature coefficient of cj	K^{-1}	0.0
Tpbsw	Temperature coefficient of pbsw	V/K	0.0
Tcjsw	Temperature coefficient of cjsw	K^{-1}	0.0
Tpbswg	Temperature coefficient of pbswg	V/K	0.0
Tcjswg	Temperature coefficient of cjswg	K^{-1}	0.0
Acde	Exponential coefficient for finite charge thickness	m/V	1.0
Moin	Coefficient for gate-bias dependent surface potential	None	15.0
Noff	C-V turn-on/off parameter	None	1.0
Voffcv	C-V lateral-shift parameter	V	0.0
Dmcg	Distance of Mid-Contact to Gate edge	m	0.0
Dmci	Distance of Mid-Contact to Isolation; defaults to Dmcg	m	defaults to Dmcg
Dmdg	Distance of Mid-Diffusion to Gate edge	m	0.0
Dmcgt	Distance of Mid-Contact to Gate edge in Test structures	m	0.0
Xgw	Distance from gate contact center to device edge	m	0.0
Xgl	Variation in Ldrawn	m	0.0
Rshg	Gate sheet resistance	Ohm/sq	0.1
Ngcon	Number of gate contacts	None	1.0
Xrcrg1	First fitting parameter the bias-dependent Rg	None	12.0
Xrcrg2	Second fitting parameter the bias-dependent Rg	None	1.0
Xw	W offset for channel width due to mask/etch effect	m	None
Xl	L offset for channel width due to mask/etch effect	m	None
Lambda	Velocity overshoot parameter	m^3 /(V×s)	0.0
Vtl	Thermal velocity	m/s	2.0e5
Lc	Velocity back scattering parameter	m	5.0e-9
Xn	Velocity back scattering coefficient	None	3.0
Vfbsdoff	S/D flatband voltage offset	V	0.0
Lintnoi	Lint offset for noise calculation	m	0.0
Lint	Length reduction parameter	m	0.0
Ll	Length reduction parameter	m	0.0
Llc	Length reduction parameter for CV	m	0.0
Lln	Length reduction parameter	None	1.0
Lw	Length reduction parameter	m	0.0
Lwc	Length reduction parameter for CV; defaults to Lw	m	defaults to Lw
Lwn	Length reduction parameter	None	1.0
Lwl	Length reduction parameter	m	0.0
Lwlc	Length reduction parameter for CV; defaults to Lwl	m	defaults to Lwl
Lmin	Minimum length for the model	m	0.0
Lmax	Maximum length for the model	m	1.0
Wr	Width dependence of rds	None	1.0
Wint	Width reduction parameter	m	0.0

Dwg	Width reduction parameter	m/V	0.0
Dwb	Width reduction parameter	m/V$^{(1/2)}$	0.0
Wl	Width reduction parameter	m	0.0
Wlc	Width reduction parameter for CV; defaults to WI	m	defaults to WI
Wln	Width reduction parameter	None	1.0
Ww	Width reduction parameter	m	0.0
Wwc	Width reduction parameter for CV; defaults to Ww	m	defaults to Ww
Wwn	Width reduction parameter	None	1.0
Wwl	Width reduction parameter	m	0.0
Wwlc	Width reduction parameter for CV; defaults to Wwl	m	defaults to Wwl
Wmin	Minimum width for the model	m	0.0
Wmax	Maximum width for the model	m	1.0
B0	A bulk narrow width parameter	m	0.0
B1	A bulk narrow width parameter	m	0.0
Cgsl	New C-V model parameter	F/m	0.0
Cgdl	New C-V model parameter	F/m	0.0
Ckappas	S/G overlap C-V parameter	V	0.6
Ckappad	D/G overlap C-V parameter; defaults to Ckappas	V	defaults to Ckappas
Cf	Fringe capacitance parameter	F/m	calculated
Clc	Vdsat parameter for C-V model	m	1.0e-7
Cle	Vdsat parameter for C-V model	None	0.6
Dwc	Delta W for C-V model; defaults to Wint	m	defaults to Win
Dlc	Delta L for C-V model; defaults to Lint	m	defaults to Lint
Dlcig	Delta L for Ig model; defaults to Lint	m	defaults to Lint
Dwj	Delta W for S/D junctions; defaults to Dwc	None	defaults to Dwc
Alpha0	substrate current model parameter	A×m/V	0.0
Alpha1	substrate current model parameter	A/V	0.0
Beta0	substrate current model parameter	V	0.0 (for version ≥ 4.50), 30.0 (otherwise)
Agidl	Pre-exponential constant for GIDL	Ohm^{-1}	0.0
Bgidl	Exponential constant for GIDL	V/m	2.3e9
Cgidl	Parameter for body-bias dependence of GIDL	V^3	0.5
Egidl	Fitting parameter for bandbending	V	0.8
Aigc	Parameter for Igc	None	0.43 (NMOS)
Bigc	Parameter for Igc	None	0.054 (NMOS)
Cigc	Parameter for Igc	V^{-1}	0.075 (NMOS)
Aigsd	Parameter for Igs,d	None	0.043 (NMOS)
Bigsd	Parameter for Igs,d	None	0.054 (NMOS)
Cigsd	Parameter for Igs,d	V^{-1}	0.075 (NMOS)
Aigbacc	Parameter for Igb	None	1.36e-2 (for version ≥ 4.50), 0.43 (otherwise)
Bigbacc	Parameter for Igb	None	1.71e-3 (for version ≥ 4.50), 0.054 (otherwise)
Cigbacc	Parameter for Igb	V^{-1}	0.075
Aigbinv	Parameter for Igb	None	1.11e-2 (for version ≥ 4.50), 0.35 (otherwise)
Bigbinv	Parameter for Igb	None	9.49e-4 (for version ≥ 4.50),

			0.03 (otherwise)
Cigbinv	Parameter for Igb	V^{-1}	0.006
Nigc	Parameter for Igc slope	None	1.0
Nigbinv	Parameter for Igbinv slope	None	3.0
Nigbacc	Parameter for Igbacc slope	None	1.0
Ntox	Exponent for Tox ratio	None	1.0
Eigbinv	Parameter for the Si bandgap for Igbinv	V	1.1
Pigcd	Parameter for Igc partition	None	1.0
Poxedge	Factor for the gate edge Tox	None	1.0
Ijthdfwd	Forward drain diode forward limiting current; defaults to Ijthsfwd	A	defaults to Ijthsfwd
Ijthsfwd	Forward source diode forward limiting current	A	0.1
Ijthdrev	Reverse drain diode forward limiting current; defaults to Ijthsrev	A	defaults to Ijthsrev
Ijthsrev	Reverse source diode forward limiting current	A	0.1
Xjbvd	Fitting parameter for drain diode breakdown current; defaults to Xjbvs	None	defaults to Xjbvs
Xjbvs	Fitting parameter for source diode breakdown current	None	1.0
Bvd	Drain diode breakdown voltage; defaults to Bvs	V	defaults to Bvs
Bvs	Source diode breakdown voltage	V	10.0
Gbmin	Minimum body conductance	Ohm^{-1}	1.0e-12
Jtss	Source bottom trap-assisted saturation current density	None	0.0
Jtsd	Drain bottom trap-assisted saturation current density	None	0.0
Jtssws	Source STI sidewall trap-assisted saturation current density	None	0.0
Jtsswd	Drain STI sidewall trap-assisted saturation current density	None	0.0
Jtsswgs	Source gate-edge sidewall trap-assisted saturation current density	None	0.0
Jtsswgd	Drain gate-edge sidewall trap-assisted saturation current density	None	0.0
Njts	Non-ideality factor for bottom junction	None	20.0
Njtssw	Non-ideality factor for STI sidewall junction	None	20.0
Njtsswg	Non-ideality factor for gate-edge sidewall junction	None	20.0
Xtss	Power dependence of Jtss on temperature	None	0.02
Xtsd	Power dependence of Jtsd on temperature	None	0.02
Xtssws	Power dependence of Jtssws on temperature	None	0.02
Xtsswd	Power dependence of Jtsswd on temperature	None	0.02
Xtsswgs	Power dependence of Jtsswgs on temperature	None	0.02
Xtsswgd	Power dependence of Jtsswgd on temperature	None	0.02
Tnjts	Temperature coefficient for Njts	None	0.0
Tnjtssw	Temperature coefficient for Njtssw	None	0.0
Tnjtsswg	Temperature coefficient for Njtsswg	None	0.0
Vtss	Source bottom trap-assisted voltage dependent parameter	None	10.0
Vtsd	Drain bottom trap-assisted voltage dependent parameter	None	10.0
Vtssws	Source STI sidewall trap-assisted voltage dependent parameter	None	10.0

Vtsswd	Drain STI sidewall trap-assisted voltage dependent parameter	None	10.0
Vtsswgs	Source gate-edge sidewall trap-assisted voltage dependent parameter	None	10.0
Vtsswgd	Drain gate-edge sidewall trap-assisted voltage dependent parameter	None	10.0
Rbdb	Resistance between bNode and dbNode	Ohm	50.0
Rbpb	Resistance between bNodePrime and bNode	Ohm	50.0
Rbsb	Resistance between bNode and sbNode	Ohm	50.0
Rbps	Resistance between bNodePrime and sbNode	Ohm	50.0
Rbpd	Resistance between bNodePrime and bNode	Ohm	50.0
Lcdsc	Length dependence of cdsc	None	0.0
Lcdscb	Length dependence of cdscb	None	0.0
Lcdscd	Length dependence of cdscd	None	0.0
Lcit	Length dependence of cit	None	0.0
Lnfactor	Length dependence of nfactor	None	0.0
Lxj	Length dependence of xj	None	0.0
Lvsat	Length dependence of vsat	None	0.0
Lat	Length dependence of at	None	0.0
La0	Length dependence of a0	None	0.0
Lags	Length dependence of ags	None	0.0
La1	Length dependence of a1	None	0.0
La2	Length dependence of a2	None	0.0
Lketa	Length dependence of keta	None	0.0
Lnsub	Length dependence of nsub	None	0.0
Lndep	Length dependence of ndep	None	0.0
Lnsd	Length dependence of nsd	None	0.0
Lphin	Length dependence of phin	None	0.0
Lngate	Length dependence of ngate	None	0.0
Lgamma1	Length dependence of gamma1	None	0.0
Lgamma2	Length dependence of gamma2	None	0.0
Lvbx	Length dependence of vbx	None	0.0
Lvbm	Length dependence of vbm	None	0.0
Lxt	Length dependence of xt	None	0.0
Lk1	Length dependence of k1	None	0.0
Lkt1	Length dependence of kt1	None	0.0
Lkt1l	Length dependence of kt1l	None	0.0
Lkt2	Length dependence of kt2	None	0.0
Lk2	Length dependence of k2	None	0.0
Lk3	Length dependence of k3	None	0.0
Lk3b	Length dependence of k3b	None	0.0
Lw0	Length dependence of w0	None	0.0
Ldvtp0	Length dependence of dvtp0	None	0.0
Ldvtp1	Length dependence of dvtp1	None	0.0
Llpe0	Length dependence of lpe0	None	0.0
Llpeb	Length dependence of lpeb	None	0.0
Ldvt0	Length dependence of dvt0	None	0.0
Ldvt1	Length dependence of dvt1	None	0.0

Ldvt2	Length dependence of dvt2	None	0.0
Ldvt0w	Length dependence of dvt0w	None	0.0
Ldvt1w	Length dependence of dvt1w	None	0.0
Ldvt2w	Length dependence of dvt2w	None	0.0
Ldrout	Length dependence of drout	None	0.0
Ldsub	Length dependence of dsub	None	0.0
Lvth0	Length dependence of vto	None	0.0
Lua	Length dependence of ua	None	0.0
Lua1	Length dependence of ua1	None	0.0
Lub	Length dependence of ub	None	0.0
Lub1	Length dependence of ub1	None	0.0
Luc	Length dependence of uc	None	0.0
Luc1	Length dependence of uc1	None	0.0
Lu0	Length dependence of u0	None	0.0
Lute	Length dependence of ute	None	0.0
Lvoff	Length dependence of voff	None	0.0
Lminv	Length dependence of minv	None	0.0
Ldelta	Length dependence of delta	None	0.0
Lrdsw	Length dependence of rdsw	None	0.0
Lrsw	Length dependence of rsw	None	0.0
Lrdw	Length dependence of rdw	None	0.0
Lprwg	Length dependence of prwg	None	0.0
Lprwb	Length dependence of prwb	None	0.0
Lprt	Length dependence of prt	None	0.0
Leta0	Length dependence of eta0	None	0.0
Letab	Length dependence of etab	None	0.0
Lpclm	Length dependence of pclm	None	0.0
Lpdiblc1	Length dependence of pdiblc1	None	0.0
Lpdiblc2	Length dependence of pdiblc2	None	0.0
Lpdiblcb	Length dependence of pdiblcb	None	0.0
Lfprout	Length dependence of pdiblcb	None	0.0
Lpdits	Length dependence of pdits	None	0.0
Lpditsd	Length dependence of pditsd	None	0.0
Lpscbe1	Length dependence of pscbe1	None	0.0
Lpscbe2	Length dependence of pscbe2	None	0.0
Lpvag	Length dependence of pvag	None	0.0
Lwr	Length dependence of wr	None	0.0
Ldwg	Length dependence of dwg	None	0.0
Ldwb	Length dependence of dwb	None	0.0
Lb0	Length dependence of b0	None	0.0
Lb1	Length dependence of b1	None	0.0
Lcgsl	Length dependence of cgsl	None	0.0
Lcgdl	Length dependence of cgdl	None	0.0
Lckappas	Length dependence of ckappas	None	0.0
Lckappad	Length dependence of ckappad	None	0.0
Lcf	Length dependence of cf	None	0.0
Lclc	Length dependence of clc	None	0.0

Lcle	Length dependence of cle	None	0.0
Lalpha0	Length dependence of alpha0	None	0.0
Lalpha1	Length dependence of alpha1	None	0.0
Lbeta0	Length dependence of beta0	None	0.0
Lagidl	Length dependence of agidl	None	0.0
Lbgidl	Length dependence of bgidl	None	0.0
Lcgidl	Length dependence of cgidl	None	0.0
Legidl	Length dependence of egidl	None	0.0
Laigc	Length dependence of aigc	None	0.0
Lbigc	Length dependence of bigc	None	0.0
Lcigc	Length dependence of cigc	None	0.0
Laigsd	Length dependence of aigsd	None	0.0
Lbigsd	Length dependence of bigsd	None	0.0
Lcigsd	Length dependence of cigsd	None	0.0
Laigbacc	Length dependence of aigbacc	None	0.0
Lbigbacc	Length dependence of bigbacc	None	0.0
Lcigbacc	Length dependence of cigbacc	None	0.0
Laigbinv	Length dependence of aigbinv	None	0.0
Lbigbinv	Length dependence of bigbinv	None	0.0
Lcigbinv	Length dependence of cigbinv	None	0.0
Lnigc	Length dependence of nigc	None	0.0
Lnigbinv	Length dependence of nigbinv	None	0.0
Lnigbacc	Length dependence of nigbacc	None	0.0
Lntox	Length dependence of ntox	None	0.0
Leigbinv	Length dependence for eigbinv	None	0.0
Lpigcd	Length dependence for pigcd	None	0.0
Lpoxedge	Length dependence for poxedge	None	0.0
Lvfbcv	Length dependence of vfbcv	None	0.0
Lvfb	Length dependence of vfb	None	0.0
Lacde	Length dependence of acde	None	0.0
Lmoin	Length dependence of moin	None	0.0
Lnoff	Length dependence of noff	None	0.0
Lvoffcv	Length dependence of voffcv	None	0.0
Lxrcrg1	Length dependence of xrcrg1	None	0.0
Lxrcrg2	Length dependence of xrcrg2	None	0.0
Llambda	Length dependence of Lambda	None	0.0
Lvtl	Length dependence of Vtl	None	0.0
Lxn	Length dependence of Xn	None	0.0
Leu	Length dependence of eu	None	0.0
Lvfbsdoff	Length dependence of Vfbsdoff	None	0.0
Wcdsc	Width dependence of cdsc	None	0.0
Wcdscb	Width dependence of cdscb	None	0.0
Wcdscd	Width dependence of cdscd	None	0.0
Wcit	Width dependence of cit	None	0.0
Wnfactor	Width dependence of nfactor	None	0.0
Wxj	Width dependence of xj	None	0.0
Wvsat	Width dependence of vsat	None	0.0

Wat	Width dependence of at	None	0.0
Wa0	Width dependence of a0	None	0.0
Wags	Width dependence of ags	None	0.0
Wa1	Width dependence of a1	None	0.0
Wa2	Width dependence of a2	None	0.0
Wketa	Width dependence of keta	None	0.0
Wnsub	Width dependence of nsub	None	0.0
Wndep	Width dependence of ndep	None	0.0
Wnsd	Width dependence of nsd	None	0.0
Wphin	Width dependence of phin	None	0.0
Wngate	Width dependence of ngate	None	0.0
Wgamma1	Width dependence of gamma1	None	0.0
Wgamma2	Width dependence of gamma2	None	0.0
Wvbx	Width dependence of vbx	None	0.0
Wvbm	Width dependence of vbm	None	0.0
Wxt	Width dependence of xt	None	0.0
Wk1	Width dependence of k1	None	0.0
Wkt1	Width dependence of kt1	None	0.0
Wkt1l	Width dependence of kt1l	None	0.0
Wkt2	Width dependence of kt2	None	0.0
Wk2	Width dependence of k2	None	0.0
Wk3	Width dependence of k3	None	0.0
Wk3b	Width dependence of k3b	None	0.0
Ww0	Width dependence of w0	None	0.0
Wdvtp0	Width dependence of dvtp0	None	0.0
Wdvtp1	Width dependence of dvtp1	None	0.0
Wlpe0	Width dependence of lpe0	None	0.0
Wlpeb	Width dependence of lpeb	None	0.0
Wdvt0	Width dependence of dvt0	None	0.0
Wdvt1	Width dependence of dvt1	None	0.0
Wdvt2	Width dependence of dvt2	None	0.0
Wdvt0w	Width dependence of dvt0w	None	0.0
Wdvt1w	Width dependence of dvt1w	None	0.0
Wdvt2w	Width dependence of dvt2w	None	0.0
Wdrout	Width dependence of drout	None	0.0
Wdsub	Width dependence of dsub	None	0.0
Wvth0	Width dependence of vto	None	0.0
Wua	Width dependence of ua	None	0.0
Wua1	Width dependence of ua1	None	0.0
Wub	Width dependence of ub	None	0.0
Wub1	Width dependence of ub1	None	0.0
Wuc	Width dependence of uc	None	0.0
Wuc1	Width dependence of uc1	None	0.0
Wu0	Width dependence of u0	None	0.0
Wute	Width dependence of ute	None	0.0
Wvoff	Width dependence of voff	None	0.0
Wminv	Width dependence of minv	None	0.0

Wdelta	Width dependence of delta	None	0.0
Wrdsw	Width dependence of rdsw	None	0.0
Wrsw	Width dependence of rsw	None	0.0
Wrdw	Width dependence of rdw	None	0.0
Wprwg	Width dependence of prwg	None	0.0
Wprwb	Width dependence of prwb	None	0.0
Wprt	Width dependence of prt	None	0.0
Weta0	Width dependence of eta0	None	0.0
Wetab	Width dependence of etab	None	0.0
Wpclm	Width dependence of pclm	None	0.0
Wpdiblc1	Width dependence of pdiblc1	None	0.0
Wpdiblc2	Width dependence of pdiblc2	None	0.0
Wpdiblcb	Width dependence of pdiblcb	None	0.0
Wfprout	Width dependence of pdiblcb	None	0.0
Wpdits	Width dependence of pdits	None	0.0
Wpditsd	Width dependence of pditsd	None	0.0
Wpscbe1	Width dependence of pscbe1	None	0.0
Wpscbe2	Width dependence of pscbe2	None	0.0
Wpvag	Width dependence of pvag	None	0.0
Wwr	Width dependence of wr	None	0.0
Wdwg	Width dependence of dwg	None	0.0
Wdwb	Width dependence of dwb	None	0.0
Wb0	Width dependence of b0	None	0.0
Wb1	Width dependence of b1	None	0.0
Wcgsl	Width dependence of cgsl	None	0.0
Wcgdl	Width dependence of cgdl	None	0.0
Wckappas	Width dependence of ckappas	None	0.0
Wckappad	Width dependence of ckappad	None	0.0
Wcf	Width dependence of cf	None	0.0
Wclc	Width dependence of clc	None	0.0
Wcle	Width dependence of cle	None	0.0
Walpha0	Width dependence of alpha0	None	0.0
Walpha1	Width dependence of alpha1	None	0.0
Wbeta0	Width dependence of beta0	None	0.0
Wagidl	Width dependence of agidl	None	0.0
Wbgidl	Width dependence of bgidl	None	0.0
Wcgidl	Width dependence of cgidl	None	0.0
Wegidl	Width dependence of egidl	None	0.0
Waigc	Width dependence of aigc	None	0.0
Wbigc	Width dependence of bigc	None	0.0
Wcigc	Width dependence of cigc	None	0.0
Waigsd	Width dependence of aigsd	None	0.0
Wbigsd	Width dependence of bigsd	None	0.0
Wcigsd	Width dependence of cigsd	None	0.0
Waigbacc	Width dependence of aigbacc	None	0.0
Wbigbacc	Width dependence of bigbacc	None	0.0
Wcigbacc	Width dependence of cigbacc	None	0.0

Waigbinv	Width dependence of aigbinv	None	0.0
Wbigbinv	Width dependence of bigbinv	None	0.0
Wcigbinv	Width dependence of cigbinv	None	0.0
Wnigc	Width dependence of nigc	None	0.0
Wnigbinv	Width dependence of nigbinv	None	0.0
Wnigbacc	Width dependence of nigbacc	None	0.0
Wntox	Width dependence of ntox	None	0.0
Weigbinv	Width dependence for eigbinv	None	0.0
Wpigcd	Width dependence for pigcd	None	0.0
Wpoxedge	Width dependence for poxedge	None	0.0
Wvfbcv	Width dependence of vfbcv	None	0.0
Wvfb	Width dependence of vfb	None	0.0
Wacde	Width dependence of acde	None	0.0
Wmoin	Width dependence of moin	None	0.0
Wnoff	Width dependence of noff	None	0.0
Wvoffcv	Width dependence of voffcv	None	0.0
Wxrcrg1	Width dependence of xrcrg1	None	0.0
Wxrcrg2	Width dependence of xrcrg2	None	0.0
Wlambda	Width dependence of Lambda	None	0.0
Wvtl	Width dependence of Vtl	None	0.0
Wxn	Width dependence of Xn	None	0.0
Weu	Width dependence of eu	None	0.0
Wvfbsdoff	Width dependence of Vfbsdoff	None	0.0
Pcdsc	Cross-term dependence of cdsc	None	0.0
Pcdscb	Cross-term dependence of cdscb	None	0.0
Pcdscd	Cross-term dependence of cdscd	None	0.0
Pcit	Cross-term dependence of cit	None	0.0
Pnfactor	Cross-term dependence of nfactor	None	0.0
Pxj	Cross-term dependence of xj	None	0.0
Pvsat	Cross-term dependence of vsat	None	0.0
Pat	Cross-term dependence of at	None	0.0
Pa0	Cross-term dependence of a0	None	0.0
Pags	Cross-term dependence of ags	None	0.0
Pa1	Cross-term dependence of a1	None	0.0
Pa2	Cross-term dependence of a2	None	0.0
Pketa	Cross-term dependence of keta	None	0.0
Pnsub	Cross-term dependence of nsub	None	0.0
Pndep	Cross-term dependence of ndep	None	0.0
Pnsd	Cross-term dependence of nsd	None	0.0
Pphin	Cross-term dependence of phin	None	0.0
Pngate	Cross-term dependence of ngate	None	0.0
Pgamma1	Cross-term dependence of gamma1	None	0.0
Pgamma2	Cross-term dependence of gamma2	None	0.0
Pvbx	Cross-term dependence of vbx	None	0.0
Pvbm	Cross-term dependence of vbm	None	0.0
Pxt	Cross-term dependence of xt	None	0.0
Pk1	Cross-term dependence of k1	None	0.0

Pkt1	Cross-term dependence of kt1	None	0.0
Pkt1l	Cross-term dependence of kt1l	None	0.0
Pkt2	Cross-term dependence of kt2	None	0.0
Pk2	Cross-term dependence of k2	None	0.0
Pk3	Cross-term dependence of k3	None	0.0
Pk3b	Cross-term dependence of k3b	None	0.0
Pw0	Cross-term dependence of w0	None	0.0
Pdvtp0	Cross-term dependence of dvtp0	None	0.0
Pdvtp1	Cross-term dependence of dvtp1	None	0.0
Plpe0	Cross-term dependence of lpe0	None	0.0
Plpeb	Cross-term dependence of lpeb	None	0.0
Pdvt0	Cross-term dependence of dvt0	None	0.0
Pdvt1	Cross-term dependence of dvt1	None	0.0
Pdvt2	Cross-term dependence of dvt2	None	0.0
Pdvt0w	Cross-term dependence of dvt0w	None	0.0
Pdvt1w	Cross-term dependence of dvt1w	None	0.0
Pdvt2w	Cross-term dependence of dvt2w	None	0.0
Pdrout	Cross-term dependence of drout	None	0.0
Pdsub	Cross-term dependence of dsub	None	0.0
Pvth0	Cross-term dependence of vto	None	0.0
Pua	Cross-term dependence of ua	None	0.0
Pua1	Cross-term dependence of ua1	None	0.0
Pub	Cross-term dependence of ub	None	0.0
Pub1	Cross-term dependence of ub1	None	0.0
Puc	Cross-term dependence of uc	None	0.0
Puc1	Cross-term dependence of uc1	None	0.0
Pu0	Cross-term dependence of u0	None	0.0
Pute	Cross-term dependence of ute	None	0.0
Pvoff	Cross-term dependence of voff	None	0.0
Pminv	Cross-term dependence of minv	None	0.0
Pdelta	Cross-term dependence of delta	None	0.0
Prdsw	Cross-term dependence of rdsw	None	0.0
Prsw	Cross-term dependence of rsw	None	0.0
Prdw	Cross-term dependence of rdw	None	0.0
Pprwg	Cross-term dependence of prwg	None	0.0
Pprwb	Cross-term dependence of prwb	None	0.0
Pprt	Cross-term dependence of prt	None	0.0
Peta0	Cross-term dependence of eta0	None	0.0
Petab	Cross-term dependence of etab	None	0.0
Ppclm	Cross-term dependence of pclm	None	0.0
Ppdiblc1	Cross-term dependence of pdiblc1	None	0.0
Ppdiblc2	Cross-term dependence of pdiblc2	None	0.0
Ppdiblcb	Cross-term dependence of pdiblcb	None	0.0
Pfprout	Cross-term dependence of pdiblcb	None	0.0
Ppdits	Cross-term dependence of pdits	None	0.0
Ppditsd	Cross-term dependence of pditsd	None	0.0
Ppscbe1	Cross-term dependence of pscbe1	None	0.0

Ppscbe2	Cross-term dependence of pscbe2	None	0.0
Ppvag	Cross-term dependence of pvag	None	0.0
Pwr	Cross-term dependence of wr	None	0.0
Pdwg	Cross-term dependence of dwg	None	0.0
Pdwb	Cross-term dependence of dwb	None	0.0
Pb0	Cross-term dependence of b0	None	0.0
Pb1	Cross-term dependence of b1	None	0.0
Pcgsl	Cross-term dependence of cgsl	None	0.0
Pcgdl	Cross-term dependence of cgdl	None	0.0
Pckappas	Cross-term dependence of ckappas	None	0.0
Pckappad	Cross-term dependence of ckappad	None	0.0
Pcf	Cross-term dependence of cf	None	0.0
Pclc	Cross-term dependence of clc	None	0.0
Pcle	Cross-term dependence of cle	None	0.0
Palpha0	Cross-term dependence of alpha0	None	0.0
Palpha1	Cross-term dependence of alpha1	None	0.0
Pbeta0	Cross-term dependence of beta0	None	0.0
Pagidl	Cross-term dependence of agidl	None	0.0
Pbgidl	Cross-term dependence of bgidl	None	0.0
Pcgidl	Cross-term dependence of cgidl	None	0.0
Pegidl	Cross-term dependence of egidl	None	0.0
Paigc	Cross-term dependence of aigc	None	0.0
Pbigc	Cross-term dependence of bigc	None	0.0
Pcigc	Cross-term dependence of cigc	None	0.0
Paigsd	Cross-term dependence of aigsd	None	0.0
Pbigsd	Cross-term dependence of bigsd	None	0.0
Pcigsd	Cross-term dependence of cigsd	None	0.0
Paigbacc	Cross-term dependence of aigbacc	None	0.0
Pbigbacc	Cross-term dependence of bigbacc	None	0.0
Pcigbacc	Cross-term dependence of cigbacc	None	0.0
Paigbinv	Cross-term dependence of aigbinv	None	0.0
Pbigbinv	Cross-term dependence of bigbinv	None	0.0
Pcigbinv	Cross-term dependence of cigbinv	None	0.0
Pnigc	Cross-term dependence of nigc	None	0.0
Pnigbinv	Cross-term dependence of nigbinv	None	0.0
Pnigbacc	Cross-term dependence of nigbacc	None	0.0
Pntox	Cross-term dependence of ntox	None	0.0
Peigbinv	Cross-term dependence for eigbinv	None	0.0
Ppigcd	Cross-term dependence for pigcd	None	0.0
Ppoxedge	Cross-term dependence for poxedge	None	0.0
Pvfbcv	Cross-term dependence of vfbcv	None	0.0
Pvfb	Cross-term dependence of vfb	None	0.0
Pacde	Cross-term dependence of acde	None	0.0
Pmoin	Cross-term dependence of moin	None	0.0
Pnoff	Cross-term dependence of noff	None	0.0
Pvoffcv	Cross-term dependence of voffcv	None	0.0
Pxrcrg1	Cross-term dependence of xrcrg1	None	0.0

Pxrcrg2	Cross-term dependence of xrcrg2	None	0.0
Plambda	Cross-term dependence of Lambda	None	0.0
Pvtl	Cross-term dependence of Vtl	None	0.0
Pxn	Cross-term dependence of Xn	None	0.0
Peu	Cross-term dependence of eu	None	0.0
Pvfbsdoff	Cross-term dependence of Vfbsdoff	None	0.0
Saref	Reference distance between OD edge to poly of one side	m	1.0e-6
Sbref	Reference distance between OD edge to poly of the other side	m	1.0e-6
Wlod	Width parameter for stress effect	m	0.0
Ku0	Mobility degradation/enhancement coefficient for LOD	m	0.0
Kvsat	Saturation velocity degradation/enhancement parameter for LOD	m	0.0
Kvth0	Threshold shift parameter for LOD	V×m	0.0
Tku0	Temperature coefficient of Ku0	None	0.0
Llodku0	Length parameter for U0 LOD effect	None	0.0
Wlodku0	Width parameter for U0 LOD effect	None	0.0
Llodvth	Length parameter for Vth LOD effect	None	0.0
Wlodvth	Width parameter for Vth LOD effect	None	0.0
Lku0	Length dependence of Ku0	None	0.0
Wku0	Width dependence of Ku0	None	0.0
Pku0	Cross-term dependence of Ku0	None	0.0
Lkvth0	Length dependence of Kvth0	None	0.0
Wkvth0	Width dependence of Kvth0	None	0.0
Pkvth0	Cross-term dependence of Kvth0	None	0.0
Stk2	K2 shift factor related to stress effect on Vth	m	0.0
Lodk2	K2 shift modification factor for stress effect	None	1.0
Steta0	Eta0 shift factor related to stress effect on Vth	m	0.0
Lodeta0	Eta0 shift modification factor for stress effect	None	1.0
Noia	Flicker noise parameter	None	6.25e41 (NMOS),
Noib	Flicker noise parameter	None	3.125e26 (NMOS),
Noic	Flicker noise parameter	None	8.75e9
Tnoia	Thermal noise parameter	None	1.5
Tnoib	Thermal noise parameter	None	3.5
Rnoia	Thermal noise coefficient	None	0.577
Rnoib	Thermal noise coefficient	None	0.5164
Ntnoi	Thermal noise parameter	None	1.0
Em	Flicker noise parameter	V/m	4.1e7
Ef	Flicker noise frequency exponent	None	1.0
Af	Flicker noise exponent	None	1.0
Kf	Flicker noise coefficient	None	0.0
Tlev	Temperature equation selector (0/1/2/3)		0
Tlevc	Temperature equation selector for capacitance (0/1/2/3)		1
Eg	Band Gap	eV	1.16
Gap1	Energy gap temperature coefficient alpha	V/°C	7.04e-4
Gap2	Energy gap temperature coefficient beta	K	1108

L	Channel length	m	None
W	Channel width	m	None
Ad	Drain area	m^2	None
As	Source area	m^2	None
Pd	Drain perimeter	m	None
Ps	Source perimeter	m	None
Nrd	Drain squares	None	None
Nrs	Source squares	None	None
Imelt	Explosion current similar to Imax; defaults to Imax (refer to note 13)	A	defaults to Imax
wBvsub	substrate junction reverse breakdown voltage warning	V	None
wBvds	gate oxide breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None
Ud	Mobility Coulumb scattering coefficient	m^{-2}	0.0 for version ≥4.61, 1e14 otherwise
Ud1	Temperature coefficient for Ud	m^{-2}	0.0
Up	Mobility channel length coefficient	m^{-2}	0
Lp	Mobility channel length exponential coefficient	m	1e-8
Tvoff	Temperature coefficient of Voff	K^{-1}	0.0
Tvfbsdoff	Temperature coefficient of Vfbsdoff	K^{-1}	0.0
Lud	Length dependence of Ud	None	0.0
Lud1	Length dependence of Ud1	None	0.0
Lup	Length dependence of Up	None	0.0
L1p	Length dependence of Lp	None	0.0
Ltvoff	Length dependence of Tvoff	None	0.0
Ltvfbsdoff	Length dependence of Tvfbsdoff	None	0.0
Wud	Width dependence of Ud	None	0.0
Wud1	Width dependence of Ud1	None	0.0
Wup	Width dependence of Up	None	0.0
Wip	Width dependence of Lp	None	0.0
Wtvoff	Width dependence of Tvoff	None	0.0
Wtvfbsdoff	Width dependence of Tvfbsdoff	None	0.0
Pud	Cross-term dependence of Ud	None	0.0
Pud1	Cross-term dependence of Ud1	None	0.0
Pup	Cross-term dependence of Up	None	0.0
P1p	Cross-term dependence of Lp	None	0.0
Ptvoff	Cross-term dependence of Tvoff	None	0.0
Ptvfbsdoff	Cross-term dependence of Tvfbsdoff	None	0.0
Rbps0	Scaling prefactor for Rbps	Ohm	50
Rbps1	Length Scaling parameter for Rbps	None	0.0
Rbpsw	Width Scaling parameter for Rbps	None	0.0
Rbpsnf	Number of fingers Scaling parameter for Rbps	None	0.0
Rbpd0	Scaling prefactor for Rbpd	Ohm	50

Rbpd1	Length Scaling parameter for Rbpd	None	0.0
Rbpdw	Width Scaling parameter for Rbpd	None	0.0
Rbpdnf	Number of fingers Scaling parameter for Rbpd	None	0.0
Rbpbx0	Scaling prefactor for Rbpbx	Ohm	100
Rbpbx1	Length Scaling parameter for Rbpbx	None	0.0
Rbpbxw	Width Scaling parameter for Rbpbx	None	0.0
Rbpbxnf	Number of fingers Scaling parameter for Rbpbx	None	0.0
Rbpby0	Scaling prefactor for Rbpby	Ohm	100
Rbpby1	Length Scaling parameter for Rbpby	None	0.0
Rbpbyw	Width Scaling parameter for Rbpby	None	0.0
Rbpbynf	Number of fingers Scaling parameter for Rbpby	None	0.0
Rbsbx0	Scaling prefactor for Rbsbx	Ohm	100
Rbsby0	Scaling prefactor for Rbsby	Ohm	100
Rbdbx0	Scaling prefactor for Rbdbx	Ohm	100
Rbdby0	Scaling prefactor for Rbdby	Ohm	100
Rbsdbx1	Length Scaling parameter for Rbsbx and Rbdbx	None	0.0
Rbsdbxw	Width Scaling parameter for Rbsbx and Rbdbx	None	0.0
Rbsdbxnf	Number of fingers Scaling parameter for Rbsbx and Rbdbx	None	0.0
Rbsdby1	Length Scaling parameter for Rbsby and Rbdby	None	0.0
Rbsdbyw	Width Scaling parameter for Rbsby and Rbdby	None	0.0
Rbsdbynf	Number of fingers Scaling parameter for Rbsby and Rbdby	None	0.0
Wpemod	Flag for well proximity effect model (Wpemod=1 to activate this model)	None	0
Web	Coefficient for Scb	None	0.0
Wec	Coefficient for Scc	None	0.0
Ktvh0we	Threshold shift factor for well proximity effect	None	0.0
K2we	K2 shift factor for well proximity effect	None	0.0
Ku0we	Mobility degradation factor for well proximity effect	None	0.0
Scref	Reference distance to calculate Sca, Scb and Scc	m	1e-6
Lkvth0we	Length dependence of Kvth0we	None	0.0
Lk2we	Length dependence of K2we	None	0.0
Lku0we	Length dependence of Ku0we	None	0.0
Wkvth0we	Width dependence of Kvth0we	None	0.0
Wk2we	Width dependence of K2we	None	0.0
Wku0we	Width dependence of Ku0we	None	0.0
Pkvth0we	Cross-term dependence of Kvth0we	None	0.0
Pk2we	Cross-term dependence of K2we	None	0.0
Pku0we	Cross-term dependence of Ku0we	None	0.0
Cvchargemod	Threshold voltage for C-V model selector	None	0
Mtrlmod	New material model selector	None	0
Eot	Equivalent gate oxide thickness	m	1.5e-9
Vddeot	Gate voltage at which EOT is measured	V	1.5 (NMOS), -1.5 (PMOS)
Ados	Density of states parameter to control charge centroid	None	1
Bdos	Density of states parameter to control charge centroid	None	1

Phig	Work function of gate	None	4.05
Epsrgate	Dielectric constant of gate relative to vacuum	None	11.7
Easub	Electron affinity of substrate	eV	4.05
Epsrsub	Dielectric constant of substrate relative to vacuum	None	11.7
Ni0sub	Intrinsic carrier concentration of substrate at 300.15K	cm^{-3}	1.45e10
Bg0sub	Band-gap of substrate at T=0K	eV	1.16
Tbgasub	First parameter of band-gap change due to temperature	eV/K	7.02e-4
Tbgbsub	Second parameter of band-gap change due to temperature	K	1108.0
Minvcv	Fitting parameter for moderate inversion in Vgsteffcv	None	0
Voffcvl	Length dependence parameter for Vth offset in CV	None	0
Dlcigd	Delta L for Ig model drain side	m	default to Dlcig
Agisl	Pre-exponential constant for GISL	Ohm^{-1}	default to Agidl
Bgisl	Exponential constant for GISL	V/m	default to Bgidl
Cgisl	Parameter for body-bias dependence of GISL	V^3	default to Cgidl
Egisl	Fitting parameter for Bandbending	V	default to Egidl
Aigs	Parameter for Igs	None	1.36e-2 (NMOS), 9.8e-3 (PMOS)
Bigs	Parameter for Igs	None	1.71e-3 (NMOS), 7.59e-4 (PMOS)
Cigs	Parameter for Igs	None	0.075 (NMOS), 0.03 (PMOS)
Aigd	Parameter for Igd	None	1.36e-2 (NMOS), 9.8e-3 (PMOS)
Bigd	Parameter for Igd	None	1.71e-3 (NMOS), 7.59e-4 (PMOS)
Cigd	Parameter for Igd	None	0.075 (NMOS), 0.03 (PMOS)
Njtsd	Non-ideality factor for bottom junction drain side	None	default to Njts
Njtsswd	Non-ideality factor for STI sidewall junction drain side	None	default to Njtssw
Njtsswgd	Non-ideality factor for gate-edge sidewall junction drain side	None	default to Njtsswg
Tnjtsd	Temperature coefficient for Njtsd	None	default to Tnjts
Tnjtsswd	Temperature coefficient for Njtsswd	None	default to Tnjtssw
Tnjtsswgd	Temperature coefficient for Njtsswgd	None	default to Tnjtsswg
Lminvcv	Length dependence of Minvcv	None	0
Lagisl	Length dependence of Agisl	None	0
Lbgisl	Length dependence of Bgisl	None	0
Lcgisl	Length dependence of Cgisl	None	0
Legisl	Length dependence of Egisl	None	0
Laigs	Length dependence of Aigs	None	0
Lbigs	Length dependence of Bigs	None	0
Lcigs	Length dependence of Cigs	None	0
Laigd	Length dependence of Aigd	None	0
Lbigd	Length dependence of Bigd	None	0
Lcigd	Length dependence of Cigd	None	0
Wminvcv	Width dependence of Minvcv	None	0
Wagisl	Width dependence of Agisl	None	0
Wbgisl	Width dependence of Bgisl	None	0
Wcgisl	Width dependence of Cgisl	None	0

Wegisl	Width dependence of Egisl	None	0
Waigs	Width dependence of Aigs	None	0
Wbigs	Width dependence of Bigs	None	0
Wcigs	Width dependence of Cigs	None	0
Waigd	Width dependence of Aigd	None	0
Wbigd	Width dependence of Bigd	None	0
Wcigd	Width dependence of Cigd	None	0
Pminvcv	Cross-term dependence of Minvcv	None	0
Pagisl	Cross-term dependence of Agisl	None	0
Pbgisl	Cross-term dependence of Bgisl	None	0
Pcgisl	Cross-term dependence of Cgisl	None	0
Pegisl	Cross-term dependence of Egisl	None	0
Paigs	Cross-term dependence of Aigs	None	0
Pbigs	Cross-term dependence of Bigs	None	0
Pcigs	Cross-term dependence of Cigs	None	0
Paigd	Cross-term dependence of Aigd	None	0
Pbigd	Cross-term dependence of Bigd	None	0
Pcigd	Cross-term dependence of Cigd	None	0
Tempeot	Temperature for extraction of EOT	Kelvin	300.15
Leffeot	Effective length for extraction of EOT	um	1.0
Weffeot	Effective width for extraction of EOT	um	10.0
Ucs	Colombic scattering exponent	None	1.67 (NMOS), 1.0 (PMOS)
Ucste	Temperature coefficient of colombic mobility	None	-4.775e-3
Jtweff	TAT current width dependance	None	0.0
Lucste	Length dependence of ucste	None	0.0
Lucs	Length dependence of ucs	None	0.0
Wucste	Width dependence of ucste	None	0.0
Wucs	Width dependence of ucs	None	0.0
Pucste	Cross-term dependence of ucste	None	0.0
Pucs	Cross-term dependence of ucs	None	0.0

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model  modelname  BSIM4 \[parm=value\]\*
```

The model statement starts with the required keyword *model* . It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *BSIM4* . Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the

parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).
Example:

```
model Nch7 BSIM4 \
Vtho=0.7 Cjs=3e-4 NMOS=yes
```

Notes/Equations

1. BSIM4 was developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.
2. More information about this model is available at:

   "http://www-device.eecs.berkeley.edu/%7ebsim3"
3. Several DC, AC, and capacitance parameters can be binned as described in the parameters table; these parameters follow this implementation:

   $$P = P_0 + \frac{P_L}{L_{eff}} + \frac{P_w}{W_{eff}} + \frac{P_p}{L_{eff} \times W_{eff}}$$

   For example, for the parameter K1, the following relationships exist: P_0=k1, P_L=lk1, P_W=wk1, P_P=pk1. The Binunit parameter is a binning unit selector. If Binunit=1, the units of L_{eff} and W_{eff} used in the preceding binning equation have units of microns, otherwise meters. For example, for a device with L_{eff}=0.5mm and W_{eff}=10mm, if Binunit=1, parameter values are le5, le4, 2e4, and 3e4 for Vsat, Lvsat, Wvsat, and Pvsat, respectively, Therefore, the effective value of Vsat for this device is:

   Vsat = 1e5 + 1e4/0.5 + 2e4/10 + 3e4/(0.5 × 10) = 1.28e5

   To get the same effective value of Vsat for Binunit=0, values of Vsat, Lvsat, Wvsat, and Pvsat would be 1e5, le2, 2e2, 3e8, respectively. Thus:

   Vsat = 1e5 + 1e-2/0.5e6 + 2e2/10e6 + 3e 8/(0.5e-6 × 10e6) = 1.28e5
4. DC operating point data is generated for this model. If a DC simulation is performed, device operating point data can be viewed for a component. The procedure for viewing device operating point data for a component is in *Using Circuit Simulators* (cktsim). The device operating point information that is displayed for the BSIM4 model is:

   Gm: small-signal Vgs to Ids transconductance, in Siemens
   Gmb: small-signal Vbs to Ids transconductance, in Siemens
   Gds: small-signal drain source conductance, in Siemens
   Vth: threshold voltage, in volts
   Vdsat: saturation voltage, in volts
   DqgDvgb: small-signal transcapacitance dQg/dVg, in farads
   DqgDvdb: small-signal transcapacitance dQg/dVd, in farads
   DqgDvsb: small-signal transcapacitance dQg/dVs, in farads
   DqbDvgb: small-signal transcapacitance dQb/dVg, in farads

DqbDvdb: small-signal transcapacitance dQb/dVd, in farads
DqbDvsb: small-signal transcapacitance dQb/dVs, in farads
DqdDvgb: small-signal transcapacitance dQd/dVg, in farads
DqdDvdb: small-signal transcapacitance dQd/dVd, in farads
DqdDvsb: small-signal transcapacitance dQd/dVs, in farads

5. If 1 is not given, it is calculated by

$$\gamma_1 = \frac{\sqrt{2q\varepsilon_{si}NDEP}}{C_{oxe}}$$

If 2 is not given, it is calculated by

$$\gamma_2 = \frac{\sqrt{2q\varepsilon_{si}NSUB}}{C_{oxe}}$$

6. If *NDEP* is not given and 1 is given, *NDEP* is calculated from

$$NDEP = \frac{\gamma_1^2 C_{oxe}{}^2}{2q\varepsilon_{si}}$$

If both 1 and *NDEP* are not given, *NDEP* defaults to 1.7e17cm^{-3} and is calculated from *NDEP*

7. If *VBX* is not given, it is calculated by

$$\frac{qNDEP \times XT^2}{2\varepsilon_{si}} = (\Phi_s - VBX)$$

8. If *VTH* 0 is not given it is calculated by

$$VTH0 = VFB + \Phi_s + K1\sqrt{\Phi_s} - V_{bs}$$

where *VFB* = -1.0
If *VTH* 0 is given, *VFB* defaults to

$$VFB = VTH0 - \Phi_s - K1\sqrt{\Phi_s - V_{bs}}$$

9. If K$_1$ and K$_2$ are not given, they are calculated by

$$K1 = \gamma_2 - 2K2\sqrt{\Phi_s - VBM}$$

$$K2 = \frac{(\gamma_1 - \gamma_2)(\sqrt{\Phi_s - VBX} - \sqrt{\Phi_s})}{2\sqrt{\Phi_s}(\sqrt{\Phi_s - VBM} - \sqrt{\Phi_s}) + VBM}$$

10. If *Cgso* is not given, it is calculated by:
If *DLC* is given and > 0.0

Cgso = *DLC* × *C* oxe - *CGSL*
if *Cgso* < 0.0, *CGSO* = 0.0

Else

$CGSO = 0.6 \times XJ \times C$ oxe

If *CGDO* is not given, it is calculated by:
If *DLC* is given and > 0.0

$CGDO = DLC \times C$ oxe - $CGDL$
if $CGDO < 0.0$, $CGDO = 0.0$

Else

$CGDO = 0.6 \times XJ \times C$ oxe

If *CGBO* is not given, it is calculated by:

$CGBO = 2 \times DWC \times C$ oxe

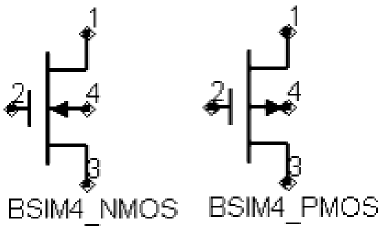
11. If *CF* is not given, it is calculated by

$$CF = \frac{2 \times EPSROX \times \varepsilon_0}{\pi} \times \log\left(1 + \frac{4.0e-7}{TOXE}\right)$$

12. For dioMod = 0, if Xjbvs < 0.0, it is reset to 1.0
For dioMod = 2, if Xjbvs 0.0, it is reset to 1.0
For dioMod = 0, if Xjbvd < 0.0, it is reset to 1.0
For dioMod = 2, if Xjbvd 0.0, it is reset to 1.0
13. Imelt, Ijth, Ijthsfwd, Ijthsrev, Ijthdfwd, and Ijthdrev Parameters
Imelt, Ijth, Ijthsfwd, Ijthsrev, Ijthdfwd, and Ijthdrev are used to determine the different diode limiting currents (also known as P-N junction explosion current).
Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value. Ijth can be specified only in the Options component.
If Ijthsfwd is not specified and Ijth is specified, Ijthsfwd = Ijth.
If Ijthsrev is not specified and Ijth is specified, Ijthsrev = Ijth.
If Ijthdfwd is not specified and Ijth is specified, Ijthdfwd = Ijth.
If Ijthdrev is not specified and Ijth is specified, Ijthdrev = Ijth.
If the Imelt value is less than the maximum value of Ijthsfwd, Ijthsrev, Ijthdfwd, and Ijthdrev, the Imelt value is increased to the maximum value.
If Imelt is specified (in the model or in Options) all diode limiting currents (Ijthsfwd, Ijthsrev, Ijthdfwd, and Ijthdrev) = Imelt; otherwise, each diode limiting current is used to limit its own diode current.
14. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent (Data Access Component)* (ccsim)). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

BSIM4_NMOS, BSIM4_PMOS (BSIM4 Transistor, NMOS, PMOS)

Symbol



Parameters

Model parameters must be specified in SI units

Name	Description	Units	Default
Model	model instance name	None	BSIM4M1
Length[†]	channel length	m	5.0e-6
Width[†]	channel width	m	5.0e-6
Nf	number of fingers	None	1.0
Sa[†]	distance between outer diameter edge to poly of one side	m	0.0
Sb[†]	distance between outer diameter edge to poly of the other side	m	0.0
Sd[†]	distance between neighboring fingers	m	0.0
Min	minimize either D or S	None	0
Ad[†]	Drain area	m^2	0.0
As[†]	Source area	m^2	0.0
Pd[†]	Drain perimeter	m	0.0
Ps[†]	Source perimeter	m	0.0
Nrd	number of squares in drain	None	1.0
Nrs	number of squares in source	None	1.0
Off	device is initially off	None	0.0
Rbdb	body resistance; defaults to Rbdb model	None	defaults to Rbdb model
Rbsb	body resistance; defaults to Rbsb model	None	defaults to Rbsb model
Rbpb	body resistance; defaults to Rbpb model	None	defaults to Rbpb model
Rbps	body resistance; defaults to Rbps model	None	defaults to Rbps model
Rbpd	body resistance; defaults to Rbpd model	None	defaults to Rbpd model

Trnqsmod	transient NQS model selector; defaults to Trnqsmod model	None	defaults to Trnqsmod model
Acnqsmod	AC NQS model selector; defaults to Acnqsmod model	None	defaults to Acnqsmod model
Rbodymod	distributed model R model selector; defaults to Rbodymod model	None	defaults to Rbodymod model
Rgatemod	gate resistance model selector; defaults to Rgatemod model	None	defaults to Rgatemod model
Geomod	geometry dependent parasitics model selector; defaults to Geomod model	None	defaults to Geomod model
Rgeomod	source/drain resistance and contact model selector; defaults to Rgeomod model	None	defaults to Rgeomod model
Temp	device operating temperature	°C	25
Mode	simulation mode: Nonlinear, Linear, Standard (refer to note 1)	None	Nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1
Sc	Distance to a single well edge	m	0.0
Sca	Integral of the first distribution function for scattered well dopant	None	0.0
Scb	Integral of the second distribution function for scattered well dopant	None	0.0
Scc	Integral of the third distribution function for scattered well dopant	None	0.0
Xgw	Distance from the gate contact to the channel edge	m	model Xgw
Ngcon	Number of gate contacts	None	model Ngcon
† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of m will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.			

Notes/Equations

1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
2. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gmb	Backgate transconductance (dIds/dVbs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Vth	Threshold voltage	volts
Vdsat	Drain-source saturation voltage	volts
DqgDvgb	(dQg/dVgb)	farads
DqgDvdb	(dQg/dVdb)	farads
DqgDvsb	(dQg/dVsb)	farads
DqbDvgb	(dQb/dVgb)	farads
DqbDvdb	(dQb/dVdb)	farads
DqbDvsb	(dQb/dVsb)	farads
DqdDvgb	(dQd/dVgb)	farads
DqdDvdb	(dQd/dVdb)	farads
DqdDvsb	(dQd/dVsb)	farads
Vgs	Internal gate-internal source voltage	volts
Vds	Internal drain-internal source voltage	volts
Vbs	Internal bulk-internal source voltage	volts
Vgms	Midgate-source voltage	volts
Vges	External gate-source voltage	volts
Vdbs	Drain body-internal source voltage	volts
Vsbs	Source body-internal source voltage	volts

bsimsoi (bsimsoi MOSFET Model and Instance)

Model Parameters

The bsimsoi model uses almost the same model parameters and model parameter definitions as the BSIMSOI4.3 model from the University of California-Berkeley. For more information about BSIMSOI4.3 see:

> http://www-device.eecs.berkeley.edu/~bsimsoi/archive/bsimsoi4p3/BSIMSOI_4p3_users_manual.pdf .

Appendix B of the University of California-Berkeley documentation covers the Model Parameter List and Appendix E covers Model Parameter Binning.

The minor differences in model parameters between the ADS bsimsoi model and the BSIMSOI4.3 model from University of California-Berkeley are as follows:

1. Model parameter names are completely lower case.
2. Model parameter *level* is removed.
3. Bsimsoi model is specified by using its model name *bsimsoi*.
4. New model parameter *version*, model version selector. It has no unit and the default value is 4.3. Available values are 3.0, 3.1, 3.11, 3.2, 4.0, and 4.3.
5. New model parameter *noimod* , the noise model selector for versions 3.11 and lower. It has no unit and the default is 1. Available values are 1, 2, 3, and 4.
6. In ADS, the transistor type of the bsimsoi model is specified by the model parameter *gender*. Available values are 1 (N-type) and -1 (P-type).

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to the *Design Kit Development* (dkarch).

```
model modelName bsimsoi[parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelName* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *bsimsoi*. Use the parameter *gender* to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch7 bsimsoi gender=1 version=4.3 vth0=0.7
```

Instance Parameters

Name	Description	Units	Default
l	Channel length	m	5e-6
w	Channel width	m	5e-6
nf	Number of fingers	1.0	
sa	Stress effect parameter	m	0.0
sb	Stress effect parameter	m	0.0
sd	Stress effect parameter	m	0.0
ad	Drain diffusion area	m^2	0.0
as	Source diffusion area	m^2	0.0
pd	Drain diffusion perimeter length	m	0.0
ps	Source diffusion perimeter length	m	0.0
nrd	Number of squares in drain series resistance	1.0	
nrs	Number of squares in source series resistance	1.0	
off	Device simulation off	0	
bjtoff	Turn off BJT current if equal to 1	0	
rth0	Thermal resistance per unit width, if not specified, rth0 is extracted from model card, if specified, it will override the one in model card.	Ohm	0.0
cth0	Thermal capacitance per unit width, if not specified, cth0 is extracted from model card, if specified, it will over-ride the one in model card.	Farads	1e-5
nrb	Number of squares in body series resistance	1.0	
frbody	Layout-dependent body resistance coefficient	1.0	
rbdb	Body resistance	Ohm	50.0
rbsb	Body resistance	Ohm	50.0
delvto	Zero bias threshold voltage variation	Volts	0.0
soimod	Instance model selector for PD/FD operation	0	
nbc	Number of body contact isolation edge	0.0	
nseg	Number of segments for channel width partitioning	1.0	
pdbcp	Parasitic perimeter length for body contact at drain side	m	0.0
psbcp	Parasitic perimeter length for body contact at source side	m	0.0
agbcp	Parasitic gate-to-body overlap area for body contact (n^+-p)	m^2	0.0
agbcp2	Parasitic gate-to-body overlap area for body contact (p^+-p)	m^2	0.0
agbcpd	Parasitic gate-to-body overlap area for body contact in DC	m^2	0.0
aebcp	Parasitic body-to-substrate overlap area for body contact	m^2	0.0
tnodeout	Temperature node flag indicating the usage of T node	0	
rgatemod	Gate resistance model selector	0	
rbodymod	Body resistance model selector	0	

Instance Netlist Format

```
modelName:instanceName D G S E [P] [B] [T] [parm=value]
```

where D is the drain node, G is the gate node, S is the source node, E is the substrate node, P is the optional external body contact node, B is the optional internal body node, and T is the optional temperature node. Refer to Note 2 for more information on optional nodes.

Example:

```
Nch7:M1  2  1  0  0  w=1u  l=0.1u
```

Notes/Equations

1. BSIMSOI4.3 was developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.
   More information about this model is available at:

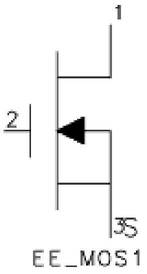
   "http://www-device.eecs.berkeley.edu/~bsimsoi/"
2. There are three optional nodes, P, B and T. P and B nodes are used for body contact devices. Consider the case when tnodeout is 0, if the user specifies four nodes, this element is a 4-terminal device, i.e., floating body. If the user specifies five nodes, the fifth node represents the external body contact node (P). There is a body resistance between the internal body node and the P node. In these two cases, an internal body node is created but it is not accessible in the circuit deck. If the user specifies six nodes, the fifth node represents the P node and the sixth node represents the internal body node (B). This configuration is useful for distributed body resistance simulation. If tnodeout is set to 1, the last node is interpreted as the temperature node. In this case, if user specifies five nodes, it is a floating body case. If user specifies six nodes, it is a body-contacted case. Finally, if the user specifies seven nodes, it is a body-contacted case with an accessible internal body node. The temperature node is useful for thermal coupling simulation.
3. *DC Operating Point Information* lists the DC operating point parameters that can be sent to the dataset.

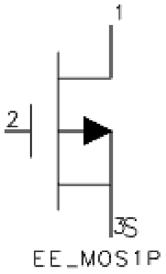
DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ie	Substrate current	amperes
Ip	External body current	amperes
Ib	Internal body current	amperes
Power	Total dissipated power	watts
Vds	External drain-source voltage	volts
Vgs	External gate-source voltage	volts
Ves	External substrate-source voltage	volts
Vps	External body contact to source voltage	volts
Vbs	External source to internal body voltage	volts
Ids	Internal drain-source current	amperes
Ibd	Internal body-drain current	amperes
Ibs	Internal body-source current	amperes
Isub	Internal impact ionization current	amperes
Igidl	Internal GIDL current	amperes
Igisl	Internal GISL current	amperes
Igs	Internal gate-source tunneling current	amperes
Igd	Internal gate-drain tunneling current	amperes
Igb	Internal gate-body tunneling current	amperes
Igcs	Internal gate-channel tunneling current at source side	amperes
Igcd	Internal gate-channel tunneling current at drain side	amperes
Vdsat	Drain-source saturation voltage	volts
Vth	Threshold voltage	volts
Qg	Internal gate charge	coulombs
Qb	Internal body charge	coulombs
Qd	Internal drain charge	coulombs
Qs	Internal source charge	coulombs
Gmbs	Body transconductance	siemens
Gm	Forward transconductance	siemens
Gmids	Gm/Ids	1/volts
Gds	Output conductance	siemens
Cgg	dQg/dVgb	farads
Cgd	dQg/dVdb	farads
Cgs	dQg/dVsb	farads
Cbg	dQb/dVgb	farads
Cbd	dQb/dVdb	farads
Cbs	dQb/dVsb	farads
Cdg	dQd/dVgb	farads
Cdd	dQd/dVdb	farads
Cds	dQd/dVsb	farads

EE_MOS1, EE_MOS1P (EEsof Nonlinear MOSFETs, N-Channel, P-Channel)

Symbol





Parameters

Name	Description	Units	Default
Model	Model instance name	None	EEMOS1
Temp	device operating temperature	°C	25.0
Noise	noise generation: yes=1, no =0	None	yes
_M	number of devices in parallel	None	1

Notes/Equations

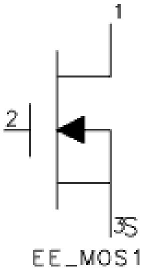
1. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	siemens
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	siemens
dIdb_dVgs	(dIdb/dVgs)	siemens
dIdb_dVgd	(dIdb/dVgd)	siemens
dIdb_dVds	(dIdb/dVds)	siemens
Cgc	Gate-source capacitance (dQgc/dVgc)	farads
Cgy	Gate-drain capacitance (dQgy/dVgy)	farads
Cds	Drain-source capacitance	farads
dQgc_dVgy	(dQgc/dVgy)	farads
dQgy_dVgc	(dQgy_dVgc)	farads
Vgs	Gate-source voltage	volts
Vds	Gate-drain voltage	volts

EE_MOS1 (EEsof Nonlinear MOSFET, N-Channel)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	EEMOS1
Temp	device operating temperature	°C	25.0
Noise	noise generation: yes=1, no =0	None	yes
_M	number of devices in parallel	None	1

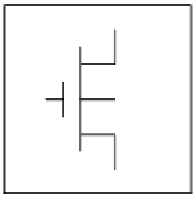
Notes/Equations

1. The following table lists the DC operating point parameters that can be sent to the dataset.

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	siemens
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	siemens
dIdb_dVgs	(dIdb/dVgs)	siemens
dIdb_dVgd	(dIdb/dVgd)	siemens
dIdb_dVds	(dIdb/dVds)	siemens
Cgc	Gate-source capacitance (dQgc/dVgc)	farads
Cgy	Gate-drain capacitance (dQgy/dVgy)	farads
Cds	Drain-source capacitance	farads
dQgc_dVgy	(dQgc/dVgy)	farads
dQgy_dVgc	(dQgy_dVgc)	farads
Vgs	Gate-source voltage	volts
Vds	Gate-drain voltage	volts

EE_MOS1_Model (EEsof Nonlinear MOSFET Model)

Symbol



Parameters

Name	Description	Units	Default
Is	Substrate diode reverse saturation current	A	1.0e-14
N	Substrate diode ideality factor	None	1.0
Vbi	Substrate diode built-in potential	V	0.7
Mj	Junction grading coefficient	None	0.5
Fc	Substrate depletion capacitance linearization point	None	1.0e-4
Vbr	Breakdown onset voltage	V	1.0e-4
Kbo	Breakdown current coefficient	None	1.0e-4
Nbr	Breakdown current exponent	None	2.0
Vinfl	Inflection point in Cgs-Vgs characteristic	V	5.0
Deltds	Capacitance forward to reverse mode transition	V	1.0
Deltgs	Cgsth to Cgso transition voltage	V	1.0
Cgsmax	Maximum value of Cgs	F	1.0e-12
Vgo	Gate-source voltage where transconductance is a maximum	V	7.0
Vto	Zero-bias threshold	V	-1.0
Gamma	Drain-source dependent threshold	1/V	0.0
Gmmax	Peak transconductance	S	10.0e-03
Delt	transconductance tail-off rate	V	2.0
Vbreak	Voltage where transconductance tail-off begins	V	4.0
Lambda	Output conductance parameter	1/V	0.0
Vsatm	Maximum value of saturation voltage	V	10.0
Vgm	Gate-source volatge where saturation voltage is VSATM	V	5.0
Rdb	Dispersion source output impedence	Ohm	1.0e+9
Cbs	Dispersion source capacitance	F	1.6e-13
Gmmaxac	AC value of Gmmax	S	60.0e-03
Deltac	AC value of Delt	V	2.0
Vbreakac	AC value of Vbreak	V	4.0
Vgoac	AC value of Vgo	V	7.0
Lambdaac	AC value of Lambda	1/V	0.0
Vsatmac	AC value of VSATM	V	10.0

Vgmac	AC value of VGM	V	5.0
Gdbm	Additional d-b branch conductance at Vds=VDSM	None	0.0
Kdb	Controls Vds dependence of D-B branch conductance	None	0.0
Vdsm	Voltage where D-B branch conductance becomes constant	V	1.0
Rd	Drain contact resistance	Ohm	1.0
Rs	Source contact resistance	Ohm	1.0
Rg	Gate metallization resistance	Ohm	1.0
Ris	Source end channel resistance	Ohm	1.0
Rid	Drain end channel resistance	Ohm	1.0
wBvg	Gate oxide breakdown voltage (warning)	V	None
wBvds	Drain-source breakdown voltage (warning)	V	None
wIdsmax	Maximum drain-source current (warning)	A	None
wPmax	Maximum power dissipation (warning)	W	None
Cdso	Zero-bias output capacitance	F	0.0
Cgso	Constant portion of gate-source capacitance	F	1.0e-13
Cgdo	Constant portion of gate-drain capacitance	F	1.0e-13
AllParams	DataAccessComponent-based parameters	None	None

Notes/Equations

1. This model supplies values for an EE_MOS device.
2. Model parameters such as Ls, Ld, Lg (as well as other package-related parameters that are included as part of the model file output from the EEMOS1 IC-CAP kernel) are not used by EE_MOS in the simulator. Only those parameters listed are part of EE_MOS. Any extrinsic devices must be added externally by the user.
3. To prevent numerical problems, the setting of some model parameters to 0 is trapped by the simulator. The parameter values are changed internally:

   Rd = 10^{-4}
   Rs = 10^{-4}
   Rg = 10^{-4}
   Ris = 10^{-4}
   Rid = 10^{-4}
   Vgm = 0.1
   Vgmac = 0.1
   Vsatm = 0.1
   Vsatmac = 0.1
   Deltds = 0.1
4. TEMP parameter is only used to calculate the noise performance of this model. Temperature scaling of model parameters is not performed.
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.
6. This device has no default artwork associated with it.

Equations/Discussion

EEMOS1 is an empirical analytic model that was developed by Agilent EEsof for the express purpose of fitting measured electrical behavior of 3-terminal n-channel MOSFETs intended for high-frequency analog applications. Unlike most physics-based MOSFET models found in SPICE programs, EEMOS1 contains no process or physical parameters. It does, however, accurately fit those electrical quantities that have direct bearing on the RF predictive abilities of the model, namely g_m vs. bias, g_{ds} vs. bias and, to a lesser degree, input and output capacitances vs. bias. The model includes the following features:

- Accurate drain-source current model fits measured current over gate and drain bias variations.
- Flexible transconductance formulation permits accurate fitting of g_m compression found in MOSFETs.
- Charge model that accurately tracks measured capacitance values.
- Dispersion model that permits simultaneous fitting of high-frequency conductances and DC characteristics.
- Well-behaved analytic expressions permit accurate extrapolations outside of the measurement range used to extract the model.
  The model equations were developed concurrently with parameter extraction techniques to ensure the model would contain only parameters that were extractable from measured data. Although the model is amenable to automated parameter extraction techniques, it was designed to consist of parameters that are easily estimated (visually) from measured data such as $g_m - V_{gs}$ plots. Because the model equations are all well-behaved analytic expressions, EEMOS1 possesses no inherent limitations with respect to its usable power range. Agilent EEsof's IC-CAP program provides the user with the capability of extracting EEMOS1 models from measured data.

Channel Current

The channel current model in EEMOS1 is comprised of empirically derived analytic expressions and requires the specification of 9 parameter values. Because EEMOS1 is intended for large-signal analog applications, no attempt is made to characterize this channel current in the subthreshold or *weak* inversion region. The channel current expression is intended for use above V_t only. The equations were developed through examination of I_{ds} vs. bias and g_m vs. bias plots on a number of DMOS devices from various manufacturers. The equations are sufficiently flexible enough to handle either enhancement or depletion mode devices. The expressions below are given for $V_{ds}>0.0V$ although the model is equally valid for $V_{ds}<0.0V$. The model assumes the device is symmetrical; simply replace V_{gs} with V_{gd} and V_{ds} with $-V_{ds}$ obtain the reverse region ($V_{ds}<0.0V$) equations. The g_m g_{ds} and I_{ds} equations take on take on two different forms depending on the value of V_{gs} relative to some of the model parameters. The I_{ds} expression is continuous through at least the second derivative everywhere except at V_t, where the second derivative is discontinuous.

The following voltages define regions of operation that are used in the current definitions:

$$V_t = Vto - Gamma \times V_{ds}$$

$$V_{gst} = V_{gs} - V_t\ .$$

for $V_{gst} \le 0$

$$g_{mo} = 0.0$$

$$I_{dso} = 0.0$$

$$g_{dso} = 0.0$$

for $V_{gst} > 0$ and $V_{gs} \le V_{break}$

$$g_{mo} = g_{mm}(V_{gs}, V_{ds})$$

$$I_{dso} = I_{dsm}(V_{gs}, V_{ds})$$

$$g_{dso} = g_{dsm}(V_{gs}, V_{ds})$$

for $V_{gst} > 0$ and $V_{gs} > V_{break}$

$$g_{mo} = a(V_{gs} - V_{asym})^{b}$$

$$I_{dso} = I_{dsm}(Vbreak, V_{ds}) + \frac{a}{b+1}[(V_{gs} - V_{asym})^{b+1} - Delt^{b+1}]$$

$$g_{dso} = g_{dsm}(Vbreak, V_{ds})$$

where:

$$g_{mm}(V, V_{ds}) = Gmmax\left[1 - \left(\frac{V - Vgo}{V_t - Vgo}\right)^{2}\right]$$

$$I_{dsm}(V,V_{ds}) = \left(Gmmax \times \left[(V - Vgo)\left(1 - \frac{1}{3}\left(\frac{V - Vgo}{V_t - Vgo}\right)^{2}\right) - \frac{2}{3}(V_t - Vgo)\right]\right)$$

$$g_{dsm}(V, V_{ds}) = Gmmax \times \left[\frac{2 \times Gamma}{3}\left(1 - \left(\frac{V - Vgo}{V_t - Vgo}\right)^{3}\right)\right]$$

$$m_{g_{mm}} = \left.\frac{\partial g_{mm}}{\partial V}\right|_{V = Vbreak}$$

$$= -\frac{2 \times Gmmax}{V_t - Vgo}\left(\frac{Vbreak - Vgo}{V_t - Vgo}\right)$$

$$V_{asym} = Vbreak - Delt$$

$$b = \frac{m_{g_{mm}} \times Delt}{g_{mm}(Vbreak, V_{ds})}$$

$$a = \frac{g_{mm}(Vbreak, V_{ds})}{Delt^b}$$

If b = −1, then the integral of g_{mo} (I_{dso}) is comprised of natural log functions:

$$I_{dso} = I_{dsm}(Vbreak, V_{ds}) + a[\log(V_{gs} - V_{asym}) - \log(Delt)]$$

The current saturation mechanism in EEMOS1 is described empirically through the parameters Vgm and Vsatm. The drain voltage where the channel current saturates is dependent on V_{gs} through the following relation:

$$V_{sat} = Vsatm \times \tanh\left[\frac{3(V_{gs} - V_t)}{Vgm}\right]$$

The preceding relations for I_{dso}, g_{mo} and g_{dso} can now be substituted in the following equations that model the current saturation and output conductance. This portion of the model is similar to an approach described by Curtice for modeling MESFETs [1].

$$I_{ds} = I_{dso}(1 + Lambda \times V_{ds})\tanh\left(\frac{3V_{ds}}{V_{sat}}\right)$$

$$g_m = \left[g_{mo}\tanh\left(\frac{3V_{ds}}{V_{sat}}\right) - I_{dso}\,\mathrm{sech}^2\left(\frac{3V_{ds}}{V_{sat}}\right) \times \left[\frac{3V_{ds}}{V_{sat}^2}\frac{\partial V_{sat}}{\partial V_{gs}}\right]\right]$$

$$\times (1 + Lambda \times V_{ds})$$

$$g_{ds} = \{g_{dso}(1 + Lambda \times V_{ds}) + I_{dso}Lambda\}\tanh\left(\frac{3V_{ds}}{V_{sat}}\right)$$

$$+ I_{dso} \times \frac{3\left(V_{sat} - V_{ds}\frac{\partial V_{sat}}{\partial V_{ds}}\right)(1 + Lambda \times V_{ds})}{V_{sat}^2}\,\mathrm{sech}^2\left(\frac{3V_{ds}}{V_{sat}}\right)$$

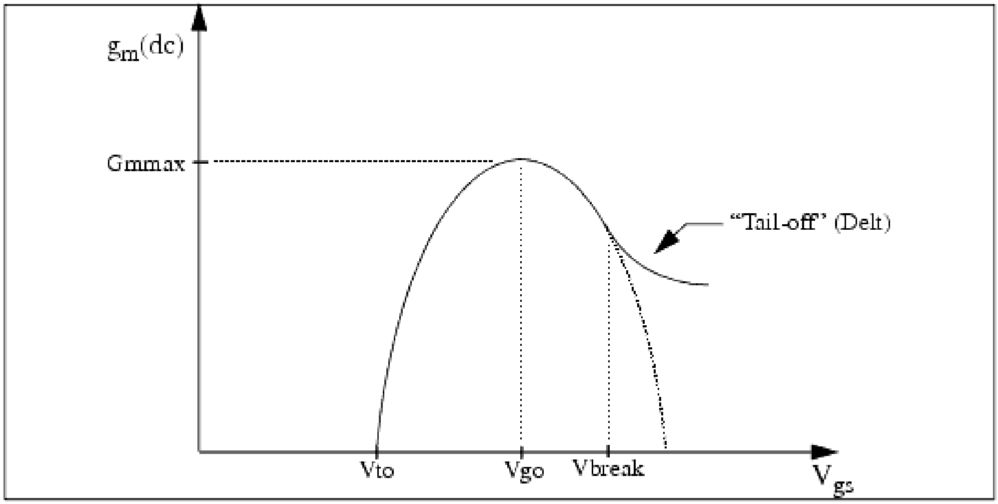
where:

$$\frac{\partial V_{sat}}{\partial V_{gs}} = \frac{3 \times Vsatm}{Vgm}\operatorname{sech}^2\left(\frac{3(V_{gs}-V_t)}{Vgm}\right)$$

$$\frac{\partial V_{sat}}{\partial V_{ds}} = -\frac{3 \times Vsatm \times Gamma}{Vgm}\operatorname{sech}^2\left(\frac{3(V_{gs}-V_t)}{Vgm}\right)$$

Qualitatively, the operation of the channel current model can be described as follows. The V_{ds} dependence of the equations is dominated by the parameters Vsatm, Vgm, Gamma, and Lambda. Output conductance is controlled by Gamma and Lambda. The parameter Vsatm represents the maximum drain-source voltage where the drain current saturates. Vgm is the gate voltage corresponding to the I-V trace where V_{sat}=Vsatm.

When Gamma=0, Vsatm=0 and Lambda=0, EEMOS1 becomes dependent on V_{gs} only. Under these simplified conditions, the parameters describing the $g_m - V_{gs}$ dependence of the model are easily explained. Vto is the V_{gs} value where g_m becomes zero. The transconductance peaks at V_{gs}=VGO with a value of Gmmax. At V_{gs}=Vbreak, the model breaks from its quadratic g_m dependence and follows a hyperbolic dependence. The parameter Delt controls the voltage asymptote of this hyperbola. The shape of this tail-off region can be altered by tuning on the parameter Delt. EEMOS1 constrains the hyperbola to match the derivative of the quadratic function at V_{gs}=Vbreak. This ensures a continuous transition between the respective modeling regions for simulation. The parameter definitions are shown in the following illustration.



EEMOS1 g_m-V_{gs} Parameters

Dispersion Current (Idb)

The circuit used to model conductance dispersion consists of the elements Rdb, Cbs (these

linear elements are also parameters) and the nonlinear source $I_{db}(V_{gs}, V_{ds})$. The model is a large-signal generalization of the dispersion model proposed by Golio et al. for MESFETs [2]. At DC, the drain-source current is just
the current I_{ds}. At high frequency (well above the transition frequency), the drain source current will be equal to I_{ds}(high frequency) = I_{ds}(dc) + I_{db}.

Linearization of the drain-source model yields the following expressions for y_{21} and y_{22} of the intrinsic EEMOS1 model:

$$y_{21} = g_{dsgs} + g_{dbgs} - \frac{g_{dbgs}}{1 + j\omega \times Cbs \times Rdb}$$

$$y_{22} = g_{dsds} + g_{dbds} + \frac{1}{Rdb} - \frac{\left(g_{dbds} + \frac{1}{Rdb}\right)}{1 + j\omega \times Cbs \times Rdb}$$

where:

$$g_{dsgs} = \frac{\partial I_{ds}}{\partial V_{gs}}$$

$$g_{dsds} = \frac{\partial I_{ds}}{\partial V_{ds}}$$

$$g_{dbgs} = \frac{\partial I_{db}}{\partial V_{gs}}$$

$$g_{dbds} = \frac{\partial I_{db}}{\partial V_{ds}}$$

Evaluating these expressions at the frequencies ω=0 and ω=infinity, produces the following results for transconductance and output conductance:
For ω = 0,

$$Re[y_{21}] = g_m = g_{dsgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds}$$

For ω = infinity,

$$Re[y_{21}] = g_m = g_{dsgs} + g_{dbgs}$$

$$Re[y_{22}] = g_{ds} = g_{dsds} + g_{dbds} + \frac{1}{Rdb}$$

Between these two extremes, the conductances make a smooth transition, the abruptness of that is governed by the time constant τdisp = Rdb × Cbs. The frequency f_0 at which the conductances are midway between these two extremes is defined as:

$$f_0 = \frac{1}{2\pi\tau_{disp}}$$

The parameter Rdb should be set large enough so that its contribution to the output conductance is negligible. Unless the user is specifically interested in simulating the device near f_0, the default values of Rdb and Cbs will be adequate for most RF applications.

The EEMOS1 I_{ds} model can be extracted to fit either DC or AC characteristics. In order to simultaneously fit both DC I-Vs and AC conductances, EEMOS1 uses a simple scheme for modeling the I_{db} current source whereby different values of the same parameters can be used in the I_{ds} equations. The DC and AC drain-source currents can be expressed as follows:

$$I_{ds}^{dc}(Voltages, Parameters) = I_{ds}(Voltages, Vto, Gamma, Vgo, Gmmax,$$

$$Delt, Vbreak, Lambda, Vsatm, Vgm$$

$$I_{ds}^{ac}(Voltages, Parameters) = I_{ds}(Voltages, Vto, Gamma, Vgoac,$$

$$Gmmaxac, Deltac, Vbreakac,$$

$$Lambdaac, Vsatmac, Vgmac$$

Parameters such as Vto that do not have an AC counterpart (there is no Vtoac parameter), have been found not to vary significantly between extractions using DC measurements versus those using AC measurements. The difference between the AC and DC values of I_{ds} plus an additional term that is a function of V_{ds} only gives the value of I_{db} for the dispersion model:

$$I_{db}(V_{gs}, V_{ds}) = I_{ds}^{ac}(V_{gs}, V_{ds}) - I_{ds}^{dc}(V_{gs}, V_{ds}) + I_{dbp}(V_{ds})$$

where I_{dbp} and its associated conductance are given by:

for V_{ds} > Vdsm and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}}\tan^{-1}((V_{ds} - Vdsm)\sqrt{Kdb \times Gdbm}) + Gdbm \times Vdsm$$

$$g_{dbp} = \frac{Gdbm}{(Kdb(Gdbm(V_{ds} - Vdsm)^2 + 1))}$$

for $V_{ds} < -Vdsm$ and $Kdb \neq 0$:

$$I_{dbp} = \sqrt{\frac{Gdbm}{Kdb}} \tan^{-1}((V_{ds} + Vdsm)\sqrt{Kdb \times Gdbm}) - Gdbm \times Vdsm$$

$$g_{dbp} = \frac{Gdbm}{Kdb \times Gdbm((V_{ds} + Vdsm)^2 + 1)}$$

for $-Vdsm \leq V_{ds} \leq Vdsm$ or $Kdb = 0$:

$$I_{dsm} = Gdbm \times V_{ds}$$

$$g_{dbm} = Gdbm$$

By setting the seven high-frequency parameters equal to their DC counterparts, the dispersion model reduces to $I_{db} = I_{dbp}$. Examination of the I_{dbp} expression reveals that the additional setting of Gdbm to zero disables the dispersion model entirely. Because the I_{dbp} current is a function of V_{ds} only, it will impact output conductance only. However, the current function I_{ds}^{ac} will impact both g_m and g_{ds}. For this reason, the model is primarily intended to use g_m data as a means for tuning I_{ds}^{ac}. Once this *fitting* is accomplished, parameters Gdbm, Kdb and Vdsm can be tuned to optimize the g_{ds} fit.

Charge Model

The EEMOS1 charge model consists of three separate charge sources that model channel charge and charge associated with the substrate (output) diode. The channel charge is partitioned between the two charge sources q_{gc} and q_{gy} such that symmetry is maintained relative to V_{ds} = 0V. These expressions were empirically developed by Agilent EEsof such that their derivatives would fit measured capacitance data. The channel charge expressions are:

$$q_{gc} = \frac{Cgsmax}{4}\left[V_{gc} - Vinfl + \sqrt{(V_{gc} - Vinfl)^2 + Deltgs^2}\right]$$

$$' \times \left[1 + \tanh\left(\frac{3(V_{gc} - V_{gy})}{Deltds}\right)\right] + Cgso \times V_{gc}$$

$$q_{gy} = \frac{Cgsmax}{4}\left[V_{gy} - Vinfl + \sqrt{(V_{gy} - Vinfl)^2 + Deltgs^2}\right]$$

$$\times\left[1 - \tanh\left(\frac{3(V_{gy} - V_{gc})}{Deltds}\right)\right] + Cgdo \times V_{gy}$$

The output charge and its derivative are modeled using the standard junction diode depletion formula:

For $-V_{ds} < Fc \times Vbi$

$$q_{ds} = -\frac{Cdso \times Vbi}{1 - Mj}\left[1 - \left(1 + \frac{V_{ds}}{Vbi}\right)^{1 - Mj}\right]$$

$$C_{dsds} = \frac{\partial q_{ds}}{\partial V_{ds}} = \frac{Cdso}{\left[1 + \frac{V_{ds}}{Vbi}\right]^{Mj}}$$

For $-V_{ds} < -Fc \times Vbi$

the capacitance is extrapolated linearly from its value at Fc× Vbi according to the standard SPICE equation for a junction diode [3]. The charge derivatives are related to the small-signal capacitances through the following expressions:

$$C_{gs} \approx C_{gcgc} + C_{gygc}$$

$$C_{gd} \approx C_{gcgy} + C_{gygy}$$

$$C_{ds} \approx C_{dsds} - C_{gcgy}$$

where:

$$C_{gcgc} = \frac{\partial q_{gc}}{\partial V_{gc}}$$

$$C_{gcgy} = \frac{\partial q_{gc}}{\partial V_{gy}}$$

$$C_{gygy} = \frac{\partial q_{gy}}{\partial V_{gy}}$$

$$C_{gygc} = \frac{\partial q_{gy}}{\partial V_{gc}}$$

Substrate Diode and Breakdown

When the drain-source voltage is reverse-biased, the substrate diode conducts according to the standard diode relation:

$$I_{for}(V_{ds}) = Is \times \left[e^{\frac{-qV_{ds}}{nkT}} - 1 \right]$$

where q is the charge on an electron, k is Boltzmann's constant, and T is the junction temperature.

The EEMOS1 breakdown model is based on a simple power law expression. The model consists of three parameters that are easily optimized to measured data. The breakdown current is given by:

For V_{ds} > Vbr,

$$I_{bkdn}(V_{ds}) = Kbo(V_{ds} - Vbr)^{Nbr}$$

For V_{ds} ≤ Vbr

$$I_{bkdn}(V_{ds}) = 0$$

Total current flowing through the substrate (body) diode from source to drain is given by:

$$I_{sub}(V_{ds}) = I_{for}(V_{ds}) - I_{bkdn}(V_{ds}$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd, Ris, Rid, and Rdb is characterized by the following spectral density.

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

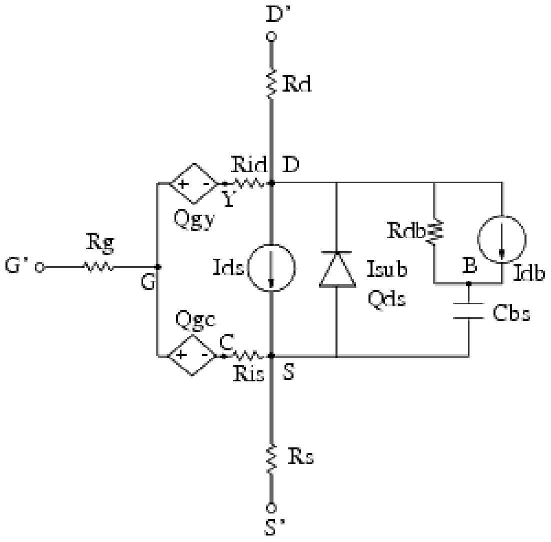
Channel noise generated by the DC transconductance gm is characterized by the following spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3}$$

In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, and Δ *f* is the noise bandwidth.

Flicker noise for this device is not modeled in this simulator version. However, the bias-dependent noise sources I_NoiseBD and V_NoiseBD (from the Sources library) can be connected external to the device to model flicker noise.

Equivalent Circuit



References

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2. J. M. Golio, M. Miller, G. Maracus, D. Johnson. "Frequency dependent electrical characteristics of GaAs MESFETs," *IEEE Trans. Elec. Devices* , vol. ED-37, pp. 1217-1227, May 1990.
3. P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE,* Second Edition, McGraw-Hill, Inc., 1993.

hisim2 (HiSIM 2 MOSFET Model and Instance)

Model Parameters

The maximum and minimum limits of the model parameter are recommended values. These values may be violated in some specific cases.

Items with * indicate minor parameters.

Basic Device Parameters

Parameter	Description	Units	Min	Max	Default	Remarks
TOX	physical oxide thickness	m			3n	
XL	difference between real and drawn gate length	m			0	
XW	difference between real and drawn gate width	m			0	
XLD	gate-overlap length	m	0	50n	0	
XWD	gate-overlap length	m	-10n	100n	0	
TPOLY	height of the gate poly-Si for fringing capacitance	m			200×10^{-9}	
LL	coefficient of gate length modification				0	
LLD	coefficient of gate length modification	m			0	
LLN	coefficient of gate length modification				0	
WL	coefficient of gate width modification				0	
WLD	coefficient of gate width modification	m			0	
WLN	coefficient of gate width modification				0	
NSUBC	substrate-impurity concentration	cm^{-3}	1×10^{16}	1×10^{19}	5×10^{17}	
NSUBP	maximum pocket concentration	cm^{-3}	1×10^{16}	1×10^{19}	1×10^{18}	
LP	pocket penetration length	m	0	300n	15n	
*NPEXT	maximum concentration of pocket tail	cm^{-3}	1×10^{16}	1×10^{18}	5×10^{17}	
*LPEXT	extension length of pocket tail	m	1×10^{-50}	10×10^{-6}	1×10^{-50}	
VFBC	flat-band voltage	V	-1.2	-0.8	-1.0	
VBI	built-in potential	V	1.0	1.2	1.1	
KAPPA	dielectric constant for gate dielectric	—			3.9	
EG0	bandgap	eV	1.0	1.3	1.1785	
BGTMP1	temperature dependence of bandgap	eVK^{-1}	50×10^{-6}	100×10^{-6}	90.25µ	fixed
BGTMP2	temperature dependence of bandgap	eVK^{-2}	-1µ	1µ	0.1µ	
TNOM	temperature selected as a nominal temperature value	°C	22	32	27	

Velocity

Parameter	Description	Units	Min	Max	Default	Remarks
VMAX	saturation velocity	cm s^{-1}	1MEG	20MEG	10MEG	
VOVER	velocity overshoot effect	cm^{VOVERP}	0	1.0	0.3	
VOVERP	L_{eff} dependence of velocity overshoot	—	0	2	0.3	
*VTMP	temperature dependence of the saturation velocity	cm s^{-1}	-2.0	1.0	0	

Quantum Mechanical Effect

Parameter	Description	Units	Min	Max	Default	Remarks
QME1	V_{gs} dependence of quantum mechanical effect	V^{-2} m	0	300n	0	
QME2	V_{gs} dependence of quantum mechanical effect	V	0	3.0	1.0	
QME3	minimum T_{ox} modification	m	0	800p	0	

Poly-Silicon Gate Depletion Effect

Parameter	Description	Units	Min	Max	Default	Remarks
PGD1	strength of poly-depletion effect	V	0	50m	0	
PGD2	threshold voltage of poly-depletion effect	V	0	1.5	1.0	
PGD3	V_{ds} dependence of poly-depletion effect	—	0	1.0	0.8	
*PGD4	L_{gate} dependence of poly-depletion effect	—	0	3.0	0	

Short Channel Effect

Parameter	Description	Units	Min	Max	Default	Remarks
PARL2	depletion width of channel/contact junction	m	0	50n	10n	
SC1	magnitude of short-channel effect	—	0	200	1.0	
SC2	V_{ds} dependence of short-channel effect	V^{-1}	0	50	1.0	
*SC3	V_{bs} dependence of short-channel effect	V^{-1} m	0	1m	0	
SCP1	magnitude of short-channel effect due to pocket	—	0	50	1.0	
SCP2	V_{ds} dependence of short-channel due to pocket	V^{-1}	0	50	0.1	
*SCP3	V_{bs} dependence of short-channel effect due to pocket	V^{-1} m	0	1m	0	
*SCP21	short-channel-effect modification for small V_{ds}	V	0	5.0	0	
*SCP22	short-channel-effect modification for small V_{ds}	V^{4}	0	50m	0	
*BS1	body-coefficient modification by impurity profile	V^{2}	0	100m	0	
*BS2	body-coefficient modification by impurity profile	V	0.5	1.0	0.9	

Mobility

Parameter	Description	Units	Min	Max	Default	Remarks
MUECB0	coulomb scattering	$cm^2\ V^{-1}\ s^{-1}$	100	100K	1K	
MUECB1	coulomb scattering	$cm^2\ V^{-1}\ s^{-1}$	15	10K	100	
MUEPH0	phonon scattering	—	0.25	0.35	0.3	fixed
MUEPH1	phonon scattering	$cm^2\ V^{-1}\ s^{-1}\ (V\ cm^{-1})^{MUEPH0}$	2K	30K	25K(nMOS),9K(pMOS)	
MUETMP	temperature dependence of phonon scattering	—	0.5	2.0	1.5	
*MUEPHL	length dependence of phonon mobility reduction	—			0	
*MUEPLP	length dependence of phonon mobility reduction	—			1.0	
MUESR0	surface-roughness scattering	—	1.8	2.2	2.0	
MUESR1	surface-roughness scattering	$cm^2\ V^{-1}\ s^{-1}\ (V\ cm^{-1})^{MUESR0}$	1×10^{14}	1×10^{16}	1×10^{15}	
*MUESRL	length dependence of surface roughness mobility reduction				0	
*MUESLP	length dependence of surface roughness mobility reduction				1.0	
NDEP	depletion charge contribution on effective-electric field	—	0	1.0	1.0	
*NDEPL	modification of Q_B contribution for short-channel case	—			0	
*NDEPLP	modification of Q_B contribution for short-channel case	—			1.0	
NINV	inversion charge contribution on effective-electric field	—	0	1.0	0.5	
BB	high-field-mobility degradation	—			2.0(nMOS),1.0(pMOS)	fixed

Channel-Length Modulation

Parameter	Description	Units	Min	Max	Default	Remarks
CLM1	hardness coefficient of channel/contact junction	—	0.5	1.0	0.7	
CLM2	coefficient for Q_B contribution	—	1.0	2.0	2.0	
CLM3	coefficient for Q_I contribution	—	1.0	5.0	1.0	
*CLM4	no longer used					
*CLM5	effect of pocket implantation	—	0	5.0	1.0	
*CLM6	effect of pocket implantation	—	0	5.0	0	

Narrow Channel Effect

Parameter	Description	Units	Min	Max	Default	Remarks
WFC	threshold voltage change due to capacitance change	F cm^{-2} m^{-1}	-5.0×10^{-15}	1×10^{-6}	0	
*WVTH0	threshold voltage shift				0	
*NSUBP0	modification of pocket concentration for narrow width	cm^{-3}			0	
*NSUBWP	modification of pocket concentration for narrow width				1.0	
*MUEPHW	phonon related mobility reduction				0	
*MUEPWP	phonon related mobility reduction				1.0	
*MUESRW	change of surface roughness related mobility				0	
*MUESWP	change of surface roughness related mobility				1.0	
*VTHSTI	threshold voltage shift due to STI				0	
*VDSTI	V_{ds} dependence of STI subthreshold				0	
*SCSTI1	the same effect as SC1 but at STI edge				0	
*SCSTI2	the same effect as SC2 but at STI edge				0	
NSTI	substrate-impurity concentration at the STI edge	cm^{-3}	1×10^{16}	1×10^{19}	5×10^{17}	
WSTI	width of the high-field region at STI edge	m			0	
*WSTIL	channel-length dependence of WSTI				0	
*WSTILP	channel-length dependence of WSTI				1.0	
*WSTIW	channel-width dependence of WSTI				0	
*WSTIWP	channel-width dependence of WSTI				1.0	
WL1	threshold voltage shift of STI leakage due to small size effect				0	
WL1P	threshold voltage shift of STI leakage due to small size effect				1.0	
NSUBPSTI1	pocket concentration change due to diffusion-region length between gate and STI	m			0	
NSUBPSTI2	pocket concentration change due to diffusion-region length between gate and STI	m			0	
NSUBPSTI3	pocket concentration change due to diffusion-region length between gate and STI	m			1.0	
MUESTI1	mobility change due to diffusion-region length between gate and STI				0	
MUESTI2	mobility change due to diffusion-region length between gate and STI				0	
MUESTI3	mobility change due to diffusion-region length between gate and STI				1.0	
SAREF	reference length of diffusion between gate and STI	m			1.0×10^{-6}	
SBREF	reference length of diffusion between gate and STI	m			1.0×10^{-6}	

Small Size Effect

Parameter	Description	Units	Min	Max	Default	Remarks
WL2	threshold voltage shift due to small size effect				0	
WL2P	threshold voltage shift due to small size effect				1.0	
*MUEPHS	mobility modification due to small size				0	
*MUEPSP	mobility modification due to small size				1.0	
*VOVERS	modification of maximum velocity due to small size	—			0	
*VOVERSP	modification of maximum velocity due to small size	—			0	

Substrate Current

Parameter	Description	Units	Min	Max	Default	Remarks
SUB1	substrate current coefficient of magnitude	V^{-1}			10	
SUB1L	L_{gate} dependence SUB1	m			2.5×10^{-3}	
SUB1LP	L_{gate} dependence SUB1	—			1.0	
SUB2	substrate current coefficient of exponential term	V			25.0	
SUB2L	L_{gate} dependence of SUB2	m	0	1.0	2×10^{-6}	
SVDS	substrate current dependence on V_{ds}	—			0.8	
SLG	substrate current dependence on L_{gate}	m			3×10^{-8}	
SLGL	substrate current dependence on L_{gate}	m^{SLGLP}			0	
SLGLP	substrate current dependence on L_{gate}	—			1.0	
SVBS	substrate current dependence on V_{bs}	—			0.5	
SVBSL	L_{gate} dependence of SVBS	$m^{SV\ BSLP}$			0	
SVBSLP	L_{gate} dependence of SVBS	—			1.0	
SVGS	substrate current dependence on V_{gs}	—			0.8	
SVGSL	L_{gate} dependence of SVGS	$m^{SV\ GSLP}$			0	
SVGSLP	L_{gate} dependence of SVGS	—			1.0	
SVGSW	W_{gate} dependence of SVGS	$m^{SV\ GSWP}$			0	
SVGSWP	W_{gate} dependence of SVGS	—			1.0	

Subthreshold Swing

Parameter	Description	Units	Min	Max	Default	Remarks
*PTHROU	correction for subthreshold swing	—	0	50m	0	

Impact-ionization Induced Bulk Potential Change

Parameter	Description	Units	Min	Max	Default	Remarks
IBPC1	impact-ionization induced bulk potential change	VA^{-1}	0	1.0×10^{12}	0	
IBPC2	impact-ionization induced bulk potential change	V^{-1}	0	1.0×10^{12}	0	

Gate Leakage Current

Parameter	Description	Units	Min	Max	Default	Remarks
GLEAK1	gate to channel current coefficient	$AV^{-3/2}\ C^{-1}$			50	
GLEAK2	gate to channel current coefficient	$V^{-1/2}\ m^{-1}$			10M	
GLEAK3	gate to channel current coefficient	—			60×10^{-3}	
GLEAK4	gate to channel current coefficient	m^{-1}			4.0	
*GLEAK5	gate to channel current coefficient (short channel correction)	$V\ m^{-1}$			7.5×10^{3}	
*GLEAK6	gate to channel current coefficient (V_{ds} dependence correction)	V			250×10^{-3}	
*GLEAK7	gate to channel current coefficient (gate length and width dependence correction)	m^{2}			1×10^{-6}	
*EGIG	temperature dependence of gate leakage	V			0.0	
*IGTEMP2	temperature dependence of gate leakage	V K			0	
*IGTEMP3	temperature dependence of gate leakage	$V\ K^{2}$			0	
GLKSD1	gate to source/drain current coefficient	$A\ m\ V^{-2}$			1f	
GLKSD2	gate to source/drain current coefficient	$V^{-1}\ m^{-1}$			5M	
GLKSD3	gate to source/drain current coefficient	m^{-1}			-5M	
GLKB1	gate to bulk current coefficient	$A\ V^{-2}$			5×10^{-16}	
GLKB2	gate to bulk current coefficient	$m\ V^{-1}$			1.0	
*GLKB3	flat-bans shift for gate to bulk current	V			0	
GLPART1	partitioning ratio of gate leakage current	—	0	1.0	0.5	
FN1	coefficient of Fowler-Nordheim-current contribution	$V^{-1.5}$ - m^{2}			50	
FN2	coefficient of Fowler-Nordheim-current contribution	$V^{-0.5}$ - m^{-1}			170×10^{-6}	
FN3	coefficient of Fowler-Nordheim-current contribution	V			0	
FVBS	V_{bs} dependence of Fowler-Nordheim current	—			12×10^{-3}	

GIDL Current

Parameter	Description	Units	Min	Max	Default	Remarks
GIDL1	magnitude of GIDL	$A\ V^{-3/2}\ C^{-1}\ m$			2.0	
GIDL2	field dependence of GIDL	$V^{-2}\ m^{-1}\ F^{-3/2}$			3×10^{7}	
GIDL3	V_{ds} dependence of GIDL	—			0.9	
*GIDL4	threshold of V_{ds} dependence	V			0	
*GIDL5	correction of high-field contribution	—			0.2	

Conservation of the Symmetry at Vds = 0 for Short-Channel MOSFETs

Parameter	Description	Units	Min	Max	Default	Remarks
VZADD0	symmetry conservation coefficient	V			10m	fixed
PZADD0	symmetry conservation coefficient	V			5m	fixed

Smoothing coefficient between linear and saturation region

Parameter	Description	Units	Min	Max	Default	Remarks
*DDLTMAX	smoothing coefficient for V_{ds}		0	20	10	
*DDLTSLP	L_{gate} dependence of smoothing coefficient		0	20	0	
*DDLTICT	L_{gate} dependence of smoothing coefficient		-3	20	10	

Source/Bulk and Drain/Bulk Diodes

Parameter	Description	Units	Min	Max	Default	Remarks
JS0	saturation current density	A m^{-2}			0.5×10^{-6}	
JS0SW	sidewall saturation current density	A m^{-1}			0	
NJ	emission coefficient	—			1.0	
NJSW	sidewall emission coefficient	—			1.0	
XTI	temperature coefficient for forward current densities	—			2.0	
XTI2	temperature coefficient for reverse current densities	—			0	
DIVX	reverse current coefficient	V^{-1}			0	
CTEMP	temperature coefficient of reverse currents	—			0	
CISB	reverse biased saturation current	—			0	
CISBK	reverse biased saturation current (at low temperature)	A			0	
CVB	bias dependence coefficient of CISB	—			0	
CVBK	bias dependence coefficient of CISB (at low temperature)	—			0	
CJ	bottom junction capacitance per unit area at zero bias	F m^{-2}			5×10^{-4}	
CJSW	source/drain sidewall junction cap. grading coefficient per unit length at zero bias	F m^{-1}			5×10^{-10}	
CJSWG	source/drain sidewall junction capacitance per unit length at zero bias	F m^{-1}			5×10^{-10}	
MJ	bottom junction capacitance grading coefficient	—			0.5	
MJSW	source/drain sidewall junction capacitance grading coefficient	—			0.33	
MJSWG	source/drain gate sidewall junction capacitance grading coefficient	—			0.33	
PB	bottom junction build-in potential	V			1.0	
PBSW	source/drain sidewall junction build-in potential	V			1.0	
PBSWG	source/drain gate sidewall junction build-in potential	V			1.0	
VDIFFJ	diode threshold voltage between source/drain and substrate	V			0.6×10^{-3}	

1/f Noise

Parameter	Description	Units	Min	Max	Default	Remarks
NFALP	contribution of the mobility fluctuation	cm s			1×10^{-19}	
NFTRP	ratio of trap density to attenuation coefficient	V^{-1} cm^{-2}			10G	
*CIT	capacitance caused by the interface trapped carriers	F cm^{-2}			0	

DFM Support

Parameter	Description	Units	Min	Max	Default	Remarks
MPHDFM	mobility dependence on NSUBC due to $_{\text{phonon}}$		-3	3	-0.3	

Non-Quasi-Static Model

Parameter	Description	Units	Min	Max	Default	Remarks
DLY1	coefficient for delay due to diffusion of carriers	s			100×10^{-12}	
DLY2	coefficient for delay due to conduction of carriers	—			0.7	
DLY3	coefficient for RC delay of bulk carriers	Ω			0.8×10^{-6}	

Capacitance

Parameter	Description	Units	Min	Max	Default	Remarks
XQY	distance from drain junction to maximum electric field point	m	0	50n	0	
*XQY1	V_{bs} dependence of Q_y	F-μm XQY2-1	0		0	
*XQY2	L_{gate} dependence of Q_y	–	0		2	
LOVER	overlap length	m			30n	
NOVER	impurity concentration in overlap region	cm^{-3}			0	
VFBOVER	flat-band voltage in overlap region	V			-0.5	
OVSLP	coefficient for overlap capacitance	—			2.1×10^{-7}	
OVMAG	coefficient for overlap capacitance	V			0.6	
CGSO	gate-to-source overlap capacitance	Fm^{-1}	0	100nm × C_{ox}		to be set by user
CGDO	gate-to-drain overlap capacitance	Fm^{-1}	0	100nm × C_{ox}		to be set by user
CGBO	gate-to-bulk overlap capacitance	Fm^{-1}	0		0	

Parasitic Resistances

Parameter	Description	Units	Min	Max	Default	Remarks
RS	source-contact resistance in LDD region	Ωm	0	10m	0	
RD	drain-contact resistance in LDD region	Ωm	0	10m	0	
RSH	source/drain sheet resistance	$V A^{-1}$ square	0	1m	0	
RSHG	gate sheet resistance	$V A^{-1}$ square	0	100µ	0	
GBMIN	substrate resistance network	—			1×10^{-12}	requested by circuit sim.
RBPB	substrate resistance network	Ω			50	treated also as an instance p.
RBPD	substrate resistance network	Ω			50	treated also as an instance p.
RBPS	substrate resistance network	Ω			50	treated also as an instance p.
RBDB	substrate resistance network	Ω			50	treated also as an instance p.
RBSB	substrate resistance network	Ω			50	treated also as an instance p.

Binning Model

Parameter	Description	Units	Min	Max	Default	Remarks
LBINN	power of L_{drawn} dependence	–			1	
WBINN	power of W_{drawn} dependence	–			1	
LMAX	maximum length of L_{drawn} valid	µm				
LMIN	minimum length of L_{drawn} valid	µm				
WMAX	maximum length of W_{drawn} valid	µm				
WMIN	minimum length of W_{drawn} valid	µm				

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelName hisim2 version=241 [parm=value]*
```

Example:
model Nch7 hisim2 Gender=1 Version=241 Tox=2.15e-9

Instance Parameters

Partly the same instance-parameter names and their definitions as in the BSIM3/4 models are adopted for the convenience of HiSIM users.

The maximum and minimum limits of the instance parameters are recommended values. These values may be violated in individual cases.

Name	**Description**	**Units**	**Min**	**Max**	**Default**	**Remarks**
L	gate length (L_{gate})	m			5μ	
W	gate width (W_{gate})	m			5μ	
Diode						
AD	area of drain junction	m^2			0	
AS	area of source junction	m^2			0	
PD	perimeter of drain junction	m			0	
PS	perimeter of source junction	m			0	
Source/Drain Resistance						
NRS	number of source squares	m			1	
NRD	number of drain squares	m			1	
Gate Resistance						
XGW	distance from the gate contact to the channel edge	m			0	
XGL	offset of the gate length	m			0	
NF	number of gate fingers	—			1	
M	multiplication factor					
NGCON	number of gate contacts	m			1	
Substrate Network						
RBPB	substrate resistance network	Ω			50	treated also as a model parameter
RBPD	substrate resistance network	Ω			50	treated also as a model parameter
RBPS	substrate resistance network	Ω			50	treated also as a model parameter
RBDB	substrate resistance network	Ω			50	treated also as a model parameter
RBSB	substrate resistance network	Ω			50	treated also as a model parameter
Length of Diffusion						
SA	length of diffusion between gate and STI	m			0	
SB	length of diffusion between gate and STI	m			0	
SD	length of diffusion between gate and gate	m			0	
Temperature						
TEMP	device temperature (T)	°C			27	
DTEMP	device temperature change	°C			0	
Design for Manufacturability						
NSUBCDFM	substrate impurity concentration	cm^{-3}	1.0×10^{16}	1.0×10^{19}		

Instance Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
modelName [:Name] d g s b
```

Example:

```
Nch7:M1 2 1 0 0 W=10u L=0.9u
```

Notes/Equations

1. To exclude specific modeled effects, following parameter settings should be chosen:

Short-Channel Effect	SC1 = SC2 = SC3 = 0
Reverse-Short-Channel Effect	LP = 0
Quantum-Mechanical Effect	QME1 = QME3 = 0
Poly-Depletion Effect	PGD1 = PGD2 = PGD3 = 0
Channel-Length Modulation	CLM1 = CLM2 = CLM3 = 0
Narrow-Channel Effect	WFC = MUEPHW = WL1 = 0
Small-Size Effect	WL2 = 0

Following flags are prepared to select required model options.

2. Contact resistances R_s and R_d are included:

   CORSRD = 0: no (default)
   CORSRD = 1 & RS/RD ≠ 0: yes, as internal resistances of HiSIM
   CORSRD = 2 & RD ≠ 0: yes, simple analytical formulation
   CORSRD = -1 & RS/RD ≠ 0: yes, as external resistances of HiSIM
3. Overlap capacitance model is selected as:

   COOVLP = 0: constant overlap capacitance (default)
   either given LOVER plus CGS0/CGD0 or LOVER only
   COOVLP = 1: yes
   selecting a model either by defining NOVER value or not
4. Substrate current I_{sub} is calculated:

   COISUB = 0: no (default)
   COISUB = 1: yes
5. Gate current I_{gate} is calculated:

   COIIGS = 0: no (default)
   COIIGS = 1: yes
6. GIDL current I_{GIDL} is calculated:

   COGIDL = 0: no (default)
   COGIDL = 1: yes
7. STI leakage current $I_{ds,STI}$ is calculated:

   COISTI = 0: no (default)
   COISTI = 1: yes
8. Lateral field induced and overlap charges/capacitances are added to intrinsic ones:

   COADOV = 0: no

COADOV = 1: yes (default)

9. Non-quasi-static mode is invoked:

    CONQS = 0: no (default)
    CONQS = 1: yes
10. Gate-contact resistance is included (This flag can also be given as a instance parameter.):

    CORG = 0: no (default)
    CORG = 1: yes
11. Substrate resistance network is invoked (This flag can also be given as a instance parameter.):

    CORBNET = 0: no (default)
    CORBNET = 1: yes
12. 1/f noise is calculated:

    COFLICK = 0: no (default)
    COFLICK = 1: yes
13. Thermal noise is calculated:

    COTHRML = 0: no (default)
    COTHRML = 1: yes
14. Induced gate and cross correlation noise are calculated:

    COIGN = 0 || COTHRML = 0: no (default)
    COIGN = 1 & COTHRML = 1: yes
15. Previous Ids is used for calculating source/drain resistance effect (R_s and/or $R_d \neq 0$):

    COIPRV = 0: no
    COIPRV = 1: yes (default)
16. Previous Φ_S is used for the iteration:

    COPPRV = 0: no
    COPPRV = 1: yes (default)
17. Parameter variations for the DFM support is considered:

    CODFM = 0: no (default)
    CODFM = 1: yes

HiSIM_HV (HiSIM_HV version 1.11 MOSFET Model and Instance)

Note
For detailed information please refer to the HiSIM_HV manual provided by the Hiroshima university.

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelName HiSIM_HV [parm=value]*
```

Example:

```
model Nch HiSIM_HV Tox=2.15e-9
```

Model Parameters

Name (Alias)	Description
Gender	+1=N-type, -1=P-type
Tnom	Parameter measurement temperature
Secured	Secured model parameters
Info	Information level (for debug, etc.)
Noise	Noise model selector
Version	Model version
Show	Show physical value
Corsrd	Handling of Rs and Rd
Corg	Activate gate resistance (1) or not (0)
Coiprv	Use ids_prv as initial guess of Ids (internal flag)
Copprv	Use ps{0/l}_prv as initial guess of Ps{0/l} (internal flag)
Coadov	Add overlap to intrisic
Coisub	Calculate isub
Coiigs	Calculate igate
Cogidl	Calculate igidl
Coovlp	Calculate overlap charge on the drain side
Coovlps	Calculate overlap charge on the source side
Coflick	Calculate 1/f noise
Coisti	Calculate STI
Conqs	Calculate in nqs mode or qs mode
Corbnet	
Cothrml	Calculate thermal noise
Coign	Calculate induced gate noise
Codfm	Calculation of model for DFM
Coselfheat	Calculation of self heating model
Cosym	Model selector for symmetry device
Vbsmin	Minimum back bias voltage to be treated in hsmhveval [V]

Vmax	Saturation velocity [cm/s]
Bgtmp1	First order temp. coeff. for band gap [V/K]
Bgtmp2	Second order temp. coeff. for band gap [V/K^2]
Eg0	
Tox	Oxide thickness [m]
Xld	Lateral diffusion of S/D under the gate [m]
Xldld	Lateral diffusion of Drain under the gate [m]
Lover	Overlap length on source side [m], alias for lovers
Lovers	Overlap length on source side [m]
Rdov11	Dependence coeff. for overlap length
Rdov12	Dependence coeff. for overlap length
Rdov13	Dependence coeff. for overlap length
Rdslp1	LDRIFT1 dependence of resistance for CORSRD=1,3
Rdict1	LDRIFT1 dependence of resistance for CORSRD=1,3
Rdslp2	LDRIFT2 dependence of resistance for CORSRD=1,3
Rdict2	LDRIFT2 dependence of resistance for CORSRD=1,3
Loverld	Overlap length on the drain side
Ldrift1	Drift region length-1 on the drain side[m]
Ldrift2	Drift region length-2 on the drain side[m]
Ldrift1s	Drift region length-1 on the source side[m]
Ldrift2s	Drift region length-2 on the source side[m]
Subld1	Impact-ionization current in the drift region [-]
Subld2	Impact-ionization current in the drift region [m^{-1}*V^{3/2}]
Ddltmax	
Ddltslp	
Ddltict	
Vfbover	
Nover	
Novers	
Xwd	Lateral diffusion along the width dir. [m]
Xl	Gate length offset due to mask/etch effect [m]
Xw	Gate width offset due to mask/etch effect [m]
Saref	Reference distance from STI edge to Gate edge [m]
Sbref	Reference distance from STI edge to Gate edge [m]
Ll	Gate length parameter
Lld	Gate length parameter
Lln	Gate length parameter
Wl	Gate width parameter
Wl1	Gate width parameter
Wl1p	Gate width parameter
Wl2	Gate width parameter
Wl2p	Gate width parameter
Wld	Gate width parameter
Wln	Gate width parameter
Xqy	[m]
Xqy1	[F m^{XQY2}]
Xqy2	[-]

Rs	Source contact resistance [ohm m]
Rd	Drain contact resistance [ohm m]
Rsh	Source/drain diffusion sheet resistance [ohm]
Rshg	Gate-elecrode sheet resistance
Vfbc	Constant part of Vfb [V]
Vbi	Built-in potential [V]
Nsubc	Constant part of Nsub [1/cm^3]
Parl2	Under diffusion [m]
Lp	Length of pocket potential [m]
Nsubp	[1/cm^3]
Nsubp0	Pocket implant parameter
Nsubwp	Pocket implant parameter
Scp1	Parameter for pocket [-]
Scp2	Parameter for pocket [1/V]
Scp3	Parameter for pocket [m/V]
Sc1	Parameter for SCE [-]
Sc2	Parameter for SCE [1/V]
Sc3	Parameter for SCE [m/V]
Sc4	Parameter for SCE [1/V]
Pgd1	Parameter for gate-poly depletion [V]
Pgd2	Parameter for gate-poly depletion [V]
Pgd3	Parameter for gate-poly depletion [-]
Pgd4	Parameter for gate-poly depletion [-]
Ndep	Coeff. of Qbm for Eeff [-]
Ndepl	Coeff. of Qbm for Eeff [-]
Ndeplp	Coeff. of Qbm for Eeff [-]
Ninv	Coeff. of Qnm for Eeff [-]
Ninvd	Modification of Vdse dependence on Eeff [1/V]
Muecb0	Const. part of coulomb scattering [cm^2/Vs]
Muecb1	Coeff. for coulomb scattering [cm^2/Vs]
Mueph0	Power of Eeff for phonon scattering [-]
Mueph1	
Muephw	
Muepwp	Phonon scattering parameter
Muephl	Phonon scattering parameter
Mueplp	Phonon scattering parameter
Muephs	
Muepsp	
Vtmp	
Wvth0	
Muesr0	Power of Eeff for S.R. scattering [-]
Muesr1	Coeff. for S.R. scattering [-]
Muesrl	Surface roughness parameter
Muesrw	Change of surface roughness related mobility
Mueswp	Change of surface roughness related mobility
Mueslp	Surface roughness parameter
Muetmp	Parameter for mobility [-]

Bb	Empirical mobility model coefficient [-]
Sub1	Parameter for Isub [1/V]
Sub2	Parameter for Isub [V]
Svgs	Coefficient for Vg of Psislsat
Svbs	Coefficient for Vbs of Psislsat
Svbsl	
Svds	
Slg	
Sub1l	
Sub2l	
Fn1	
Fn2	
Fn3	
Fvbs	
Svgsl	
Svgslp	
Svgswp	
Svgsw	
Svbslp	
Slgl	
Slglp	
Sub1lp	
Nsti	Parameter for STI [1/cm^3]
Wsti	Parameter for STI [m]
Wstil	Parameter for STI [?]
Wstilp	Parameter for STI [?]
Wstiw	Parameter for STI [?]
Wstiwp	Parameter for STI [?]
Scsti1	Parameter for STI [-]
Scsti2	Parameter for STI [1/V]
Vthsti	Parameter for STI
Vdsti	Parameter for STI [-]
Muesti1	STI Stress mobility parameter
Muesti2	STI Stress mobility parameter
Muesti3	STI Stress mobility parameter
Nsubpsti1	STI Stress pocket implant parameter
Nsubpsti2	STI Stress pocket implant parameter
Nsubpsti3	STI Stress pocket implant parameter
Lpext	Pocket extension
Npext	Pocket extension
Scp22	
Scp21	
Bs1	
Bs2	
Cgso	G-S overlap capacitance per unit W [F/m]
Cgdo	G-D overlap capacitance per unit W [F/m]
Cgbo	G-B overlap capacitance per unit L [F/m]

Tpoly	Height of poly gate on the source side[m]
Js0	Saturation current density [A/m^2]
Js0sw	Side wall saturation current density [A/m]
Nj	Emission coefficient [-]
Njsw	Sidewall emission coefficient
Xti	Junction current temperature exponent coefficient [-]
Cj	Bottom junction capacitance per unit area at zero bias [F/m^2]
Cjsw	Source/drain sidewall junction capacitance grading coefficient per unit length at zero bias [F/m]
Cjswg	Source/drain gate sidewall junction capacitance per unit length at zero bias [F/m]
Mj	Bottom junction capacitance grading coefficient
Mjsw	Source/drain sidewall junction capacitance grading coefficient
Mjswg	Source/drain gate sidewall junction capacitance grading coefficient
Pb	Bottom junction build-in potential [V]
Pbsw	Source/drain sidewall junction build-in potential [V]
Pbswg	Source/drain gate sidewall junction build-in potential [V]
Xti2	Temperature coefficient [-]
Cisb	Reverse bias saturation current [-]
Cvb	Bias dependence coefficient of cisb [-]
Ctemp	Temperature coefficient [-]
Cisbk	Reverse bias saturation current [A]
Cvbk	Bias dependence coefficient of cisb [-]
Divx	[1/V]
Clm1	Parameter for CLM [-]
Clm2	Parameter for CLM [1/m]
Clm3	Parameter for CLM [-]
Clm5	Parameter for CLM [-]
Clm6	Parameter for CLM [um^{-clm5}]
Vover	Parameter for overshoot [m^{voverp}]
Voverp	Parameter for overshoot [-]
Vovers	Parameter for overshoot [-]
Voversp	Parameter for overshoot [-]
Wfc	Parameter for narrow channel effect [m*F/(cm^2)]
Nsubcw	Parameter for narrow channel effect
Nsubcwp	Parameter for narrow channel effect
Qme1	Parameter for quantum effect [mV]
Qme2	Parameter for quantum effect [V]
Qme3	Parameter for quantum effect [m]
Gidl1	Parameter for GIDL [?]
Gidl2	Parameter for GIDL [?]
Gidl3	Parameter for GIDL [?]
Gidl4	Parameter for GIDL [?]
Gidl5	Parameter for GIDL [?]
Glpart1	Parameter for gate current [-]
Gleak1	Parameter for gate current [A*V^(-3/2)/C]
Gleak2	Parameter for gate current [V^(-1/2)/m]
Gleak3	Parameter for gate current [-]

Gleak4	Parameter for gate current [1/m]
Gleak5	Parameter for gate current [V/m]
Gleak6	Parameter for gate current [V]
Gleak7	Parameter for gate current [m^2]
Glksd1	Parameter for gate current [A*m/V^2]
Glksd2	Parameter for gate current [1/(V*m)]
Glksd3	Parameter for gate current [1/m]
Glkb1	Parameter for gate current [A/V^2]
Glkb2	Parameter for gate current [m/V]
Glkb3	Parameter for gate current [V]
Egig	Parameter for gate current [V]
Igtemp2	Parameter for gate current [V*k]
Igtemp3	Parameter for gate current [V*k^2]
Vzadd0	Vzadd at Vds=0 [V]
Pzadd0	Pzadd at Vds=0 [V]
Nftrp	
Nfalp	
Cit	
Falph	Parameter for 1/f noise
Kappa	Dielectric constant for high-k stacked gate
Pthrou	Modify subthreshold slope [-]
Vdiffj	Threshold voltage for S/D junction diode [V]
Dly1	Parameter for transit time [-]
Dly2	Parameter for transit time [-]
Dly3	Parameter for transforming bulk charge [s/F]
Dlyov	Parameter for transforming overlap charge [s/F]
Ovslp	
Ovmag	
Gbmin	
Rbpb	
Rbpd	
Rbps	
Rbdb	
Rbsb	
Ibpc1	Parameter for impact-ionization induced bulk potential change
Ibpc2	Parameter for impact-ionization induced bulk potential change
Mphdfm	NSUBCDFM dependence of phonon scattering for DFM
Rdvg11	
Rdvg12	
Rth0	Thermal resistance
Cth0	Thermal capacitance
Powrat	
Tcjbd	Temperature dependence of cjbd
Tcjbs	Temperature dependence of cjbs
Tcjbdsw	Temperature dependence of cjbdsw
Tcjbssw	Temperature dependence of cjbssw
Tcjbdswg	Temperature dependence of cjbdswg

Tcjbsswg	Temperature dependence of cjbsswg
Qdftvd	Qdrift Vd dependence
Rdvd	
Rdvb	
Rd20	
Rd21	
Rd22	
Rd22d	
Rd23	
Rd24	
Rd25	
Rd26	Alias for qovsm
Rdvdl	
Rdvdlp	
Rdvds	
Rdvdsp	
Rd23l	
Rd23lp	
Rd23s	
Rd23sp	
Rds	
Rdsp	
Qovsm	Smoothing Qover at depletion/inversion transition
Ldrift	Alias for ldrift2
Rdtemp1	Temperature-dependence of Rd
Rdtemp2	Temperature-dependence of Rd
Rth0r	Heat radiation for SHE
Rdvdtemp1	Temperature-dependence of RDVD
Rdvdtemp2	Temperature-dependence of RDVD
Rth0w	Width-dependence of RTH0
Rth0wp	Width-dependence of RTH0
Rth0nf	nf-dependence of RTH0
Cvdsover	vds drop along the overlap
Lmin	Minimum length for the model
Lmax	Maximum length for the model
Wmin	Minimum width for the model
Wmax	Maximum width for the model
Lbinn	L modulation coefficient for binning
Wbinn	W modulation coefficient for binning
Lvmax	Length dependence of vmax
Lbgtmp1	Length dependence of bgtmp1
Lbgtmp2	Length dependence of bgtmp2
Leg0	Length dependence of eg0
Lvfbover	Length dependence of vfbover
Lnover	Length dependence of nover
Lnovers	Length dependence of nover on source size
Lwl2	Length dependence of wl2

Lvfbc	Length dependence of vfbc
Lnsubc	Length dependence of nsubc
Lnsubp	Length dependence of nsubp
Lscp1	Length dependence of scp1
Lscp2	Length dependence of scp2
Lscp3	Length dependence of scp3
Lsc1	Length dependence of sc1
Lsc2	Length dependence of sc2
Lsc3	Length dependence of sc3
Lpgd1	Length dependence of pgd1
Lpgd3	Length dependence of pgd3
Lndep	Length dependence of ndep
Lninv	Length dependence of ninv
Lmuecb0	Length dependence of muecb0
Lmuecb1	Length dependence of muecb1
Lmueph1	Length dependence of mueph1
Lvtmp	Length dependence of vtmp
Lwvth0	Length dependence of wvth0
Lmuesr1	Length dependence of muesr1
Lmuetmp	Length dependence of muetmp
Lsub1	Length dependence of sub1
Lsub2	Length dependence of sub2
Lsvds	Length dependence of svds
Lsvbs	Length dependence of svbs
Lsvgs	Length dependence of svgs
Lfn1	Length dependence of fn1
Lfn2	Length dependence of fn2
Lfn3	Length dependence of fn3
Lfvbs	Length dependence of fvbs
Lnsti	Length dependence of nsti
Lwsti	Length dependence of wsti
Lscsti1	Length dependence of scsti1
Lscsti2	Length dependence of scsti2
Lvthsti	Length dependence of vthsti
Lmuesti1	Length dependence of muesti1
Lmuesti2	Length dependence of muesti2
Lmuesti3	Length dependence of muesti3
Lnsubpsti1	Length dependence of nsubpsti1
Lnsubpsti2	Length dependence of nsubpsti2
Lnsubpsti3	Length dependence of nsubpsti3
Lcgso	Length dependence of cgso
Lcgdo	Length dependence of cgdo
Ljs0	Length dependence of js0
Ljs0sw	Length dependence of js0sw
Lnj	Length dependence of nj
Lcisbk	Length dependence of cisbk
Lclm1	Length dependence of clm1

Lclm2	Length dependence of clm2
Lclm3	Length dependence of clm3
Lwfc	Length dependence of wfc
Lgidl1	Length dependence of gidl1
Lgidl2	Length dependence of gidl2
Lgleak1	Length dependence of gleak1
Lgleak2	Length dependence of gleak2
Lgleak3	Length dependence of gleak3
Lgleak6	Length dependence of gleak6
Lglksd1	Length dependence of glksd1
Lglksd2	Length dependence of glksd2
Lglkb1	Length dependence of glkb1
Lglkb2	Length dependence of glkb2
Lnftrp	Length dependence of nftrp
Lnfalp	Length dependence of nfalp
Lpthrou	Length dependence of pthrou
Lvdiffj	Length dependence of vdiffj
Libpc1	Length dependence of ibpc1
Libpc2	Length dependence of ibpc2
Wvmax	Width dependence of vmax
Wbgtmp1	Width dependence of bgtmp1
Wbgtmp2	Width dependence of bgtmp2
Weg0	Width dependence of eg0
Wvfbover	Width dependence of vfbover
Wnover	Width dependence of nover
Wnovers	Width dependence of novers on source size
Wwl2	Width dependence of wl2
Wvfbc	Width dependence of vfbc
Wnsubc	Width dependence of nsubc
Wnsubp	Width dependence of nsubp
Wscp1	Width dependence of scp1
Wscp2	Width dependence of scp2
Wscp3	Width dependence of scp3
Wsc1	Width dependence of sc1
Wsc2	Width dependence of sc2
Wsc3	Width dependence of sc3
Wpgd1	Width dependence of pgd1
Wpgd3	Width dependence of pgd3
Wndep	Width dependence of ndep
Wninv	Width dependence of ninv
Wmuecb0	Width dependence of muecb0
Wmuecb1	Width dependence of muecb1
Wmueph1	Width dependence of mueph1
Wvtmp	Width dependence of vtmp
Wwvth0	Width dependence of wvth0
Wmuesr1	Width dependence of muesr1
Wmuetmp	Width dependence of muetmp

Wsub1	Width dependence of sub1
Wsub2	Width dependence of sub2
Wsvds	Width dependence of svds
Wsvbs	Width dependence of svbs
Wsvgs	Width dependence of svgs
Wfn1	Width dependence of fn1
Wfn2	Width dependence of fn2
Wfn3	Width dependence of fn3
Wfvbs	Width dependence of fvbs
Wnsti	Width dependence of nsti
Wwsti	Width dependence of wsti
Wscsti1	Width dependence of scsti1
Wscsti2	Width dependence of scsti2
Wvthsti	Width dependence of vthsti
Wmuesti1	Width dependence of muesti1
Wmuesti2	Width dependence of muesti2
Wmuesti3	Width dependence of muesti3
Wnsubpsti1	Width dependence of nsubpsti1
Wnsubpsti2	Width dependence of nsubpsti2
Wnsubpsti3	Width dependence of nsubpsti3
Wcgso	Width dependence of cgso
Wcgdo	Width dependence of cgdo
Wjs0	Width dependence of js0
Wjs0sw	Width dependence of js0sw
Wnj	Width dependence of nj
Wcisbk	Width dependence of cisbk
Wclm1	Width dependence of clm1
Wclm2	Width dependence of clm2
Wclm3	Width dependence of clm3
Wwfc	Width dependence of wfc
Wgidl1	Width dependence of gidl1
Wgidl2	Width dependence of gidl2
Wgleak1	Width dependence of gleak1
Wgleak2	Width dependence of gleak2
Wgleak3	Width dependence of gleak3
Wgleak6	Width dependence of gleak6
Wglksd1	Width dependence of glksd1
Wglksd2	Width dependence of glksd2
Wglkb1	Width dependence of glkb1
Wglkb2	Width dependence of glkb2
Wnftrp	Width dependence of nftrp
Wnfalp	Width dependence of nfalp
Wpthrou	Width dependence of pthrou
Wvdiffj	Width dependence of vdiffj
Wibpc1	Width dependence of ibpc1
Wibpc2	Width dependence of ibpc2
Pvmax	Cross-term dependence of vmax

Pbgtmp1	Cross-term dependence of bgtmp1
Pbgtmp2	Cross-term dependence of bgtmp2
Peg0	Cross-term dependence of eg0
Pvfbover	Cross-term dependence of vfbover
Pnover	Cross-term dependence of nover
Pnovers	Cross-term dependence of nover on source size
Pwl2	Cross-term dependence of wl2
Pvfbc	Cross-term dependence of vfbc
Pnsubc	Cross-term dependence of nsubc
Pnsubp	Cross-term dependence of nsubp
Pscp1	Cross-term dependence of scp1
Pscp2	Cross-term dependence of scp2
Pscp3	Cross-term dependence of scp3
Psc1	Cross-term dependence of sc1
Psc2	Cross-term dependence of sc2
Psc3	Cross-term dependence of sc3
Ppgd1	Cross-term dependence of pgd1
Ppgd3	Cross-term dependence of pgd3
Pndep	Cross-term dependence of ndep
Pninv	Cross-term dependence of ninv
Pmuecb0	Cross-term dependence of muecb0
Pmuecb1	Cross-term dependence of muecb1
Pmueph1	Cross-term dependence of mueph1
Pvtmp	Cross-term dependence of vtmp
Pwvth0	Cross-term dependence of wvth0
Pmuesr1	Cross-term dependence of muesr1
Pmuetmp	Cross-term dependence of muetmp
Psub1	Cross-term dependence of sub1
Psub2	Cross-term dependence of sub2
Psvds	Cross-term dependence of svds
Psvbs	Cross-term dependence of svbs
Psvgs	Cross-term dependence of svgs
Pfn1	Cross-term dependence of fn1
Pfn2	Cross-term dependence of fn2
Pfn3	Cross-term dependence of fn3
Pfvbs	Cross-term dependence of fvbs
Pnsti	Cross-term dependence of nsti
Pwsti	Cross-term dependence of wsti
Pscsti1	Cross-term dependence of scsti1
Pscsti2	Cross-term dependence of scsti2
Pvthsti	Cross-term dependence of vthsti
Pmuesti1	Cross-term dependence of muesti1
Pmuesti2	Cross-term dependence of muesti2
Pmuesti3	Cross-term dependence of muesti3
Pnsubpsti1	Cross-term dependence of nsubpsti1
Pnsubpsti2	Cross-term dependence of nsubpsti2
Pnsubpsti3	Cross-term dependence of nsubpsti3

Pcgso	Cross-term dependence of cgso
Pcgdo	Cross-term dependence of cgdo
Pjs0	Cross-term dependence of js0
Pjs0sw	Cross-term dependence of js0sw
Pnj	Cross-term dependence of nj
Pcisbk	Cross-term dependence of cisbk
Pclm1	Cross-term dependence of clm1
Pclm2	Cross-term dependence of clm2
Pclm3	Cross-term dependence of clm3
Pwfc	Cross-term dependence of wfc
Pgidl1	Cross-term dependence of gidl1
Pgidl2	Cross-term dependence of gidl2
Pgleak1	Cross-term dependence of gleak1
Pgleak2	Cross-term dependence of gleak2
Pgleak3	Cross-term dependence of gleak3
Pgleak6	Cross-term dependence of gleak6
Pglksd1	Cross-term dependence of glksd1
Pglksd2	Cross-term dependence of glksd2
Pglkb1	Cross-term dependence of glkb1
Pglkb2	Cross-term dependence of glkb2
Pnftrp	Cross-term dependence of nftrp
Pnfalp	Cross-term dependence of nfalp
Ppthrou	Cross-term dependence of pthrou
Pvdiffj	Cross-term dependence of vdiffj
Pibpc1	Cross-term dependence of ibpc1
Pibpc2	Cross-term dependence of ibpc2

Instance Netlist Format

modelName [:Name] d g s b

Example

Nch7:M1 2 1 0 0 W=10u L=0.9u

Instance Parameters

Name (Alias)	Description
Temp	Device operating temperature
Trise (Dtemp)	Temperature rise over ambient
Mode	Nonlinear spectral model on/off
Noise	Noise generation on/off
L	Length
W	Width
Ad	Drain area
As	Source area
Pd	Drain perimeter
Ps	Source perimeter
Nrd	Number of squares in drain
Nrs	Number of squares in source
Off	Device is initially off
Corbnet	Activate body resistance (1) or not (0)
Rbpb	
Rbpd	
Rbps	
Rbdb	
Rbsb	
Corg	Activate gate resistance (1) or not (0)
Ngcon	Number of gate contacts
Xgw	Distance from gate contact to channel edge
Xgl	Offset of gate length due to variation in patterning
Nf	Number of fingers
Sa	Distance from STI edge to Gate edge [m]
Sb	Distance from STI edge to Gate edge \m]
Sd	Distance from Gate edge to Gate edge \m]
Nsubcdfm	Constant part of Nsub for DFM \1/cm^3]
M	Multiplication factor [-]
Subld1	Parameter for impact-ionization current in the drift region [-]
Subld2	Parameter for impact-ionization current in the drift region [m^{-1}*V^{3/2}]
Lover	Overlap length on source side [m]
Lovers	Overlap length on source side [m]
Loverld	Overlap length on drain side [m]
Ldrift1	Parameter for drift region length-1 [m]
Ldrift2	Parameter for drift region length-2 [m]
Ldrift1s	Parameter for drift region length-1 on souce side[m]
Ldrift2s	Parameter for drift region length-2 on souce side[m]
m	Multiplicity

DC Operating Point Information

Name	Description	Units
Vds	Vds	V
Vgs	Vgs	V
Vbs	Vbs	V
Ids	Ids	A
Isub	Isub	A
Igidl	Igidl	A
Igisl	Igisl	A
Igd	Igd	A
Igs	Igs	A
Igb	Igb	A
Ibs	Ibs	A
Ibd	Ibd	A
Gm	dIds_dVgsi	S
Gmt	dIds_dTi	S
Gds	dIds_dVdsi	S
Gmbs	dIds_dVbsi	S
Gbd	Gbd	S
Gbd	Gbs	S
Q	Qb	C
Qg	Qg	C
Qd	Qd	C
Cgg	Cgg	F
Cgd	Cgd	F
Cgs	Cgs	F
Cdg	Cdg	F
Cdd	Cdd	F
Cds	Cds	F
Cbg	Cbg	F
Cbdb	Cbdb	F
Csbs	Csbs	F
Cgdo	Cgdo	F
Cgso	Cgso	F
Cgbo	Cgbo	F
CAPBD	CAPBD	F
CAPBS	CAPBS	F
Von	Von	V
VDSAT	VDSAT	V
Qbs	Qbs	C
Qbd	Qbd	C
m	multiplicity	

HiSIM_HV_1_2 (HiSIM_HV Version 1.2 Model and Instance)

Note
For detailed information please refer to the HiSIM_HV manual provided by the Hiroshima university.

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to Design Kit Development.

```
model modelName HiSIM_HV [parm=value]*
```

Example:

model Nch HiSIM_HV_1_2 Tox=2.15e-9

Model Parameters

Name (Alias)	**Description**
Gender	+1=N-type, -1=P-type
Tnom	Parameter measurement temperature
Secured	Secured model parameters
Info	Information level (for debug, etc.)
Noise	Noise model selector
Version	Model version
Show	Show physical value
Corsrd	Handling of Rs and Rd
Corg	Activate gate resistance (1) or not (0)
Coiprv	Use ids_prv as initial guess of Ids (internal flag)
Copprv	Use ps{0/l}_prv as initial guess of Ps{0/l} (internal flag)
Coadov	Add overlap to intrisic
Coisub	Calculate isub
Coiigs	Calculate igate
Cogidl	Calculate igidl
Coovlp	Calculate overlap charge on the drain side
Coovlps	Calculate overlap charge on the source side
Coflick	Calculate 1/f noise
Coisti	Calculate STI
Conqs	Calculate in nqs mode or qs mode
Corbnet	
Cothrml	Calculate thermal noise
Coign	Calculate induced gate noise
Codfm	Calculation of model for DFM
Coselfheat	Calculation of self heating model
Cosym	Model selector for symmetry device
Vbsmin	Minimum back bias voltage to be treated in hsmhveval [V]
Vmax	Saturation velocity [cm/s]

Bgtmp1	First order temp. coeff. for band gap [V/K]
Bgtmp2	Second order temp. coeff. for band gap [V/K^2]
Eg0	
Tox	Oxide thickness [m]
Xld	Lateral diffusion of S/D under the gate [m]
Xldld	Lateral diffusion of Drain under the gate [m]
Lover	Overlap length on source side [m], alias for lovers
Lovers	Overlap length on source side [m]
Rdov11	Dependence coeff. for overlap length
Rdov12	Dependence coeff. for overlap length
Rdov13	Dependence coeff. for overlap length
Rdslp1	LDRIFT1 dependence of resistance for CORSRD=1,3
Rdict1	LDRIFT1 dependence of resistance for CORSRD=1,3
Rdslp2	LDRIFT2 dependence of resistance for CORSRD=1,3
Rdict2	LDRIFT2 dependence of resistance for CORSRD=1,3
Loverld	Overlap length on the drain side
Ldrift1	Drift region length-1 on the drain side[m]
Ldrift2	Drift region length-2 on the drain side[m]
Ldrift1s	Drift region length-1 on the source side[m]
Ldrift2s	Drift region length-2 on the source side[m]
Subld1	Impact-ionization current in the drift region [-]
Subld2	Impact-ionization current in the drift region [m^{-1}*V^{3/2}]
Ddltmax	
Ddltslp	
Ddltict	
Vfbover	
Nover	
Novers	
Xwd	Lateral diffusion along the width dir. [m]
Xl	Gate length offset due to mask/etch effect [m]
Xw	Gate width offset due to mask/etch effect [m]
Saref	Reference distance from STI edge to Gate edge [m]
Sbref	Reference distance from STI edge to Gate edge [m]
Ll	Gate length parameter
Lld	Gate length parameter
Lln	Gate length parameter
Wl	Gate width parameter
Wl1	Gate width parameter
Wl1p	Gate width parameter
Wl2	Gate width parameter
Wl2p	Gate width parameter
Wld	Gate width parameter
Wln	Gate width parameter
Xqy	[m]
Xqy1	[F m^{XQY2}]
Xqy2	[-]
Rs	Source contact resistance [ohm m]

Rd	Drain contact resistance [ohm m]
Rsh	Source/drain diffusion sheet resistance [ohm]
Rshg	Gate-elecrode sheet resistance
Vfbc	Constant part of Vfb [V]
Vbi	Built-in potential [V]
Nsubc	Constant part of Nsub [1/cm^3]
Parl2	Under diffusion [m]
Lp	Length of pocket potential [m]
Nsubp	[1/cm^3]
Nsubp0	Pocket implant parameter
Nsubwp	Pocket implant parameter
Scp1	Parameter for pocket [-]
Scp2	Parameter for pocket [1/V]
Scp3	Parameter for pocket [m/V]
Sc1	Parameter for SCE [-]
Sc2	Parameter for SCE [1/V]
Sc3	Parameter for SCE [m/V]
Sc4	Parameter for SCE [1/V]
Pgd1	Parameter for gate-poly depletion [V]
Pgd2	Parameter for gate-poly depletion [V]
Pgd3	Parameter for gate-poly depletion [-]
Pgd4	Parameter for gate-poly depletion [-]
Ndep	Coeff. of Qbm for Eeff [-]
Ndepl	Coeff. of Qbm for Eeff [-]
Ndeplp	Coeff. of Qbm for Eeff [-]
Ninv	Coeff. of Qnm for Eeff [-]
Ninvd	Modification of Vdse dependence on Eeff [1/V]
Muecb0	Const. part of coulomb scattering [cm^2/Vs]
Muecb1	Coeff. for coulomb scattering [cm^2/Vs]
Mueph0	Power of Eeff for phonon scattering [-]
Mueph1	
Muephw	
Muepwp	Phonon scattering parameter
Muephl	Phonon scattering parameter
Mueplp	Phonon scattering parameter
Muephs	
Muepsp	
Vtmp	
Wvth0	
Muesr0	Power of Eeff for S.R. scattering [-]
Muesr1	Coeff. for S.R. scattering [-]
Muesrl	Surface roughness parameter
Muesrw	Change of surface roughness related mobility
Mueswp	Change of surface roughness related mobility
Mueslp	Surface roughness parameter
Muetmp	Parameter for mobility [-]
Bb	Empirical mobility model coefficient [-]

Sub1	Parameter for Isub [1/V]
Sub2	Parameter for Isub [V]
Svgs	Coefficient for Vg of Psislsat
Svbs	Coefficient for Vbs of Psislsat
Svbsl	
Svds	
Slg	
Sub1l	
Sub2l	
Fn1	
Fn2	
Fn3	
Fvbs	
Svgsl	
Svgslp	
Svgswp	
Svgsw	
Svbslp	
Slgl	
Slglp	
Sub1lp	
Nsti	Parameter for STI [1/cm^3]
Wsti	Parameter for STI [m]
Wstil	Parameter for STI [?]
Wstilp	Parameter for STI [?]
Wstiw	Parameter for STI [?]
Wstiwp	Parameter for STI [?]
Scsti1	Parameter for STI [-]
Scsti2	Parameter for STI [1/V]
Vthsti	Parameter for STI
Vdsti	Parameter for STI [-]
Muesti1	STI Stress mobility parameter
Muesti2	STI Stress mobility parameter
Muesti3	STI Stress mobility parameter
Nsubpsti1	STI Stress pocket implant parameter
Nsubpsti2	STI Stress pocket implant parameter
Nsubpsti3	STI Stress pocket implant parameter
Lpext	Pocket extension
Npext	Pocket extension
Scp22	
Scp21	
Bs1	
Bs2	
Cgso	G-S overlap capacitance per unit W [F/m]
Cgdo	G-D overlap capacitance per unit W [F/m]
Cgbo	G-B overlap capacitance per unit L [F/m]
Tpoly	Height of poly gate on the source side[m]

Js0	Saturation current density [A/m^2]
Js0sw	Side wall saturation current density [A/m]
Nj	Emission coefficient [-]
Njsw	Sidewall emission coefficient
Xti	Junction current temparature exponent coefficient [-]
Cj	Bottom junction capacitance per unit area at zero bias [F/m^2]
Cjsw	Source/drain sidewall junction capacitance grading coefficient per unit length at zero bias [F/m]
Cjswg	Source/drain gate sidewall junction capacitance per unit length at zero bias [F/m]
Mj	Bottom junction capacitance grading coefficient
Mjsw	Source/drain sidewall junction capacitance grading coefficient
Mjswg	Source/drain gate sidewall junction capacitance grading coefficient
Pb	Bottom junction build-in potential [V]
Pbsw	Source/drain sidewall junction build-in potential [V]
Pbswg	Source/drain gate sidewall junction build-in potential [V]
Xti2	Temperature coefficient [-]
Cisb	Reverse bias saturation current [-]
Cvb	Bias dependence coefficient of cisb [-]
Ctemp	Temperature coefficient [-]
Cisbk	Reverse bias saturation current [A]
Cvbk	Bias dependence coefficient of cisb [-]
Divx	[1/V]
Clm1	Parameter for CLM [-]
Clm2	Parameter for CLM [1/m]
Clm3	Parameter for CLM [-]
Clm5	Parameter for CLM [-]
Clm6	Parameter for CLM [um^{-clm5}]
Vover	Parameter for overshoot [m^{voverp}]
Voverp	Parameter for overshoot [-]
Vovers	Parameter for overshoot [-]
Voversp	Parameter for overshoot [-]
Wfc	Parameter for narrow channel effect [m*F/(cm^2)]
Nsubcw	Parameter for narrow channel effect
Nsubcwp	Parameter for narrow channel effect
Qme1	Parameter for quantum effect [mV]
Qme2	Parameter for quantum effect [V]
Qme3	Parameter for quantum effect [m]
Gidl1	Parameter for GIDL [?]
Gidl2	Parameter for GIDL [?]
Gidl3	Parameter for GIDL [?]
Gidl4	Parameter for GIDL [?]
Gidl5	Parameter for GIDL [?]
Glpart1	Parameter for gate current [-]
Gleak1	Parameter for gate current [A*V^(-3/2)/C]
Gleak2	Parameter for gate current [V^(-1/2)/m]
Gleak3	Parameter for gate current [-]
Gleak4	Parameter for gate current [1/m]

Gleak5	Parameter for gate current [V/m]
Gleak6	Parameter for gate current [V]
Gleak7	Parameter for gate current [m^2]
Glksd1	Parameter for gate current [A*m/V^2]
Glksd2	Parameter for gate current [1/(V*m)]
Glksd3	Parameter for gate current [1/m]
Glkb1	Parameter for gate current [A/V^2]
Glkb2	Parameter for gate current [m/V]
Glkb3	Parameter for gate current [V]
Egig	Parameter for gate current [V]
Igtemp2	Parameter for gate current [V*k]
Igtemp3	Parameter for gate current [V*k^2]
Vzadd0	Vzadd at Vds=0 [V]
Pzadd0	Pzadd at Vds=0 [V]
Nftrp	
Nfalp	
Cit	
Falph	Parameter for 1/f noise
Kappa	Dielectric constant for high-k stacked gate
Pthrou	Modify subthreshold slope [-]
Vdiffj	Threshold voltage for S/D junction diode [V]
Dly1	Parameter for transit time [-]
Dly2	Parameter for transit time [-]
Dly3	Parameter for transforming bulk charge [s/F]
Dlyov	Parameter for transforming overlap charge [s/F]
Ovslp	
Ovmag	
Gbmin	
Rbpb	
Rbpd	
Rbps	
Rbdb	
Rbsb	
Ibpc1	Parameter for impact-ionization induced bulk potential change
Ibpc2	Parameter for impact-ionization induced bulk potential change
Mphdfm	NSUBCDFM dependence of phonon scattering for DFM
Rdvg11	
Rdvg12	
Rth0	Thermal resistance
Cth0	Thermal capacitance
Powrat	
Tcjbd	Temperature dependence of cjbd
Tcjbs	Temperature dependence of cjbs
Tcjbdsw	Temperature dependence of cjbdsw
Tcjbssw	Temperature dependence of cjbssw
Tcjbdswg	Temperature dependence of cjbdswg
Tcjbsswg	Temperature dependence of cjbsswg

Qdftvd	Qdrift Vd dependence
Rdvd	
Rdvb	
Rd20	
Rd21	
Rd22	
Rd22d	
Rd23	
Rd24	
Rd25	
Rd26	alias for qovsm
Rdvdl	
Rdvdlp	
Rdvds	
Rdvdsp	
Rd23l	
Rd23lp	
Rd23s	
Rd23sp	
Rds	
Rdsp	
Qovsm	Smoothing Qover at depletion/inversion transition
Ldrift	alias for ldrift2
Rdtemp1	Temperature-dependence of Rd
Rdtemp2	Temperature-dependence of Rd
Rth0r	Heat radiation for SHE
Rdvdtemp1	Temperature-dependence of RDVD
Rdvdtemp2	Temperature-dependence of RDVD
Rth0w	Width-dependence of RTH0
Rth0wp	Width-dependence of RTH0
Rth0nf	nf-dependence of RTH0
Cvdsover	vds drop along the overlap
Lmin	Minimum length for the model
Lmax	Maximum length for the model
Wmin	Minimum width for the model
Wmax	Maximum width for the model
Lbinn	L modulation coefficient for binning
Wbinn	W modulation coefficient for binning
Lvmax	Length dependence of vmax
Lbgtmp1	Length dependence of bgtmp1
Lbgtmp2	Length dependence of bgtmp2
Leg0	Length dependence of eg0
Lvfbover	Length dependence of vfbover
Lnover	Length dependence of nover
Lnovers	Length dependence of nover on source size
Lwl2	Length dependence of wl2
Lvfbc	Length dependence of vfbc

Lnsubc	Length dependence of nsubc
Lnsubp	Length dependence of nsubp
Lscp1	Length dependence of scp1
Lscp2	Length dependence of scp2
Lscp3	Length dependence of scp3
Lsc1	Length dependence of sc1
Lsc2	Length dependence of sc2
Lsc3	Length dependence of sc3
Lpgd1	Length dependence of pgd1
Lpgd3	Length dependence of pgd3
Lndep	Length dependence of ndep
Lninv	Length dependence of ninv
Lmuecb0	Length dependence of muecb0
Lmuecb1	Length dependence of muecb1
Lmueph1	Length dependence of mueph1
Lvtmp	Length dependence of vtmp
Lwvth0	Length dependence of wvth0
Lmuesr1	Length dependence of muesr1
Lmuetmp	Length dependence of muetmp
Lsub1	Length dependence of sub1
Lsub2	Length dependence of sub2
Lsvds	Length dependence of svds
Lsvbs	Length dependence of svbs
Lsvgs	Length dependence of svgs
Lfn1	Length dependence of fn1
Lfn2	Length dependence of fn2
Lfn3	Length dependence of fn3
Lfvbs	Length dependence of fvbs
Lnsti	Length dependence of nsti
Lwsti	Length dependence of wsti
Lscsti1	Length dependence of scsti1
Lscsti2	Length dependence of scsti2
Lvthsti	Length dependence of vthsti
Lmuesti1	Length dependence of muesti1
Lmuesti2	Length dependence of muesti2
Lmuesti3	Length dependence of muesti3
Lnsubpsti1	Length dependence of nsubpsti1
Lnsubpsti2	Length dependence of nsubpsti2
Lnsubpsti3	Length dependence of nsubpsti3
Lcgso	Length dependence of cgso
Lcgdo	Length dependence of cgdo
Ljs0	Length dependence of js0
Ljs0sw	Length dependence of js0sw
Lnj	Length dependence of nj
Lcisbk	Length dependence of cisbk
Lclm1	Length dependence of clm1
Lclm2	Length dependence of clm2

Lclm3	Length dependence of clm3
Lwfc	Length dependence of wfc
Lgidl1	Length dependence of gidl1
Lgidl2	Length dependence of gidl2
Lgleak1	Length dependence of gleak1
Lgleak2	Length dependence of gleak2
Lgleak3	Length dependence of gleak3
Lgleak6	Length dependence of gleak6
Lglksd1	Length dependence of glksd1
Lglksd2	Length dependence of glksd2
Lglkb1	Length dependence of glkb1
Lglkb2	Length dependence of glkb2
Lnftrp	Length dependence of nftrp
Lnfalp	Length dependence of nfalp
Lpthrou	Length dependence of pthrou
Lvdiffj	Length dependence of vdiffj
Libpc1	Length dependence of ibpc1
Libpc2	Length dependence of ibpc2
Wvmax	Width dependence of vmax
Wbgtmp1	Width dependence of bgtmp1
Wbgtmp2	Width dependence of bgtmp2
Weg0	Width dependence of eg0
Wvfbover	Width dependence of vfbover
Wnover	Width dependence of nover
Wnovers	Width dependence of novers on source size
Wwl2	Width dependence of wl2
Wvfbc	Width dependence of vfbc
Wnsubc	Width dependence of nsubc
Wnsubp	Width dependence of nsubp
Wscp1	Width dependence of scp1
Wscp2	Width dependence of scp2
Wscp3	Width dependence of scp3
Wsc1	Width dependence of sc1
Wsc2	Width dependence of sc2
Wsc3	Width dependence of sc3
Wpgd1	Width dependence of pgd1
Wpgd3	Width dependence of pgd3
Wndep	Width dependence of ndep
Wninv	Width dependence of ninv
Wmuecb0	Width dependence of muecb0
Wmuecb1	Width dependence of muecb1
Wmueph1	Width dependence of mueph1
Wvtmp	Width dependence of vtmp
Wwvth0	Width dependence of wvth0
Wmuesr1	Width dependence of muesr1
Wmuetmp	Width dependence of muetmp
Wsub1	Width dependence of sub1

Wsub2	Width dependence of sub2
Wsvds	Width dependence of svds
Wsvbs	Width dependence of svbs
Wsvgs	Width dependence of svgs
Wfn1	Width dependence of fn1
Wfn2	Width dependence of fn2
Wfn3	Width dependence of fn3
Wfvbs	Width dependence of fvbs
Wnsti	Width dependence of nsti
Wwsti	Width dependence of wsti
Wscsti1	Width dependence of scsti1
Wscsti2	Width dependence of scsti2
Wvthsti	Width dependence of vthsti
Wmuesti1	Width dependence of muesti1
Wmuesti2	Width dependence of muesti2
Wmuesti3	Width dependence of muesti3
Wnsubpsti1	Width dependence of nsubpsti1
Wnsubpsti2	Width dependence of nsubpsti2
Wnsubpsti3	Width dependence of nsubpsti3
Wcgso	Width dependence of cgso
Wcgdo	Width dependence of cgdo
Wjs0	Width dependence of js0
Wjs0sw	Width dependence of js0sw
Wnj	Width dependence of nj
Wcisbk	Width dependence of cisbk
Wclm1	Width dependence of clm1
Wclm2	Width dependence of clm2
Wclm3	Width dependence of clm3
Wwfc	Width dependence of wfc
Wgidl1	Width dependence of gidl1
Wgidl2	Width dependence of gidl2
Wgleak1	Width dependence of gleak1
Wgleak2	Width dependence of gleak2
Wgleak3	Width dependence of gleak3
Wgleak6	Width dependence of gleak6
Wglksd1	Width dependence of glksd1
Wglksd2	Width dependence of glksd2
Wglkb1	Width dependence of glkb1
Wglkb2	Width dependence of glkb2
Wnftrp	Width dependence of nftrp
Wnfalp	Width dependence of nfalp
Wpthrou	Width dependence of pthrou
Wvdiffj	Width dependence of vdiffj
Wibpc1	Width dependence of ibpc1
Wibpc2	Width dependence of ibpc2
Pvmax	Cross-term dependence of vmax
Pbgtmp1	Cross-term dependence of bgtmp1

Pbgtmp2	Cross-term dependence of bgtmp2
Peg0	Cross-term dependence of eg0
Pvfbover	Cross-term dependence of vfbover
Pnover	Cross-term dependence of nover
Pnovers	Cross-term dependence of nover on source size
Pwl2	Cross-term dependence of wl2
Pvfbc	Cross-term dependence of vfbc
Pnsubc	Cross-term dependence of nsubc
Pnsubp	Cross-term dependence of nsubp
Pscp1	Cross-term dependence of scp1
Pscp2	Cross-term dependence of scp2
Pscp3	Cross-term dependence of scp3
Psc1	Cross-term dependence of sc1
Psc2	Cross-term dependence of sc2
Psc3	Cross-term dependence of sc3
Ppgd1	Cross-term dependence of pgd1
Ppgd3	Cross-term dependence of pgd3
Pndep	Cross-term dependence of ndep
Pninv	Cross-term dependence of ninv
Pmuecb0	Cross-term dependence of muecb0
Pmuecb1	Cross-term dependence of muecb1
Pmueph1	Cross-term dependence of mueph1
Pvtmp	Cross-term dependence of vtmp
Pwvth0	Cross-term dependence of wvth0
Pmuesr1	Cross-term dependence of muesr1
Pmuetmp	Cross-term dependence of muetmp
Psub1	Cross-term dependence of sub1
Psub2	Cross-term dependence of sub2
Psvds	Cross-term dependence of svds
Psvbs	Cross-term dependence of svbs
Psvgs	Cross-term dependence of svgs
Pfn1	Cross-term dependence of fn1
Pfn2	Cross-term dependence of fn2
Pfn3	Cross-term dependence of fn3
Pfvbs	Cross-term dependence of fvbs
Pnsti	Cross-term dependence of nsti
Pwsti	Cross-term dependence of wsti
Pscsti1	Cross-term dependence of scsti1
Pscsti2	Cross-term dependence of scsti2
Pvthsti	Cross-term dependence of vthsti
Pmuesti1	Cross-term dependence of muesti1
Pmuesti2	Cross-term dependence of muesti2
Pmuesti3	Cross-term dependence of muesti3
Pnsubpsti1	Cross-term dependence of nsubpsti1
Pnsubpsti2	Cross-term dependence of nsubpsti2
Pnsubpsti3	Cross-term dependence of nsubpsti3
Pcgso	Cross-term dependence of cgso

Pcgdo	Cross-term dependence of cgdo
Pjs0	Cross-term dependence of js0
Pjs0sw	Cross-term dependence of js0sw
Pnj	Cross-term dependence of nj
Pcisbk	Cross-term dependence of cisbk
Pclm1	Cross-term dependence of clm1
Pclm2	Cross-term dependence of clm2
Pclm3	Cross-term dependence of clm3
Pwfc	Cross-term dependence of wfc
Pgidl1	Cross-term dependence of gidl1
Pgidl2	Cross-term dependence of gidl2
Pgleak1	Cross-term dependence of gleak1
Pgleak2	Cross-term dependence of gleak2
Pgleak3	Cross-term dependence of gleak3
Pgleak6	Cross-term dependence of gleak6
Pglksd1	Cross-term dependence of glksd1
Pglksd2	Cross-term dependence of glksd2
Pglkb1	Cross-term dependence of glkb1
Pglkb2	Cross-term dependence of glkb2
Pnftrp	Cross-term dependence of nftrp
Pnfalp	Cross-term dependence of nfalp
Ppthrou	Cross-term dependence of pthrou
Pvdiffj	Cross-term dependence of vdiffj
Pibpc1	Cross-term dependence of ibpc1
Pibpc2	Cross-term dependence of ibpc2
Cosubnode (Cotemp)	Switch tempNode to subNode
Coldrift	selector for Ldrift parameter
Vmaxt1	Saturation velocity coeff. [-]
Vmaxt2	Saturation velocity coeff. [-]
Xwdld	Xwdld
Xwdc	Lateral diffusion along the width dir. for capacitance [m]
Ninvdw	Coeff of modification of Vdse dependence on Eeff [-]
Ninvdwp	Coeff of modification of Vdse dependence on Eeff [-]
Ninvdt1	Coeff of modification of Vdse dependence on Eeff [-]
Ninvdt2	Coeff of modification of Vdse dependence on Eeff [-]
Rthtemp1	Thermal Resistance
Rthtemp2	Thermal Resistance
Prattemp1	Prattemp1
Prattemp2	Prattemp2
Rdvsub	model parameter for the substrate effect
Rdvdsub	model parameter for the substrate effect
Ddrift	model parameter for the substrate effect
Vbisub	model parameter for the substrate effect
Nsubsub	model parameter for the substrate effect
Lcgbo	Length dependence of cgbo
Lcvdsover	Length dependence of cvdsover

Lfalph	Length dependence of falph
Lnpext	Length dependence of npext
Lpowrat	Length dependence of powrat
Lrd	Length dependence of rd
Lrd22	Length dependence of rd22
Lrd23	Length dependence of rd23
Lrd24	Length dependence of rd24
Lrdict1	Length dependence of rdict1
Lrdov13	Length dependence of rdov13
Lrdslp1	Length dependence of rdslp1
Lrdvb	Length dependence of rdvb
Lrdvd	Length dependence of rdvd
Lrdvg11	Length dependence of rdvg11
Lrs	Length dependence of rs
Lrth0	Length dependence of rth0
Lvover	Length dependence of vover
Wcgbo	Width dependence of cgbo
Wcvdsover	Width dependence of cvdsover
Wfalph	Width dependence of falph
Wnpext	Width dependence of npext
Wpowrat	Width dependence of powrat
Wrd	Width dependence of rd
Wrd22	Width dependence of rd22v
Wrd23	Width dependence of rd23
Wrd24	Width dependence of rd24
Wrdict1	Width dependence of rdict1
Wrdov13	Width dependence of rdov13
Wrdslp1	Width dependence of rdslp1
Wrdvb	Width dependence of rdvb
Wrdvd	Width dependence of rdvd
Wrdvg11	Width dependence of rdvg11
Wrs	Width dependence of rs
Wrth0	Width dependence of rth0
Wvover	Width dependence of vover
Pcgbo	Cross-term dependence of cgbo
Pcvdsover	Cross-term dependence of cvdsover
Pfalph	Cross-term dependence of falph
Pnpext	Cross-term dependence of npext
Ppowrat	Cross-term dependence of powrat
Prd	Cross-term dependence of rd
Prd22	Cross-term dependence of rd22
Prd23	Cross-term dependence of rd23
Prd24	Cross-term dependence of rd24
Prdict1	Cross-term dependence of rdict1
Prdov13	Cross-term dependence of rdov13
Prdslp1	Cross-term dependence of rdslp1
Prdvb	Cross-term dependence of rdvb

Prdvd	Cross-term dependence of rdvd
Prdvg11	Cross-term dependence of rdvg11
Prs	Cross-term dependence of rs
Prth0	Cross-term dependence of rth0
Pvover	Cross-term dependence of vover
Vgs_max	Maximum gate to source voltage (TSMC SOA warning)
Vgd_max	Maximum gate to drain voltage (TSMC SOA warning)
Vds_max	Maximum drain to source voltage (TSMC SOA warning)
Vbd_max	Maximum bulk to drain voltage (TSMC SOA warning)

Instance Netlist Format

```
modelName [:Name] d g s b
```

Example

```
Nch7:M1 2 1 0 0 W=10u L=0.9u
```

Instance Parameters

Name (Alias)	Description
Temp	Device operating temperature
Trise (Dtemp)	Temperature rise over ambient
Mode	Nonlinear spectral model on/off
Noise	Noise generation on/off
L	Length
W	Width
Ad	Drain area
As	Source area
Pd	Drain perimeter
Ps	Source perimeter
Nrd	Number of squares in drain
Nrs	Number of squares in source
Off	Device is initially off
Corbnet	Activate body resistance (1) or not (0)
Rbpb	
Rbpd	
Rbps	
Rbdb	
Rbsb	
Corg	Activate gate resistance (1) or not (0)
Ngcon	Number of gate contacts
Xgw	Distance from gate contact to channel edge
Xgl	Offset of gate length due to variation in patterning
Nf	Number of fingers
Sa	Distance from STI edge to Gate edge [m]
Sb	Distance from STI edge to Gate edge [m]
Sd	Distance from Gate edge to Gate edge [m]
Nsubcdfm	Constant part of Nsub for DFM [1/cm^3]
M	Multiplication factor [-]

Subld1	Parameter for impact-ionization current in the drift region [-]
Subld2	Parameter for impact-ionization current in the drift region [m^{-1}*V^{3/2}]
Lover	Overlap length on source side [m]
Lovers	Overlap length on source side [m]
Loverld	Overlap length on drain side [m]
Ldrift1	Parameter for drift region length-1 [m]
Ldrift2	Parameter for drift region length-2 [m]
Ldrift1s	Parameter for drift region length-1 on source side[m]
Ldrift2s	Parameter for drift region length-2 on source side[m]
Coselfheat	Calculation of self heating model
Cosubnode	Switch tempNode to subNode
Vds	Vds
Vgs	Vgs
Vbs	Vbs
Ids	Ids
Isub	Isub
Igidl	Igidl
Igisl	Igisl
Igd	Igd
Igs	Igs
Igb	Igb
Ibs	Ibs
Ibd	Ibd
Gm	dIds_dVgsi
Gmt	dIds_dTi
Gds	dIds_dVdsi
Gmbs	dIds_dVbsi
Gbd	Gbd
Gbd	Gbs
Qb	Qb
Qg	Qg
Qd	Qd
Cgg	Cgg
Cgd	Cgd
Cgs	Cgs
Cdg	Cdg
Cdd	Cdd
Cds	Cds
Cbg	Cbg
Cbdb	Cbdb
Csbs	Csbs
Cgdo	Cgdo
Cgso	Cgso
Cgbo	Cgbo
CAPBD	CAPBD
CAPBS	CAPBS
Von	Von

VDSAT	VDSAT
Qbs	Qbs
Qbd	Qbd
m	multiplicity

DC Operating Point Information

Name	Description	Units
Vds	Vds	V
Vgs	Vgs	V
Vbs	Vbs	V
Ids	Ids	A
Isub	Isub	A
Igidl	Igidl	A
Igisl	Igisl	A
Igd	Igd	A
Igs	Igs	A
Igb	Igb	A
Ibs	Ibs	A
Ibd	Ibd	A
Gm	dIds_dVgsi	S
Gmt	dIds_dTi	S
Gds	dIds_dVdsi	S
Gmbs	dIds_dVbsi	S
Gbd	Gbd	S
Gbd	Gbs	S
Qb	Qb	C
Qg	Qg	C
Qd	Qd	C
Cgg	Cgg	F
Cgd	Cgd	F
Cgs	Cgs	F
Cdg	Cdg	F
Cdd	Cdd	F
Cds	Cds	F
Cbg	Cbg	F
Cbdb	Cbdb	F
Csbs	Csbs	F
Cgdo	Cgdo	F
Cgso	Cgso	F
Cgbo	Cgbo	F
CAPBD	CAPBD	F
CAPBS	CAPBS	F
Von	Von	V
VDSAT	VDSAT	V
Qbs	Qbs	C
Qbd	Qbd	C
m	multiplicity	

hisim (HiSIM MOSFET Model and Instance)

Model Parameters

Name	Description	Units	Default
Version	model version		231
Gender	transistor type: 1 (N-type) and -1 (P-type)		1
Tox	physical oxide thickness	m	3n
Xld	gate-overlap length	m	0
Xwd	gate-overlap width	m	0
Tpoly	height of the gate poly-Si for fringing capacitance	m	200×10^{-9}
Ll	coefficient of gate length modification		0
Lld	coefficient of gate length modification	m	0
Lln	coefficient of gate length modification		0
Wl	coefficient of gate width modification		0
Wld	coefficient of gate width modification	m	0
Wln	coefficient of gate width modification		0
Nsubc	substrate-impurity concentration	cm^{-3}	5×10^{17}
Nsubp	maximum pocket concentration	cm^{-3}	1×10^{18}
Lp	pocket penetration length	m	15n
Npext	maximum concentration of pocket tail	cm^{-3}	5×10^{17}
Lpext	extension length of pocket tail	m	1×10^{-50}
Vfbc	flat-band voltage	V	-1.0
Vbi	built-in potential	V	1.0
Kappa	dielectric constant for gate dielectric	—	3.9
Eg0	bandgap	eV	1.1785
Bgtmp1	temperature dependence of bandgap	$eV\ K^{-1}$	90.25µ
Bgtmp2	temperature dependence of bandgap	$eV\ K^{-2}$	0.1µ
Tnom	temperature selected as a nominal temperature value	°C	27
Vmax	saturation velocity	$cm\ s^{-1}$	10MEG
Vover	velocity overshoot effect	cm^{Voverp}	0.3
Voverp	L_{eff} dependence of velocity overshoot	—	0.3
Vtmp	temperature dependence of the saturation velocity	$cm\ s^{-1}$	0
Qme1	V_{gs} dependence of quantum mechanical effect	$V^{-2}\ m$	0
Qme2	V_{gs} dependence of quantum mechanical effect	V	1.0
Qme3	minimum T_{ox} modification	m	0
Pgd1	strength of poly-depletion effect	V	1.0e-4
Pgd2	threshold voltage of poly-depletion effect	V	1.0
Pgd3	V_{ds} dependence of poly-depletion effect	—	0.8
Pgd4	L_{gate} dependence of poly-depletion effect	—	0

Parl2	depletion width of channel/contact junction	m	10n
Sc1	magnitude of short-channel effect	—	1.0
Sc2	V_{bs} dependence of short-channel effect	V^{-1}	1.0
Sc3	V_{bs} dependence of short-channel effect	$V^{-1}m$	0
Scp1	magnitude of short-channel effect due to pocket	—	1.0
Scp2	V_{ds} dependence of short-channel due to pocket	V^{-1}	0.1
Scp3	V_{bs} dependence of short-channel effect due to pocket	$V^{-1}m$	0
Scp21	short-channel-effect modification for small V_{ds}	V	0
Scp22	short-channel-effect modification for small V_{ds}	V^4	0
Bs1	body-coeffcient modifcation by impurity profile	V^2	0
Bs2	body-coeffcient modifcation by impurity profile	V	0.9
Muecb0	Coulomb scattering	$cm^2V^{-1}s^{-1}$	1K
Muecb1	Coulomb scattering	$cm^2V^{-1}s^{-1}$	100
Mueph0	phonon scattering	—	0.3
Mueph1	phonon scattering	$cm^2V^{-1}s^{-1}(V\ cm^{-1})^{Mueph0}$	25K(nMOS), 9K(pMOS)
Muetmp	temperature dependence of phonon scattering	—	1.5
Muephl	length dependence of phonon mobility reduction	—	0
Mueplp	length dependence of phonon mobility reduction	—	1.0
Muesr0	surface-roughness scattering	—	2.0
Muesr1	surface-roughness scattering	$cm^2V^{-1}s^{-1}(V\ cm^{-1})^{Muesr0}$	1×10^{15}
Muesrl	length dependence of surface roughness mobility reduction		0
Mueslp	length dependence of surface roughness mobility reduction		1.0
Ndep	depletion charge contribution on effective-electric field	—	1.0
Ninv	inversion charge contribution on effective-electric field	—	0.5
Bb	high-field-mobility degradation	—	2.0(nMOS), 1.0(pMOS)
Wfc	threshold voltage change due to capacitance change	$F\ cm^{-2}m^{-1}$	0
Wvth0	threshold voltage shift		0
Nsubp0	modification of pocket concentration for narrow width	cm^{-3}	0
Nsubwp	modification of pocket concentration for narrow width		1.0
Muephw	phonon related mobility reduction		0
Muepwp	phonon related mobility reduction		1.0
Muesrw	change of surface roughness related mobility		0
Mueswp	change of surface roughness related mobility		1.0
Vthst1	threshold voltage shift due to Sti		0
Scsti1	the same effect as Sc1 but at Sti edge		0
Scsti2	the same effect as Sc2 but at Sti edge		0
Scsti3	the same effect as Sc3 but at Sti edge		0
Nsti	substrate-impurity concentration at the Sti edge	cm^{-3}	1×10^{17}
Wsti	width of the high-field region at Sti edge	m	0
Wstil	channel-length dependence of Wsti		0
Wstilp	channel-length dependence of Wsti		1.0

Wl1	threshold volatge shift of Sti leakage due to small size effect		0
Wl2	threshold volatge shift of Sti leakage due to small size effect		1.0
Nsubpsti1	pocket concentration change due to diffusion-region length between gate and Sti	m	0
Nsubpsti2	pocket concentration change due to diffusion-region length between gate and Sti	m	0
Nsubpsti3	pocket concentration change due to diffusion-region length between gate and Sti	m	1.0
Muesti1	mobility change due to diffusion-region length between gate and Sti		0
Muesti2	mobility change due to diffusion-region length between gate and Sti		0
Muesti3	mobility change due to diffusion-region length between gate and Sti		1.0
Wl2	threshold volatge shift due to small size effect		0
Wl2p	threshold volatge shift due to small size effect		1.0
Muephs	mobility modification due to small size		0
Muepsp	mobility modification due to small size		1.0
Vovers	modification of maximum velocity due to small size	—	0
Voversp	modification of maximum velocity due to small size	—	0
Clm1	hardness coeffcient of channel/contact junction	—	0.7
Clm2	coeffcient for Q_B contribution	—	2.0
Clm3	coeffcient for Q_I contribution	—	1.0
Clm4	smoothing coeffcient for g_{ds}	V	500×10^{-6}
Clm5	effect of pocket implantation	—	1.0
Clm6	effect of pocket implantation	—	0
Sub1	substrate current coeffcient of magnitude	V^{-1}	10
Sub1l	L_{gate} dependence Sub1	m	2.5×10^{-3}
Sub1lp	L_{gate} dependence Sub1	—	1.0
Sub2	substrate current coeffcient of exponential term	V	25.0
Sub2l	L_{gate} dependence of Sub2	m	2×10^{-6}
Svds	substrate current dependence on V_{ds}	—	0.8
Slg	substrate current dependence on L_{gate}	m	3×10^{-8}
Slgl	substrate current dependence on L_{gate}	m^{Slglp}	0
Slglp	substrate current dependence on L_{gate}	—	1.0
Svbs	substrate current dependence on V_{bs}	—	0.5
Svbsl	L_{gate} dependence of Svbs	m^{Svbslp}	0
Svbslp	L_{gate} dependence of Svbs	—	1.0
Svgs	substrate current dependence on V_{gs}	—	0.8
Svgsl	L_{gate} dependence of Svgs	m^{Svgslp}	0
Svgslp	L_{gate} dependence of Svgs	—	1.0

Svgsw	W_{gate} dependence of Svgs	m^{Svgswp}	0
Svgswp	W_{gate} dependence of Svgs	—	1.0
Ibpc1	impact-ionization induced bulk potential change	$V\ A^{-1}$	0
Ibpc2	impact-ionization induced bulk potential change	V^{-1}	0
Gleak1	gate to channel current coefficient	$A\ V^{-3/2}\ C^{-1}$	50
Gleak2	gate to channel current coefficient	$V^{-1/2}\ m^{-1}$	10MEG
Gleak3	gate to channel current coefficient	—	60×10^{-3}
Gleak4	gate to channel current coefficient	m^{-1}	4.0
Gleak5	gate to channel current coefficient (short channel correction)	$V\ m^{-1}$	7.5×10^{3}
Gleak6	gate to channel current coefficient (V_{ds} dependence correction)	V	250×10^{-3}
Gleak7	gate to channel current coefficient (gate length and width dependence correction)	m^{2}	1×10^{-6}
Igtemp1	temperature dependence of gate leakage	V	0
Igtemp2	temperature dependence of gate leakage	VK	0
Igtemp3	temperature dependence of gate leakage	VK^{2}	0
Glksd1	gate to source/drain current coefficient	AmV^{-2}	1f
Glksd2	gate to source/drain current coefficient	$V^{-1}\ m^{-1}$	5MEG
Glksd3	gate to source/drain current coefficient	m^{-1}	-5MEG
Glkb1	gate to bulk current coefficient	$A\ V^{-2}$	5×10^{-16}
Glkb2	gate to bulk current coefficient	$M\ V^{-1}$	1.0
Glpart1	partitioning ratio of gate leakage current	—	0.5
Fn1	coefficient of Fowler-Nordheim current contribution	$V^{-1.5}\times m^{2}$	50
Fn2	coefficient of Fowler-Nordheim current contribution	$V^{-0.5}\times m^{-1}$	170×10^{-6}
Fn3	coefficient of Fowler-Nordheim current contribution	V	0
Fvbs	V_{bs} dependence of Fowler-Nordheim current	—	12×10^{-3}
Gidl1	magnitude of Gidl	$A\ V^{-3/2}\ C^{-1}\ m$	2.0
Gidl2	Field dependence of Gidl	$V^{-2}\ m^{-1}\ F^{-3/2}$	3×10^{7}
Gidl3	V_{ds} dependence of Gidl	—	0.9
Gidl4	threshold of V_{ds} dependence	V	0.9
Gidl5	correction of high-field contribution	—	0.2
Vzadd0	symmetry conservation coefficient	V	10m
Pzadd0	symmetry conservation coefficient	V	5m
Js0	saturation current density	$A\ m^{-2}$	0.5×10^{-6}
Js0sw	sidewall saturation current density	$A\ m^{-2}$	0
Nj	emission coefficient	—	1.0
Njsw	sidewall emission coefficient	—	1.0
Xti	temperature coefficient for forward current densities	—	2.0
Xti2	temperature coefficient for reverse current densities	—	0
Divx	reverse current coefficient	V^{-1}	0
Ctemp	temperature coefficient of reverse currents	—	0
Cisb	reverse biased saturation current	—	0

Cisbk	reverse biased saturation current (at low temperature)	A	0
Cvb	bias dependence coefficient of Cisb	—	0
Cvbk	bias dependence coefficient of Cisb (at low temperature)	—	0
Cj	bottom junction capacitance per unit area at zero bias	F m^{-2}	5×10^{-4}
Cjsw	source/drain sidewall junction cap. grading coefficient per unit length at zero bias	F m^{-1}	5×10^{-10}
Cjswg	source/drain sidewall junction capacitance per unit length at zero bias	F m^{-1}	5×10^{-10}
Mj	bottom junction capacitance grading coefficient	—	0.5
Mjsw	source/drain sidewall junction capacitance grading coefficient	—	0.33
Mjswg	source/drain gate sidewall junction capacitance grading coefficient	—	0.33
Pb	bottom junction build-in potential	V	1.0
Pbsw	source/drain sidewall junction build-in potential	V	1.0
Pbswg	source/drain gate sidewall junction build-in potential	V	1.0
Vdiffj	diode threshold voltage between source/drain and substrate	V	0.6×10^{-3}
Nfalp	contribution of the mobility fluctuation	cm s	1×10^{-19}
Nftrp	ratio of trap density to attenuation coefficient	V^{-1} cm^{-2}	10G
Cit	capacitance caused by the interface trapped carriers	F cm^{-2}	0
Pthrou	correction for subthreshold swing	—	0
Dly1	coefficient for delay due to diffusion of carriers	s	100×10^{-12}
Dly2	coefficient for delay due to conduction of carriers	—	0.7
Dly3	coefficient for RC delay of bulk carriers	Ω	0.8×10^{-6}
Xqy	distance from drain junction to maximum electric field point	m	0
Lover	overlap length	m	50n
Ovslp	coefficient for overlap capacitance	—	2.1×10^{-7}
Ovmag	coefficient for overlap capacitance	V	0.6
Cgso	gate-to-source overlap capacitance	F m^{-1}	
Cgdo	gate-to-drain overlap capacitance	F m^{-1}	
Cgbo	gate-to-bulk overlap capacitance	F m^{-1}	0
Rs	source-contact resistance in Ldd region	V A^{-1m}	0
Rd	drain-contact resistance in Ldd region	V A^{-1m}	0
Rsh	source/drain sheet resistance	V $A^{-1square}$	0
Rshg	gate sheet resistance	V $A^{-1square}$	0
Gbmin	substrate resistance network	—	1×10^{-12}
Rbpb	substrate resistance network	Ω	50
Rbpd	substrate resistance network	Ω	50
Rbps	substrate resistance network	Ω	50
Rbdb	substrate resistance network	Ω	50
Rbsb	substrate resistance network	Ω	50

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelName hisim [parm=value]*
```

The model statement starts with the required keyword model. It is followed by the modelName that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is hisim. Use the parameter gender to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch7 hisim Gender=1 Version=231 Tox=2.15e-9
```

Instance Parameters

Name	Description	Units	Default
L	gate length (L_{gate})	m	5µ
W	gate width (W_{gate})	m	5µ
Ad	area of drain junction	m^2	0
As	area of source junction	m^2	0
Pd	perimeter of drain junction	m	0
Ps	perimeter of source junction	m	0
Nrs	number of source squares	m	1
Nrd	number of drain squares	m	1
Xgw	distance from the gate contact to the channel edge	m	0
Xgl	offset of the gate length	m	0
Nf	number of gate fingers	m	1
Ngcon	number of gate contacts	m	1
Corg	gate-contact resistance included		0
Lod	length of diffusion between gate and STI	m	10µ
Temp	device temperature (T)	°C	27
Trise	temperature rise over ambient	°C	0
Corbnet	substrate resistance network invoked		0
Rbpb	substrate resistance network	Ω	50
Rbpd	substrate resistance network	Ω	50
Rbps	substrate resistance network	Ω	50
Rbdb	substrate resistance network	Ω	50
Rbsb	substrate resistance network	Ω	50

Instance Netlist Format

```
modelName:instanceName D G S B [parm=value]
```

where D is the drain node, G is the gate node, S is the source node, B is the body (substrate) node.

Example:

```
Nch7:M1 2 1 0 0 W=10u L=0.9u
```

Notes/Equations

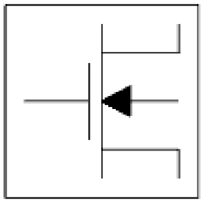
1. HiSIM model is developed jointly by Hiroshima University and STARC, Copyright 2006. Complete HiSIM user's documentation can be requested from STARC.
2. This hisim model is based on SPICE source code of HiSIM version 2.3.1 provided by STARC. Only version 2.3.1 is available. The Non-Quasi-Static mode is not implemented currently. HiSIM2 source code, and all copyrights, trade secrets or other intellectual property rights in and to the source code in its entirety, is owned by Hiroshima University and STARC.
3. The following table lists the DC operating point parameters that can be sent to the dataset:

DC Operating Point Parameters

Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Body current	A
Power	Total dissipated power	W
Vds	External drain-source voltage	V
Vgs	External gate-source voltage	V
Vbs	External body-source voltage	V
Ids	Internal drain-source current	A
Ibd	Internal body-drain diode current	A
Ibs	Internal body-source diode current	A
Isub	Internal substrate current	A
Igidl	Internal Gate-Induced Drain Leakage current	A
Igs	Internal gate-source current	A
Igd	Internal gate-drain current	A
Igb	Internal gate-body current	A
Vdsat	Drain-source saturation voltage	V
Vth	Threshold voltage	V
Qg	Internal gate charge	C
Qb	Internal body charge	C
Qd	Internal drain charge	C
Qs	Internal source charge	C
Gmbs	Body effect transconductance	S
Gm	Forward transconductance	S
Gmids	Gm/Ids	1/V
Gds	Channel conductance	S
Cgg	dQg/dVgb	F
Cgd	dQg/dVdb	F
Cgs	dQg/dVsb	F
Cbg	dQb/dVgb	F
Cbd	dQb/dVdb	F
Cbs	dQb/dVsb	F
Cdg	dQd/dVgb	F
Cdd	dQd/dVdb	F
Cds	dQd/dVsb	F

LEVEL1_Model (MOSFET Level-1 Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	IDS model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	1
Capmod	capacitance model selector: 0=NO CAP 1=CMEYER/WARD 2=SMOOTH 3=QMEYER	None	1
Vto †	zero-bias threshold voltage	V	0.0
Kp †	transconductance coefficient	A/V^2	2.0e-5
Gamma	bulk threshold	$V^{(1/2)}$	0.0
Phi †	surface potential	V	0.6
Lambda	channel-length modulation	1/V	0.0
Rd	Drain Resistance	Ohm	fixed at 0.0
Rs	Source Resistance	Ohm	fixed at 0.0
Cbd †	Bulk-Drain Zero-bias Junction Capacitance	F	0.0
Cbs †	Bulk-Source Zero-bias zero-bias Junction Capacitance	F	0.0
Is †	Gate Saturation Current	A	1.0e-14
Pb †	bulk junction potential	V	0.8
Cgso	gate-source overlap capacitance per meter of channel width	F/m	0.0
Cgdo	gate-drain overlap capacitance per meter of channel width	F/m	0.0
Cgbo	gate-bulk overlap capacitance per meter of channel length	F/m	0.0
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Cj †	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0
Mj	bulk junction bottom grading coefficient	None	0.5
Cjsw †	zero-bias bulk junction periphery capacitance per meter of junction	F/m	0.0

	perimeter		
Mjsw	bulk junction periphery grading coefficient	None	1/3
Js †	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	1.0e-7
Nsub	substrate (bulk) doping density	cm^{-3}	0.0
Nss	surface state density	cm^{-2}	0.0
Tpg	Type of Gate Material: 1=opposite to bulk, 1=same as bulk, 0=aluminum	None	1
Ld	lateral diffusion length	m	0.0
Uo †	surface mobility	cm^2 /(Vs)	600.0
Nlev	noise model level	None	-1
Gdsnoi	drain noise parameters for Nlev=3	None	1
Kf	flicker-noise coefficient	None	0.0
Af	flicker-noise exponent	None	1.0
Fc	bulk junction forward-bias depletion capacitance coefficient	None	0.5
Rg	gate resistance	Ohm	fixed at 0.0
Rds	drain-source shunt resistance	Ohm	fixed at infinity ††
Tnom	Nominal ambient temperature	°C	25
Trise	temperature rise above ambient	°C	0
N	bulk P-N emission coefficient	None	1.0
Tt	bulk P-N transit time		0.0
Ffe (Ef)	flicker noise frequency exponent	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 10)	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	area calculation method	None	0
Hdif	length of heavily doped diffusion (Acm=2, 3 only)	m	0.0
Ldif	length of lightly doped diffusion adjacent to gate (Acm=1, 2 only)	m	0.0
Wmlt	width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	Ohm	0.0
Rsc	additional source resistance due to contact resistance	Ohm	0.0
Wmin	Binning minimum width (parsed but not used, use BinModel)	m	0.0
Wmax	Binning maximum width (parsed but not used, use BinModel)	m	1.0
Lmin	Binning minimum length (parsed but not used, use BinModel)	m	0.0

Lmax	Binning maximum length (parsed but not used, use BinModel)	m	1.0
AllParams	Data Access Component (DAC) Based Parameters	None	None
† Parameter value varies with temperature based on model Tnom and device Temp. †† Value of 0.0 is interpreted as infinity.			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=1 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET*. Idsmod=1 is a required parameter that is used to tell the simulator to use the Spice level 1 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Nch1 MOSFET Idsmod=1 \
 Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

1. The simulator provides three MOSFET device models that differ in formulation of I-V characteristics. MOSFET Level1_Model is Shichman-Hodges model derived from [1].
2. Vto, Kp, Gamma, Phi, and Lambda determine the DC characteristics of a MOSFET device. ADS will calculate these parameters (except Lambda) if instead of specifying them, you specify the process parameters Tox, Uo, Nsub, and Nss.
3. Vto is positive (negative) for enhancement mode and negative (positive) for depletion mode N-channel (P-channel) devices.
4. P-N junctions between the bulk and the drain and the bulk and the source are modeled by parasitic diodes. Each bottom junction is modeled by a diode and each periphery junction is modeled by a depletion capacitance.
5. Diode parameters for the bottom junctions can be specified as absolute values (Is, Cbd and Cbs) or as per unit junction area values (Js and Cj).
   If Cbd = 0.0 and Cbs = 0.0, then Cbd and Cbs will be calculated:

   Cbd = Cj Ad, Cbs = Cj As

   If Js > 0.0 and Ad > 0.0 and As > 0.0, then Is for drain and source will be calculated:

Is(drain) = Js Ad, Is(source) = Js As

6. Drain and source ohmic resistances can be specified as absolute values (Rd, Rs) or as per unit square value (Rsh).
   If Nrd 0.0 or Nrs 0.0, Rd and Rs will be calculated:
   Rd = Rsh Nrd, Rs = Rsh Nrs
7. Charge storage in the MOSFET consists of capacitances associated with parasitics and intrinsic device.
   Parasitic capacitances consist of three constant overlap capacitances (Cgdo, Cgso, Cgbo) and the depletion layer capacitances for both substrate junctions (divided into bottom and periphery), that vary as Mj and Mjsw power of junction voltage, respectively, and are determined by the parameters Cbd, Cbs, Cj, Cjsw, Mj, Mjsw, Pb and Fc.
   The intrinsic capacitances consist of the nonlinear thin-oxide capacitance, which is distributed among the gate, drain, source, and bulk regions.
8. Charge storage is modeled by fixed and nonlinear gate and junction capacitances. MOS gate capacitances, as a nonlinear function of terminal voltages, are modeled by Meyer's piece-wise linear model for levels 1, 2, and 3. The Ward charge conservation model is also available for levels 2 and 3, by specifying the XQC parameter to a value smaller than or equal to 0.5. For Level 1, the model parameter TOX must be specified to invoke the Meyer model when Capmod is equal to 1 (default value). If Capmod = 0, no gate capacitances will be calculated. If Capmod = 2, a smooth version of the Meyer model is used. If Capmod =3, the charge conserving first-order MOS charge model [2] that was used in Libra is used.
9. To include the thin-oxide charge storage effect, model parameter Tox must be > 0.0.
10. Imax and Imelt Parameters
    Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
    If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
    If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
11. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The depletion capacitances Cbd, Cbs, Cj, and Cjsw vary as:

$$Cbd^{NEW} = Cbd\left[\frac{1 + Mj[4\times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cbs^{NEW} = Cbs\left[\frac{1 + Mj[4\times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cj^{NEW} = Cj\left[\frac{1 + Mj[4\times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cjsw^{NEW} = Cjsw\left[\frac{1 + Mjsw[4\times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mjsw[4\times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.

The surface potential Phi and the bulk junction potential Pb vary as:

$$Phi^{NEW} = \frac{Temp}{Tnom}\times Phi + \frac{2k\times Temp}{q}1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

$$Pb^{NEW} = \frac{Temp}{Tnom}\times Pb + \frac{2k\times Temp}{q}1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

The transconductance Kp and mobility Uo vary as:

$$Kp^{NEW} = Kp\left(\frac{Temp}{Tnom}\right)^{3/2}$$

$$Uo^{NEW} = Uo\left(\frac{Temp}{Tnom}\right)^{3/2}$$

The source and drain to substrate leakage currents Is and Js vary as:

$$Is^{NEW} = Is\times exp\left(\frac{q\times E_G^{Tnom}}{k\times Tnom} - \frac{q\times E_G^{Temp}}{k\times Temp}\right)$$

$$Js^{NEW} = Js\times exp\left(\frac{q\times E_G^{Tnom}}{k\times Tnom} - \frac{q\times E_G^{Temp}}{k\times Temp}\right)$$

where E_G is the silicon bandgap energy as a function of temperature.

The MOSFET threshold voltage variation with temperature is given by:

$$Vto^{NEW} = Vto + \gamma\left(\sqrt{Phi^{NEW}} - \sqrt{Phi}\right) + \frac{Phi^{NEW} - Phi}{2} - \frac{E_G^{Temp} - E_G^{Tnom}}{2}$$

Noise Model

Thermal noise generated by resistor Rg, Rs, Rd, and Rds is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Channel and flicker noise (Kf, Af, Ffe) generated by DC transconductance g_m and current flow from drain to source is characterized by spectral density:

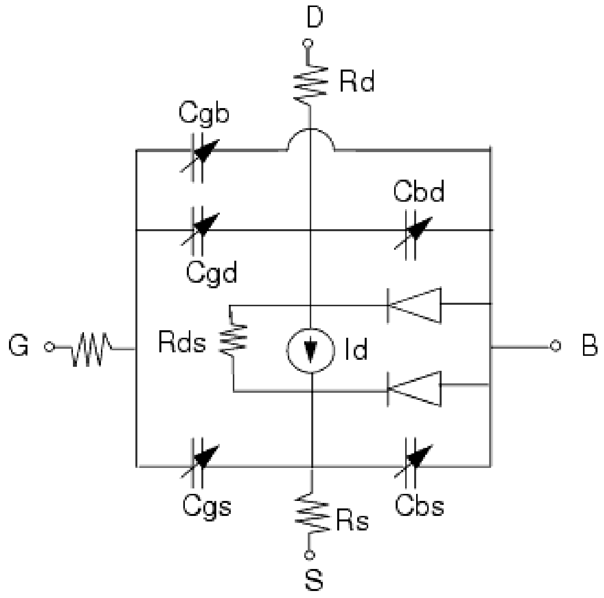
$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3} + k_f \frac{I_{DS}^{a_f}}{f^{f_{fe}}}$$

In the preceding expressions, *k* is Boltzmann's constant, T is operating temperature in Kelvin, *q* is electron charge, *kf* , *a* f, and *f* fe are model parameters, *f* is simulation frequency, and Δ *f* is noise bandwidth.

References

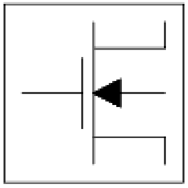
1. H. Shichman and D. A. Hodges. "Modeling and simulation of insulated-gate field-effect transistor switching circuits," *IEEE Journal of Solid-State Circuits,* SC-3, 285, Sept. 1968.
2. Karen A. Sakallah, Yao-tsung Yen, and Steve S. Greenberg. "The Meyer Model Revisited: Explaining and Correcting the Charge Non-Conservation Problem," *ICCAD* , 1987.
3. P. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE* , New York: McGraw-Hill, Second Edition 1993.

Equivalent Circuit


D
Rd
Cgb
Cbd
Cgd
G
Rds
Id
B
Cgs
Rs
Cbs
S

LEVEL2_Model (MOSFET Level-2 Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	IDS model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	2
Capmod	capacitance model selector: 0=NO CAP 1=CMEYER/WARD 2=SMOOTH 3=QMEYER	None	1
Vto †	zero-bias threshold voltage	V	0.0
Kp †	Transconductance	A/V^2	2.0e-5
Gamma	bulk threshold	$V^{(1/2)}$	0.0
Phi †	surface potential	V	0.6
Lambda	channel-length modulation	1/V	0.0
Rd	drain resistance	Ohm	fixed at 0.0
Rs	source resistance	Ohm	fixed at 0.0
Cbd †	bulk-drain zero-bias junction capacitance	F	0.0
Cbs †	bulk-source zero-bias junction capacitance	F	0.0
Is	Gate Saturation Current	A	1.0e-14
Pb †	bulk junction potential	V	0.8
Cgso	gate-source overlap capacitance per meter of channel width	F/m	0.0
Cgdo	gate-drain overlap capacitance per meter of channel width	F/m	0.0
Cgbo	gate-bulk overlap capacitance per meter of channel length	F/m	0.0
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Cj †	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0 ††
Mj	bulk junction bottom grading coefficient	None	0.5
Cjsw †	zero-bias bulk junction periphery capacitance per meter of junction perimeter	F/m	0.0

Mjsw	bulk junction periphery grading coefficient	None	1/3
Js[†]	Gate Saturation Current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	1.0e-7
Nsub	substrate (bulk) doping density	cm^{-3}	0.0
Nss	surface state density	cm^{-2}	0.0
Nfs	fast surface state density	cm^{-2}	0.0
Tpg	Type of Gate Material: 1=opposite to bulk, 1=same as bulk, 0=aluminum	None	1
Xj	metallurgical junction depth	m	0.0
Ld	lateral diffusion length	m	0.0
Uo[†]	surface mobility	cm^2/(V×s)	600.0
Ucrit	critical field for mobility degradation	V/cm	1.0e4
Uexp	critical field exponent in mobility degradation	None	0.0
Vmax	Maximum Drift Velocity of Carriers	m/s	0.0
Neff	total channel charge coefficient	None	1.0
Xqc (Xpart)	fraction of channel charge attributed to drain	None	1.0
Nlev	noise model level	None	-1
Gdsnoi	drain noise parameters for Nlev=3	None	1
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Fc	bulk junction forward-bias depletion capacitance coefficient	None	0.5
Delta	width effect on threshold voltage	None	0.0
Rg	gate ohmic resistance	Ohm	fixed at 0.0
Rds	drain-source shunt resistance	Ohm	fixed at infinity [††]
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0
N	bulk P-N emission coefficient	None	1.0
Tt	bulk P-N transit time		0.0
Ffe (Ef)	flicker noise frequency exponent	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 10)	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	area calculation method	None	0
Hdif	length of heavily doped diffusion (Acm=2, 3 only)	m	0.0
Ldif	length of lightly doped diffusion adjacent to gate (Acm=1, 2 only)	m	0.0

Wmlt	width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	Ohm	0.0
Rsc	additional source resistance due to contact resistance	Ohm	0.0
AllParams	Data Access Component (DAC) Based Parameters	None	None
† Parameter value varies with temperature based on Tnom of the model and Temp of the device. †† A value of 0.0 is interpreted as infinity.			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=2 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET*. Idsmod=2 is a required parameter that is used to tell the simulator to use the Spice level 2 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table- these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch2 MOSFET Idsmod=2 \
Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

1. The simulator provides three MOSFET device models that differ in formulation of I-V characteristics. LEVEL2_Model is a geometry-based, analytical model derived from [1].
2. LEVEL2_Model includes second order effects such as threshold voltage shift, mobility reduction, velocity saturation, channel length modulation, and subthreshold conduction.
3. Parameters Vto, Kp, Gamma, Phi, and Lambda determine the DC characteristics of a MOSFET device. The program will calculate these parameters (except Lambda) if, instead of specifying them, you specify the process parameters Tox, Uo, Nsub, and Nss.
4. Vto is positive (negative) for enhancement mode and negative (positive) for depletion mode N-channel (P-channel) devices.

5. The P-N junctions between the bulk and the drain and the bulk and the source are modeled by parasitic diodes. Each bottom junction is modeled by a diode and each periphery junction is modeled by a depletion capacitance.
6. The diode parameters for the bottom junctions can be specified as absolute values (Is, Cbd and Cbs) or as per unit junction area values (Js and Cj).
   If Cbd = 0.0 and Cbs = 0.0, then Cbd and Cbs will be calculated:

   $$Cbd = Cj \times Ad, Cbs = Cj \times As$$

   If Js > 0.0 and Ad > 0.0 and As > 0.0, then Is for drain and source will be calculated:

   $$Is(drain) = Js \times Ad, Is(source) = Js \times As$$
7. Drain and source ohmic resistances can be specified as absolute values (Rd, Rs) or as per unit square value (Rsh).
   If Nrd ≠ 0.0 or Nrs ≠ 0.0, Rd and Rs will be calculated:
   $Rd = Rsh \times Nrd, Rs = Rsh \times Nrs$
8. Charge storage is modeled by fixed and nonlinear gate and junction capacitances. MOS gate capacitances, as a nonlinear function of terminal voltages, are modeled by Meyer's piece-wise linear model for levels 1, 2, and 3. The Ward charge conservation model is also available for levels 2 and 3, by specifying the XQC parameter to a value smaller than or equal to 0.5. For Level 1, the model parameter TOX must be specified to invoke the Meyer model when Capmod is equal to 1 (default value). If Capmod = 0, no gate capacitances will be calculated. If Capmod = 2, a smooth version of the Meyer model is used. If Capmod =3, the charge conserving first-order MOS charge model [2] that was used in Libra is used.
9. The simulator uses Ward and Dutton [2] charge-controlled capacitance model if Xqc ≤ 0.5. If Xqc > 0.5, the charge-conserving first-order MOS charge model is used.
10. Imax and Imelt Parameters
    Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
    If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
    If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
11. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)
The depletion capacitances Cbd, Cbs, Cj, and Cjsw vary as:

$$Cbd^{NEW} = Cbd\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cbs^{NEW} = Cbs\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cj^{NEW} = Cj\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cjsw^{NEW} = Cjsw\left[\frac{1 + Mjsw[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mjsw[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.

The surface potential Phi and the bulk junction potential Pb vary as:

$$Phi^{NEW} = \frac{Temp}{Tnom} \times Phi + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

$$Pb^{NEW} = \frac{Temp}{Tnom} \times Pb + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

The transconductance Kp and mobility Uo vary as:

$$Kp^{NEW} = Kp\left(\frac{Temp}{Tnom}\right)^{3/2}$$

$$Uo^{NEW} = Uo\left(\frac{Temp}{Tnom}\right)^{3/2}$$

The source and drain to substrate leakage currents Is and Js vary as:

$$Is^{NEW} = Is \times exp\left(\frac{q \times E_G^{Tnom}}{k \times Tnom} - \frac{q \times E_G^{Temp}}{k \times Temp}\right)$$

$$Js^{NEW} = Js \times exp\left(\frac{q \times E_G^{Tnom}}{k \times Tnom} - \frac{q \times E_G^{Temp}}{k \times Temp}\right)$$

where E_G is the silicon bandgap energy as a function of temperature.

The MOSFET threshold voltage variation with temperature is given by:

$$Vto^{NEW} = Vto + \gamma\left(\sqrt{Phi^{NEW}} - \sqrt{Phi}\right) + \frac{Phi^{NEW} - Phi}{2} - \frac{E_G^{Temp} - E_G^{Tnom}}{2}$$

Noise Model

Thermal noise generated by resistor Rg, Rs, Rd, and Rds is characterized by the following spectral density:

$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Channel noise and flicker noise (Kf, Af, Ffe) generated by the DC transconductance g_m and current flow from drain to source is characterized by the following spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3} + k_f \frac{I_{DS}^{a_f}}{f^{f_{fe}}}$$

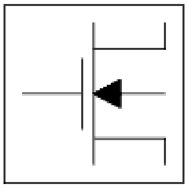
In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, *kf* , *af* , and *ffe* are model parameters, `f` is the simulation frequency, and Δ *f* is the noise bandwidth.

References

1. 1Vladimirescu and S. Liu. The Simulation of MOS Integrated Circuits Using SPICE2, Memorandum No. M80/7, February 1980.
2. D. E. Ward, and R. W. Dutton. "A Charge-Oriented Model for MOS Transistors Capacitances," *IEEE Journal on Solid-State Circuits* , SC-13, 1978.
3. P. Antognetti and G. Massobrio *. Semiconductor device modeling with SPICE* , New York: McGraw-Hill, Second Edition 1993.

LEVEL3_Model (MOSFET Level-3 Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	IDS model: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	3
Capmod	capacitance model selector: 0=NO CAP 1=CMEYER/WARD 2=SMOOTH 3=QMEYER	None	1
Vto †	zero-bias threshold voltage	V	0.0
Kp †	transconductance	A/V^2	2.0e-5
Gamma	bulk threshold	$V^{(1/2)}$	0.0
Phi †	surface potential	V	0.6
Rd	drain resistance	Ohm	fixed at 0
Rs	source resistance	Ohm	fixed at 0
Cbd †	bulk-drain zero-bias junction capacitance	F	0.0
Cbs †	bulk-source zero-bias junction capacitance	F	0.0
Is †	Gate Saturation Current	A	1.0e-14
Pb †	bulk junction potential	V	0.8
Cgso	gate-source overlap capacitance per meter of channel width	F/m	0.0
Cgdo	gate-drain overlap capacitance per meter of channel width	F/m	0.0
Cgbo	gate-bulk overlap capacitance per meter of channel length	F/m	0.0
Rsh	drain and source diffusion sheet resistance	Ohm/sq	0.0
Cj †	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0
Mj	bulk junction bottom grading coefficient	None	0.5
Cjsw †	Zero-bias Bulk Junction Sidewall Capacitance per meter of junction perimeter	F/m	0.0
Mjsw	Junction Sidewall grading coefficient	None	1/3

Js †	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	1.0e-7
Nsub	substrate (bulk) doping density	cm^{-3}	0.0
Nss	surface state density	cm^{-2}	0.0
Nfs	fast surface state density	cm^{-2}	0.0
Tpg	gate material type: 1=opposite substrate, 1=same as substrate, 0=aluminum	None	1
Xj	metallurgical junction depth	m	0.0
Ld	lateral diffusion length	m	0.0
Uo †	surface mobility	cm^2/(V×s)	600.0
Vmax	Maximum Drift Velocity of Carriers	m/s	0.0
Xqc (Xpart)	coefficient of channel charge share	None	1.0
Nlev	noise model level	None	-1
Gdsnoi	drain noise parameters for Nlev=3	None	1
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Fc	bulk junction forward-bias depletion capacitance coefficient	None	0.5
Delta	width effect on threshold voltage	None	0.0
Theta	mobility modulation	1/V	0.0
Eta	static feedback	None	0.0
Kappa	saturation field factor	None	0.2
Rg	gate resistance	Ohm	fixed at 0
Rds	drain-source shunt resistance	Ohm	fixed at infinity ††
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0
N	bulk P-N emission coefficient	None	1.0
Tt	bulk P-N transit time		0.0
Ffe (Ef)	flicker noise frequency exponent	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 8)	A	defaults to Imax
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	area calculation method	None	0
Hdif	length of heavily doped diffusion (Acm=2, 3 only)	m	0.0
Ldif	length of lightly doped diffusion adjacent to gate (Acm=1, 2 only)	m	0.0

Wmlt	width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	Ohm	0.0
Rsc	additional source resistance due to contact resistance	Ohm	0.0
AllParams	Data Access Component (DAC) Based Parameters	None	None
† Parameter value varies with temperature based on Tnom of model and Temp of device. †† Value of 0.0 is interpreted as infinity.			

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOSFET Idsmod=3 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOSFET* . Idsmod=3 is a required parameter that is used to tell the simulator to use the Spice level 3 equations. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch3 MOSFET Idsmod=3 \
Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

1. The simulator provides three MOSFET device models that differ in formulation of I-V characteristics. LEVEL3_Model is a semi-empirical model derived from [1]. LEVEL3_Model includes second order effects such as threshold voltage shift, mobility reduction, velocity saturation, channel length modulation, and subthreshold conduction.
2. Parameters Vto, Kp, Gamma, Phi, and Lambda determine the DC characteristics of a MOSFET device. ADS will calculate these parameters (except Lambda) if, instead of specifying them, you specify the process parameters Tox, Uo, Nsub, and Nss.
3. Vto is positive (negative) for enhancement mode and negative (positive) for depletion mode N-channel (P-channel) devices.
4. P-N junctions between the bulk and the drain and the bulk and the source are modeled by parasitic diodes. Each bottom junction is modeled by a diode and each

periphery junction is modeled by a depletion capacitance.

5. Diode parameters for the bottom junctions can be specified as absolute values (Is, Cbd and Cbs) or as per unit junction area values (Js and Cj).
   If Cbd=0.0 and Cbs=0.0, Cbd and Cbs will be calculated:

   $$Cbd = Cj \times Ad \quad Cbs = Cj \times As$$

   If Js>0.0 and Ad>0.0 and As>0.0, Is for drain and source will be calculated:

   $$Is(drain) = Js \times Ad \quad Is(source) = Js \times As$$

   Drain and source ohmic resistances can be specified as absolute values (Rd, Rs) or as per unit square value (Rsh).
   If Nrd≠0.0 or Nrs≠0.0, Rd and Rs will be calculated:

   $$Rd = Rsh \times Nrd \quad Rs = Rsh \times Nrs$$
6. Charge storage in the MOSFET consists of capacitances associated with parasitics and intrinsic device.
   The parasitic capacitances consist of three constant overlap capacitances (Cgdo, Cgso, Cgbo) and the depletion layer capacitances for both substrate junctions (divided into bottom and periphery) that vary as Mj and Mjsw power of junction voltage, respectively, and are determined by the parameters Cbd, Cbs, Cj, Cjsw, Mj, Mjsw, Pb and Fc.
   The intrinsic capacitances consist of the nonlinear thin-oxide capacitance, which is distributed among the gate, drain, source, and bulk regions.
7. Charge storage is modeled by fixed and nonlinear gate and junction capacitances. MOS gate capacitances, as a nonlinear function of terminal voltages, are modeled by Meyer's piece-wise linear model for levels 1, 2, and 3. The Ward charge conservation model is also available for levels 2 and 3, by specifying the XQC parameter to a value smaller than or equal to 0.5. For Level 1, the model parameter TOX must be specified to invoke the Meyer model when Capmod is equal to 1 (default value). If Capmod = 0, no gate capacitances will be calculated. If Capmod = 2, a smooth version of the Meyer model is used. If Capmod =3, the charge conserving first-order MOS charge model [2] that was used in Libra is used.
8. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
9. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

Temperature Scaling

The model specifies Tnom, the nominal temperature at which the model parameters were calculated or extracted. To simulate the device at temperatures other than Tnom, several model parameters must be scaled with temperature. The temperature at which the device is simulated is specified by the device item Temp parameter. (Temperatures in the following equations are in Kelvin.)

The depletion capacitances Cbd, Cbs, Cj, and Cjsw vary as:

$$Cbd^{NEW} = Cbd\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cbs^{NEW} = Cbs\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cj^{NEW} = Cj\left[\frac{1 + Mj[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cjsw^{NEW} = Cjsw\left[\frac{1 + Mjsw[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mjsw[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

where γ is a function of the junction potential and the energy gap variation with temperature.
The surface potential Phi and the bulk junction potential Pb vary as:

$$Phi^{NEW} = \frac{Temp}{Tnom} \times Phi + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

$$Pb^{NEW} = \frac{Temp}{Tnom} \times Pb + \frac{2k \times Temp}{q} 1n\left(\frac{n_i^{Tnom}}{n_i^{Temp}}\right)$$

The transconductance Kp and mobility Uo vary as:

$$Kp^{NEW} = Kp\left(\frac{Temp}{Tnom}\right)^{3/2}$$

$$Uo^{NEW} = Uo\left(\frac{Temp}{Tnom}\right)^{3/2}$$

The source and drain to substrate leakage currents Is and Js vary as:

$$Is^{NEW} = Is \times exp\left(\frac{q \times E_G^{Tnom}}{k \times Tnom} - \frac{q \times E_G^{Temp}}{k \times Temp}\right)$$

$$Js^{NEW} = Js \times exp\left(\frac{q \times E_G^{Tnom}}{k \times Tnom} - \frac{q \times E_G^{Temp}}{k \times Temp}\right)$$

where E $_G$ is the silicon bandgap energy as a function of temperature.

The MOSFET threshold voltage variation with temperature is given by:

$$Vto^{NEW} = Vto + \gamma\left(\sqrt{Phi^{NEW}} - \sqrt{Phi}\right) + \frac{Phi^{NEW} - Phi}{2} - \frac{E_G^{Temp} - E_G^{Tnom}}{2}$$

Noise Model

Thermal noise generated by resistor Rg, Rs, Rd, and Rds is characterized by the following spectral density:

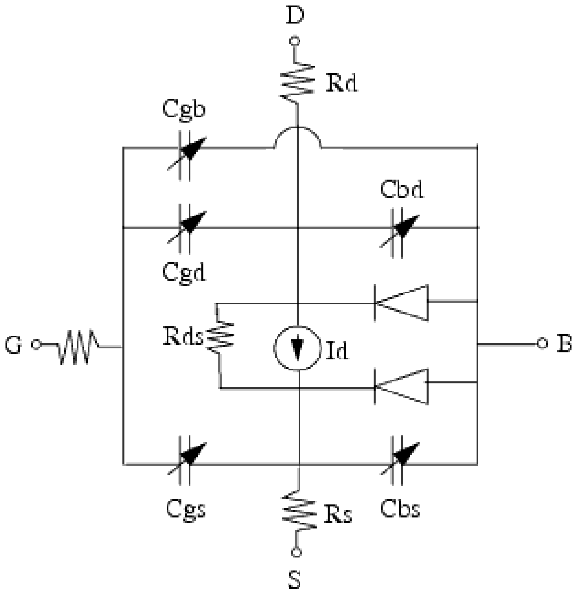
$$\frac{<i^2>}{\Delta f} = \frac{4kT}{R}$$

Channel noise and flicker noise (Kf, Af, Ffe) generated by DC transconductance g $_m$ and current flow from drain to source is characterized by the spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3} + k_f\frac{I_{DS}^{a_f}}{f^{f_{fe}}}$$

In the preceding expressions, *k* is Boltzmann's constant, *T* is the operating temperature in Kelvin, *q* is the electron charge, *kf* , *af* , and *ffe* are model parameters, *f* is the simulation frequency, and Δ f is the noise bandwidth.

Equivalent Circuit

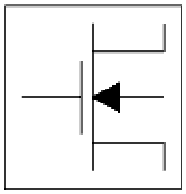


References

1. Vladimirescu, and S. Liu. The Simulation of MOS Integrated Circuits Using SPICE2, Memorandum No. M80/7, February 1980.
2. Karen A. Sakallah, Yao-tsung Yen, and Steve S. Greenberg. "The Meyer Model Revisited: Explaining and Correcting the Charge Non-Conservation Problem," *ICCAD* , 1987.
3. P. Antognetti and G. Massobrio . *Semiconductor device modeling with SPICE* , New York: McGraw-Hill, Second Edition 1993.

LEVEL3_MOD_Model (Level-3 NMOD MOSFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Idsmod	IDS model type: 1=LEVEL1 2=LEVEL2 3=LEVEL3 4=BSIM1 5=BSIM2 6=NMOD 8=BSIM3	None	6
Capmod	capacitance model selector: 0=NO CAP 1=CMEYER/WARD 2=SMOOTH 3=QMEYER	None	1
Vto †	zero-bias threshold voltage	V	0.0
Kp †	transconductance	A/V^2	2.0e-5
Gamma	bulk threshold	$V^{(1/2)}$	0.0
Gamma2	bulk threshold parameter deep in substrate	$V^{(1/2)}$	0.0
Zeta	mobility modulation with substrate bias	None	0.0
Phi †	surface potential	V	0.6
Rd	drain resistance	Ohm	fixed at 0.0
Rs	source resistance	Ohm	fixed at 0.0
Cbd †	zero-bias bulk-drain junction capacitance	F	0.0
Cbs †	zero-bias bulk-source junction capacitance	F	0.0
Is †	bulk junction saturation current	A	1.0e-14
Pb †	bulk junction potential	V	0.8
Cgso	gate-source overlap cap. per meter of channel width	F/m	0.0
Cgdo	gate-drain overlap cap. per meter of channel width	F/m	0.0
Cgbo	gate-bulk overlap cap. per meter of channel length	F/m	0.0
Rsh	drain and source diffusion sheet resistance	Ohm/sq.	0.0
Cj †	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0
Mj	bulk junction bottom grading coefficient	None	0.5

Cjsw †	zero-bias bulk junction periphery capacitance perimeter of junction perimeter	F/m	0.0
Mjsw	bulk junction periphery grading coefficient	None	1/3
Js †	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	1.0e-7
Nsub	substrate (bulk) doping density	cm^{-3}	0.0
Nss	surface state density	cm^{-2}	0.0
Nfs	fast surface state density	cm^{-2}	0.0
Tpg	Type of Gate Material: 1=opposite substrate, 1=same as substrate, 0=aluminum	None	1
Xj	metallurgical junction depth	m	0.0
Ld	lateral diffusion length	m	0.0
Uo †	surface mobility	cm^2 /(V×S)	600.0
Ucrit	critical field for mobility degradation	V/cm	1.0e4
Uexp	field exponent in mobility degradation	None	0.0
Vmax	carriers maximum drift velocity	m/s	0.0
Xqc (Xpart)	coefficient of channel charge share	None	1.0
Nlev	Noise model level	None	-1
Gdsnoi	Drain noise parameter for Nlev=3	None	1
Kf	flicker noise coefficient	None	0.0
Af	flicker noise exponent	None	1.0
Fc	bulk junction forward-bias depletion cap. coefficient	None	0.5
Delta	width effect on threshold voltage	None	0.0
Theta	mobility modulation	1/V	0.0
Eta	static feedback	None	0.0
Kappa	saturation field factor	None	0.2
Kappag	field correction factor gate drive dependence	None	0.0
Xmu	subthreshold fitting model parameter for NMOD	None	1.0
Rg	gate resistance	Ohm	fixed at 0.0
Rds	drain-source shunt resistance	Ohm	fixed at infinity ††
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0
N	bulk P-N emission coefficient	None	1.0
Tt	bulk P-N transit time		0.0
Ffe (Ef)	flicker noise frequency exponent	None	1.0
Imax	explosion current	A	10.0
Imelt	explosion current similar to Imax; defaults to Imax (refer to Note 2)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None

wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
Acm	Area Calculation Method	None	0
Hdif	Length of heavily doped diffusion (ACM=2,3 only)	m	0.0
Ldif	Length of lightly doped diffusion adjacent to gate (ACM=1,2 only)	m	0.0
Wmlt	Width diffusion layer shrink reduction factor	None	1.0
Lmlt	Gate length shrink factor	None	1.0
Xw	Accounts for masking and etching effects	m	0.0
Rdc	Additional drain resistance due to contact resistance	Ohm	0.0
Rsc	Additional source resistance due to contact resistance	Ohm	0.0
AllParams	DataAccessComponent-based parameters	None	None

† Parameter value varies with temperature based on Tnom of model and Temp of device. †† Value of 0.0 is interpreted as infinity.

Notes/Equations

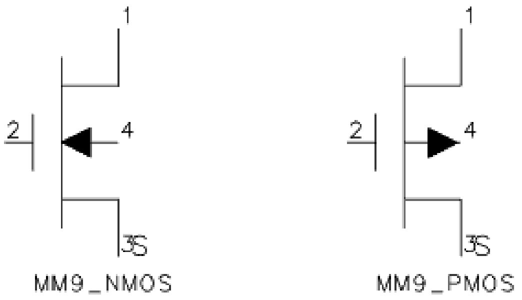
1. LEVEL3_MOD_Model is an enhanced version of the SPICE level 3 model. It exhibits smooth and continuous transitions in the weak to strong inversion region, and in the region between linear and saturation modes of device operation.
2. Imax and Imelt Parameters
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.
   If Imelt is specified (in the model or in Options) junction explosion current = Imelt; otherwise, if Imax is specified (in the model or in Options) junction explosion current = Imax; otherwise, junction explosion current = model Imelt default value (which is the same as the model Imax default value).
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent (Data Access Component)* (ccsim)). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

References

1. J. A. Power and W. A. Lane, "An Enhanced Spice MOSFET Model Suitable for Analog Applications," IEEE Transactions on CAD, Vol 11, No. 11, November 1992.

MM9_NMOS, MM9_PMOS (Philips MOS Model 9, NMOS, PMOS)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	MOSFETM1
Length †	channel length	m	1.0e-4
Width †	channel width	m	1.0e-4
Ab †	diffusion area	m2	1.0e-12
Ls †	length of sidewall not under gate	m	1.0e-4
Lg †	length of sidewall under gate	m	1.0e-4
Region	dc operating region: 0=off, 1=on, 2=rev, 3=sat	None	on
Temp (Ta)	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mult	number of devices in parallel	None	1
Mode	device simulation mode: nonlinear, linear (refer to note 3)	None	nonlinear
Noise	Noise generation option; yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.

Notes/Equations

1. MOS Model 9 (version 903) is a compact MOS-transistor model intended for the simulation of circuit behavior with emphasis on analog applications. The model gives a complete description of all transistor action related quantities: nodal currents and

charges, noise-power spectral densities and weak-avalanche currents. The equations describing these quantities are based on the gradual-channel approximation with a number of first-order corrections for small-size effects. The consistency is maintained by using the same carrier-density and electrical-field expressions in the calculation of all model quantities. The Philips JUNCAP model is implemented with the MM9 model to describe junction charges and leakage currents.

2. More information about the model can be obtained from:

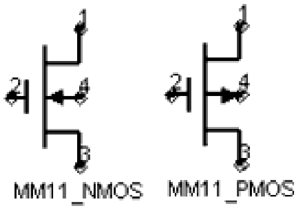
   http://www.nxp.com/models/mos_models/model9/
3. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
4. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gid_ds	(dId/dVds)	siemens
Gid_gs	(dId/dVgs)	siemens
Gid_sb	(dId/dVsb)	siemens
Gib_ds	(dIb/dVds)	siemens
Gib_gs	(dIb/dVgs)	siemens
Gib_sb	(dIb/dVsb)	siemens
Gis_ds	(dIs/dVds)	siemens
Gis_gs	(dIs/dVgs)	siemens
Gis_sb	(dIs/dVsb)	siemens
Cg_ds	(dQg/dVds)	farads
Cg_gs	(dQg/dVgs)	farads
Cg_sb	(dQg/dVsb)	farads
Cb_ds	(dQb/dVds)	farads
Cb_gs	(dQb/dVgs)	farads
Cb_sb	(dQb/dVsb)	farads
Cs_ds	(dQs/dVds)	farads
Cs_gs	(dQs/dVgs)	farads
Cs_sb	(dQs/dVsb)	farads
Cd_ds	(dQd/dVds)	farads
Cd_gs	(dQd/dVgs)	farads
Cd_sb	(dQd/dVsb)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts

MM11_NMOS, MM11_PMOS (Philips MOS Model 11 NMOS, PMOS)

Symbol



Parameters

Name	Description	Units	Default
Model	Model instance name	None	MOSFETM1
L †	channel length	m	2.0e-6
W †	channel width	m	1.0e-5
Temp (Ta)	device operating temperature	°C	25
Dta (Trise)	temperature offset of the device with respect to Temp	K	0.0
Mult	number of devices in parallel	None	1
Mode	device simulation mode: nonlinear, linear	None	nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
_M	number of devices in parallel	None	1

† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.

Notes/Equations

1. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter, or Circuit Envelope analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point. In standard entry mode, the integer value 1 is used for a nonlinear device and 0 is used for a linear device.
2. More information about the model can be obtained from:

   http://www.nxp.com/models/mos_models/model11/
3. The following table lists the DC operating point parameters that can be sent to the

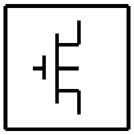
dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gds	Output conductance (dIds/dVds)	siemens
Gm	Forward transconductance (dIds/dVgs)	siemens
Gmb	Backgate transconductance (dIds/dVbs)	siemens
Iavl	Drain-bulk weak avalanche current	amperes
Igs	Gate-source tunneling current	amperes
Igd	Gate-drain tunneling current	amperes
Igb	Gate-bulk tunneling current	amperes
Vto	Zero bias threshold voltage	volts
Vts	Threshold voltage including back-bias effects	volts
Vth	Threshold voltage including back-bias and drain-bias effects	volts
Vgt	Effective gate drive voltage including back-bias and drain-bias effects	volts
Vdss	Drain saturation voltage	volts
Vsat	Saturation limit (Vds-Vdsat)	volts
Cdd	(dQd/dVds)	farads
Cdg	(-dQd/dVgs)	farads
Cds	(Cdd-Cdg-Cdb)	farads
Cdb	(dQd/dVsb)	farads
Cgd	(-dQg/dVds)	farads
Cgg	(dQg/dVgs)	farads
Cgs	(Cgg-Cgd-Cgb)	farads
Cgb	(dQg/dVsb)	farads
Csd	(-dQs/dVds)	farads
Csg	(-dQs/dVgs)	farads
Css	(Csg+Csd+Csb)	farads
Csb	(dQs/dVsb)	farads
Cbd	(-dQb/dVds)	farads
Cbg	(-dQb/dVgs)	farads
Cbs	(Cbb-Cbd-Cbg)	farads
Cbb	(-dQb/dVsb)	farads
Cgdol	Gate-drain overlap capacitance	farads
Cgsol	Gate-source overlap capacitance	farads
Weff	Effective gate width	meters
Leff	Effective gate length	meters
Fknee	Flicker noise corner frequency	hertz
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts

MM30_Model (Philips MOS Model 30)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Ron	ohmic resistance at zero-bias	Ohm	1.0
Rsat	space charge resistance at zero-bias	Ohm	1.0
Vsat	critical drain-source voltage for hot carrier	V	10.0
Psat	velocity saturation coefficient	None	1.0
Vp	pinchoff voltage at zero gate and substrate voltages	V	-1.0
Tox	gate oxide thickness	cm	-1.0
Dch	doping level channel	cm^{-3}	1.0e+15
Dsub	doping level substrate	cm^{-3}	1.0e+15
Vsub	substrate diffusion voltage	V	0.6
Cgate	gate capacitance at zero-bias	F	0.0
Csub	substrate capacitance at zero-bias	F	0.0
Tausc	space charge transit time of the channel	F	0.0
Tref (Tr, Tnom)	reference temperature	°C	25.0
Trise	temperature rise above ambient	°C	0
Vgap	bandgap voltage channel	V	1.2
Ach	temperature coefficient resistivity of the channel	None	0.0
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOS30 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOS30*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Nch9 MOS30 \
 Ron=5 Dsub=3e NMOS=yes
```

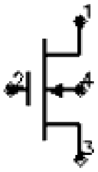
Notes/Equations

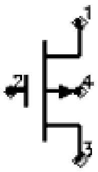
1. The junction-field-effect transistor (JFET) and the depletion mode metal-oxide (MOSFET) are semiconductor devices whose operation is achieved by depleting an already existing channel via a voltage-controlled P-N junction (JFET) or a gate-controlled surface depletion (MOSFET). These devices are often used as a load in high-voltage MOS devices. This long channel JFET/MOSFET model is specially developed to describe the drift region of LDMOS, EPMOS and VDMOS devices. Please refer to the NXP report *The MOS model, level 3002*. The *pdf* file MOSModel 30.02 is downloadable at the following web site:

   http://www.nxp.com/models/hv_models/model31/

MM30_NMOS, MM30_PMOS (Philips MOS Model 30, NMOS, PMOS)

Symbol





Parameters

Name	Description	Units	Default
Model	model instance name	None	MOSFETM1
Temp	temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mult	multiplication factor	None	1.0
_M	number of devices in parallel	None	1

Notes/Equations

1. The following table lists the DC operating point parameters that can be sent to the dataset.

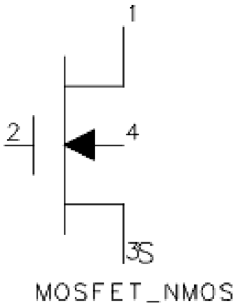
DC Operating Point Information

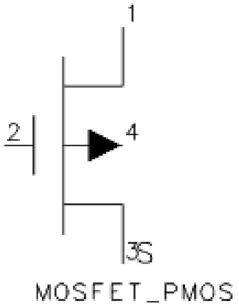
Name	**Description**	**Units**
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
gds_s	(dIds/dVs)	siemens
gds_d	(dIds/dVd)	siemens
gds_g	(dIds/dVg)	siemens
gds_b	(dIds/dVb)	siemens
cgs_s	(dQgs/dVs)	farads
cgs_d	(dQgs/dVd)	farads
cgs_g	(dQgs/dVg)	farads
cgs_b	(dQgs/dVb)	farads
cgd_s	(dQgd/dVs)	farads
cgd_d	(dQgd/dVd)	farads
cgd_g	(dQgd/dVg)	farads
cgd_b	(dQgd/dVb)	farads
cbs_s	(dQbs/dVs)	farads
cbs_d	(dQbs/dVd)	farads
cbs_g	(dQbs/dVg)	farads
cbs_b	(dQbs/dVb)	farads
cbd_s	(dQbd/dVs)	farads
cbd_d	(dQbd/dVd)	farads
cbd_g	(dQbd/dVg)	farads
cbd_b	(dQbd/dVb)	farads
cds_s	(dQds/dVs)	farads
cds_d	(dQds/dVd)	farads
cds_g	(dQds/dVg)	farads
cds_b	(dQds/dVb)	farads
Qgs	Gate-source charge	coulombs
Qgd	Gate-drain charge	coulombs
Qbs	Bulk-source charge	coulombs
Qbd	Bulk-drain charge	coulombs
Qds	Drain-source charge	coulombs
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts

2. Parameter Ids is divided by scale^2.

MOSFET_NMOS, MOSFET_PMOS (Nonlinear MOSFETs, NMOS, PMOS)

Symbol





Parameters

Name	Description	Units	Default
Model	Model instance name	None	MOSFETM1
Length †	channel length	m	1.0e-4
Width †	channel width	m	1.0e-4
Ad †	drain diffusion area	m^2	0.0
As †	source diffusion area	m^2	0.0
Pd †	drain junction perimeter	m	0.0
Ps †	source junction perimeter	m	0.0
Nrd	number of equivalent squares in drain diffusion region. Nrd is multiplied by Rsh (sheet resistance factor specified in Model) to get parasitic series drain resistance	None	1.0
Nrs	number of equivalent squares in source diffusion region. Nrs is multiplied by Rsh (sheet resistance factor specified in Model) to get parasitic series source resistance	None	1 .0
Mult	(obsolete: use _M instead)	None	None
Region	DC operating region, 0=off, 1=on, 2=rev, 3=sat	None	on
Temp	device operating temperature (refer to Note 1)	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear or linear (refer to Note 3)	None	nonlinear
Noise	noise generation option: yes=1, no=0	None	yes
Nqsmod	Non-Quasi Static Model Selector (BSIM3v3.2 only): 1=on or 0=off	None	0
Geo	source/drain sharing selector	None	0
_M	number of devices in parallel	None	1
Stimod ††	LOD stress effect model selector	None	0
Sa1 - Sa10 ††	Distance between OD edge to poly of one side (#1 - #10)	m	0
Sb1 - Sb10 ††	Distance between OD edge to poly of the other side (#1 - #10)	m	0
Sw1 - Sw10 ††	Width of Sa1/Sb1, Sa2/Sb2, Sa3/Sb3, etc.	m	Wdrawn for Sw1, 0 for Sw2 - Sw10
Sa ††	Alias for Sa1	m	Sa1
Sb ††	Alias for Sb1	m	Sb1

† Each instance parameter whose dimension contains a power of meter will be multiplied by the Scale to the same power. For example, a parameter with a dimension of *m* will be multiplied by $scale^1$ and a parameter with a dimension of m^2 will be multiplied by $scale^2$. Note that only parameters whose dimensions contain meter are scaled. For example, a parameter whose dimension contains *cm* instead of meter is not scaled.

†† Intended for Foundry use only.

Range of Usage

Length, Width, Ad, As, Pd, Ps > 0

Notes

1. The Temp parameter specifies the physical (operating) temperature of the device. If this is different than the temperature at which the model parameters are valid or extracted (specified by the Tnom parameter of the associated model) certain model parameters are scaled such that the device is simulated at its operating temperature. Refer to the appropriate model to see which parameter values are scaled.
2. The _M parameter affects MOSFET channel width, diode leakage, capacitors, and resistors in the following manner.
   Width: _M × Weff
   Areas and perimeters:

   _M × Ad
   _M × As
   _M × Pd
   _M × Ps

   Diode leakage:

   if (Js == 0), then Is = _M × Is

   Capacitors:

   if (Cj == 0), then Cbd = _M × Cbd, Cbs = _M × Cbs

   Resistors:

   if (Nrs × Rsh == 0), then Rs = Rs/_M; else Rs = (Nrs × Rsh)/_M
   if (Nrd × Rsh == 0), then Rd = Rd/_M; else Rd (Nrd × Rsh)/_M

   Due to second-order effects in some models (BSIM3 for example), the use of the _M parameter is not exactly equivalent to parallel multiple devices.
3. The Mode parameter is used only during harmonic balance, oscillator, or large-signal S-parameter analysis. By identifying devices that are operating in their linear region, the simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point.
4. The following table lists the DC operating point parameters that can be sent to the dataset.

DC Operating Point Information

Name	Description	Units
Id	Drain current	amperes
Ig	Gate current	amperes
Is	Source current	amperes
Ib	Bulk current	amperes
Power	DC power dissipated	watts
Gm	Forward transconductance (dIds/dVgs)	siemens
Gmb	Backgate transconductance (dIds/dVbs)	siemens
Gds	Output conductance (dIds/dVds)	siemens
Vth	Threshold voltage	volts
Vdsat	Drain-source saturation voltage	volts
Capbd	Bulk-drain capacitance	farads
Capbs	Bulk-source capacitance	farads
CgdM	Gate-drain Meyer capacitance	farads
CgbM	Gate-bulk Meyer capacitance	farads
CgsM	Gate-source Meyer capacitance	farads
DqgDvgb	(dQg/dVgb)	farads
DqgDvdb	(dQg/dVdb)	farads
DqgDvsb	(dQg/dVsb)	farads
DqbDvgb	(dQb/dVgb)	farads
DqbDvdb	(dQb/dVdb)	farads
DqbDvsb	(dQb/dVsb)	farads
DqdDvgb	(dQd/dVgb)	farads
DqdDvdb	(dQd/dVdb)	farads
DqdDvsb	(dQd/dVsb)	farads
Vgs	Gate-source voltage	volts
Vds	Drain-source voltage	volts
Vbs	Bulk-source voltage	volts

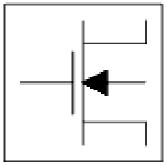
5. This device has no default artwork associated with it.

References

1. H. Shichman and D. A. Hodges. "Modeling and simulation of insulated-gate field-effect transistor switching circuits," *IEEE Journal of Solid-State Circuits,* SC-3, 285, September 1968.
2. A. Vladimirescu and S. Liu. *The Simulation of MOS Integrated Circuits Using SPICE2,* Memorandum No. M80/7, February 1980.
3. P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE,* McGraw-Hill, Inc., 1988.
4. D. A. Divekar, *FET Modeling for Circuit Simulation* , Kluwer Academic Publishers, 1988.

MOS_Model9_Process (Philips MOS Model 9, Process Based)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Type	Type of model: 1:SINGLE_DEVICE 2:PROCESS_BASED	None	2
Ler	effective channel length of reference transistor	m	1.0e-4
Wer	effective channel width of reference transistor	m	1.0e-4
Lvar	difference between actual and programmed poly-silicon gate length	m	0.0
Lap	effective channel length reduction per side due to lateral diffusion of source/drain dopant ions	m	0.0
Wvar	difference between actual and programmed field-oxide opening		0.0
Wot	effective channel width reduction per side due to lateral diffusion of channel-stop dopant ions	m	0.0
Tr (Tref, Tnom)	temperature for reference transistor	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Vtor	threshold voltage at zero back-bias	V	0.87505
Stvto	coefficient of temperature dependence of Vto	V/K	0.0
Slvto	coefficient of length dependence of Vto	V×m	0.0
Sl2vto	second coefficient of length dependence of Vto	$V \times m^{2}$	0.0
Swvto	coefficient of width dependence of Vto	V×m	0.0
Kor	low back-bias body factor	$V^{(1/2)}$	0.74368
Slko	coefficient of length dependence of Ko	$m \times V^{(1/2)}$	0.0
Swko	coefficient of width dependence of Ko	$m \times V^{(1/2)}$	0.0
Kr	high back-bias body factor	$V^{(1/2)}$	0.55237
Slk	coefficient of length dependence of K	$m \times V^{(1/2)}$	0.0
Swk	coefficient of width dependence of K	$m \times V^{(1/2)}$	0.0
Phibr	surface potential at strong inversion	V	0.65
Vsbxr	transition voltage for dual-k factor model	V	0.63304
Slvsbx	coefficient of length dependence of Vsbx	V×m	0.0

Swvsbx	coefficient of width dependence of Vsbx	V×m	0.0
Betsq	gain factor	A/V^{2}	0.12069e-3
Etabet	exponent of temperature dependence of gain factor	None	0.0
The1r	coefficient of mobility due to gate-induced field	1/V	0.99507e-01
Stthe1r	coefficient of temperature dependence of The1	1/V/K	0.0
Slthe1r	coefficient of length dependence of The1	m/V	0.0
Stlthe1	coefficient of temperature dependence of length dependence of The1	m/V/K	0.0
Swthe1	coefficient of width dependence of The1	m/V	0.0
Wdog	characteristic drain gate width below which dogboning appears	m	0.0
Fthe1	coefficient describing the width dependence of The1 for W < Wdog	None	0.0
The2r	coefficient of mobility due to back-bias	$V^{(-1/2)}$	0.43225e-01
Stthe2r	coefficient of temperature dependence of The2	$V^{(-1/2)}/K$	0.0
Slthe2r	coefficient of length dependence of The2	$m/V^{(1/2)}$	0.0
Stlthe2	coefficient of temperature dependence of length dependence of The2	$m/V^{(1/2)}/K$	0.0
Swthe2	coefficient of width dependence of The2	$m/V^{(1/2)}$	0.0
The3r	coefficient of mobility due to lateral field	1/V	0.0
Stthe3r	coefficient of temperature dependence of The3	1/V/K	0.0
Slthe3r	coefficient of length dependence of The3	m/V	0.0
Stlthe3	coefficient of temperature dependence of length dependence of The3	m/V/K	0.0
Swthe3	coefficient of width dependence of The3	m/V	0.0
Gam1r	coefficient for drain-induced threshold shift for large gate drive	V	0.38096e-2
Slgam1	coefficient of length dependence of Gam1	V×m	0.0
Swgam1	coefficient of width dependence of Gam1	V×m	0.0
Etadsr	exponent of Vds dependence of Gam1	None	0.6
Alpr	factor of channel-length modulation	None	0.1e-1
Etaalp	exponent of length dependence of Alp	None	0.0
Slalp	coefficient of length dependence of Alp	m	0.0
Swalp	coefficient of width dependence of Alp	m	0.0
Vpr	characteristic voltage of channel length modulation	V	0.67876e1
Gamoor	coefficient of drain-induced threshold shift at zero gate drive	None	0.29702e-4
Slgamoo	coefficient of length dependence of Gamoo	m	0.0
Etagamr	exponent of back-bias dependence of Gamo	None	2.0
Mor	factor of subthreshold slope	None	0.44
Stmo	coefficient of temperature dependence of Mo	1/K	0.0
Slmo	coefficient of length dependence of Mo	$m^{(1/2)}$	0.0
Etamr	exponent of back-bias dependence of M	None	2.0
Zet1r	weak-inversion correction factor	None	0.20153e1
Etazet	exponent of length dependence of Zet	None	0.0
Slzet1	coefficient of length dependence of Zet		0.0
Vsbtr	limiting voltage of VSB dependence of M and Gamo	V	0.61268e1
Slvsbt	coefficient of length dependence of Vsbt	m×V	0.0
A1r	factor of weak-avalanche current	None	0.20348e2
Sta1	coefficient of temperature dependence of A1	1/K	0.0
Sla1	coefficient of length dependence of A1	m	0.0

Swa1	coefficient of width dependence of A1	m	0.0
A2r	exponent of weak-avalanche current	V	0.33932e2
Sla2	coefficient of length dependence of A2	m×V	0.0
Swa2	coefficient of width dependence of A2	m×V	0.0
A3r	factor of drain-source voltage above which weak-avalanche occurs	None	0.10078e1
Sla3	coefficient of length dependence of A3	m	0.0
Swa3	coefficient of width dependence of A3	m	0.0
Tox	thickness of oxide layer	m	1.0e-6
Col	gate overlap per unit channel width	F/m	0.0
Ntr	coefficient of thermal noise	None	0.0
Nfmod	noise model selector	None	0
Nfr	Coefficient of the Flicker Noise (Nfmod=0)	None	0.0
Nfar	first coefficient of flicker noise (Nfmod=1)	1/(V×m)	7.15e+22
Nfbr	second coefficient of flicker noise (Nfmod=1)	1/(V×m^2)	2.16e+7
Nfcr	third coefficient of flicker noise (Nfmod=1)	1/V	0.0
Vr	voltage at which junction parameters have been determined	V	0.0
Jsgbr	bottom saturation current density due to electron-hole generation at V=Vr	A/m^2	1.0e-14
Jsdbr	bottom saturation current density due to diffusion from back contact	A/m^2	1.0e-14
Jsgsr	sidewall saturation current density due to electron-hole generation at V=Vr	A/m	1.0e-14
Jsdsr	sidewall saturation current density due to diffusion from back contact	A/m	1.0e-14
Jsggr	gate edge saturation current density due to electron-hole generation at V=Vr	A/m	1.0e-14
Jsdgr	gate edge saturation current density due to diffusion from back contact	A/m	1.0e-14
Cjbr	bottom junction capacitance at V=Vr	F/m^2	0.0
Cjsr	sidewall junction capacitance at V=Vr	F/m	0.0
Cjgr	gate edge junction capacitance at V=Vr	F/m	0.0
Vdbr	diffusion voltage of bottom junction at V=Vr	V	0.8
Vdsr	diffusion voltage of sidewall junction at V=Vr	V	0.8
Vdgr	diffusion voltage of gate edge junction at V=Vr	V	0.8
Pb	bottom-junction grading coefficient	None	0.5
Ps	sidewall-junction grading coefficient	None	0.5
Pg	gate-edge-junction grading coefficient	None	0.5
Nb	emission coefficient of bottom forward current	None	1.0
Ns	emission coefficient of sidewall forward current	None	1.0
Ng	emission coefficient of gate-edge forward current	None	1.0
wVsubfwd	substrate junction forward bias warning	V	None
wBvsub	substrate junction reverse breakdown voltage warning	V	None
wBvg	gate oxide breakdown voltage warning	V	None
wBvds	drain-source breakdown voltage warning	V	None
wIdsmax	maximum drain-source current warning	A	None
wPmax	maximum power dissipation warning	W	None
The3Clipping	flag for The3 clipping: no, yes	None	no
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOS9 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOS9*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Nch10 MOS9 \
 Vtor=0.7 Etabetr=0.4 NMOS=yes
```

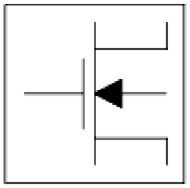
Notes/Equations/References

1. This model supplies values for an MM9 device.
2. Information about this model is available at

   http://www.nxp.com/models/mos_models/model9/
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MOS_Model9_Single (Philips MOS Model 9, Single Device)

Symbol



Parameters

Name	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Type	Model type: 1:SINGLE_DEVICE 2:PROCESS_BASED	None	1
Vto	threshold voltage at zero back-bias	V	0.87505
Ko	low-back-bias body factor	$V^{(1/2)}$	0.74368
K	high-back-bias body factor	$V^{(1/2)}$	0.55237
Phib	surface potential at strong inversion	V	0.65
Vsbx	transition voltage for dual-k factor model	V	0.63304
Bet	gain factor	A/V^2	0.12069e-3
The1	coefficient of mobility reduction due to gate-induced field	1/V	0.99507e-01
The2	coefficient of mobility reduction due to back-bias	$V^{(-1/2)}$	0.43225e-01
The3	coefficient of mobility reduction due to lateral field	1/V	0.0
Gam1	coefficient for drain-induced threshold shift for large gate drive	V	0.38096e-2
Etads	exponent of VDS dependence of Gam1	None	0.6
Alp	factor of channel-length modulation	None	0.1e-1
Vp	characteristic voltage of channel length modulation	V	0.67876e1
Gamoo	coefficient of drain-induced threshold shift at zero gate drive	None	0.29702e-4
Etagam	exponent of back-bias dependence of Gamo	None	2.0
Mo	factor of subthreshold slope	None	0.44
Etam	exponent of back-bias dependence of M	None	2.0
Zet1	weak-inversion correction factor	None	0.20153e1
Vsbt	limiting voltage of vsb dependence of M and Gamo	V	0.61268e1
A1	factor of weak-avalanche current	None	0.20348e2
A2	exponent of weak-avalanche current	V	0.33932e2
A3	factor of drain-source voltage above which weak-avalanche occurs	None	0.10078e1
Cox	gate-to-channel capacitance	F	1e-12

Cgdo	gate-drain overlap capacitance	F	1e-12
Cgso	gate-source overlap capacitance	F	1e-12
Nt	coefficient of thermal noise	None	0.0
Nfmod	noise model selector	None	0
Nf	coefficient of flicker noise (Nfmod=0)	None	0.0
Nfa	first coefficient of flicker noise (Nfmod=1)	1/(V×m)	7.15e+22
Nfb	second coefficient of flicker noise (Nfmod=1)	1/(V×m^{2})	2.16e+7
Nfc	third coefficient of flicker noise (Nfmod=1)	1/V	0.0
Tox	Thickness of the gate oxide layer (for Nfmod=1)	m	1.0e-6
Isgb	Bottom Saturation Current Density due to Electron-Hole generation	A	1.0e-14
Isdb	Bottom Saturation Current Density due to Diffusion from Back Contact	A	1.0e-14
Isgs	Sidewall Saturation Current Density due to Electron-Hole generation	A	1.0e-14
Isds	Sidewall Saturation Current Density due to Diffusion from Back Contact	A	1.0e-14
Isgg	Gate-Edge Saturation Current Density due to Electron-Hole Generation	A	1.0e-14
Isdg	Gate-Edge Saturation Current Density due to Diffusion from Back Contact	A	1.0e-14
Cjb	bottom junction capacitance	F	0.0
Cjs	sidewall junction capacitance	F	0.0
Cjg	gate edge junction capacitance	F	0.0
Vdb	diffusion voltage of bottom area Ab	V	0.8
Vds	diffusion voltage of Locos-edge Ls	V	0.8
Vdg	diffusion voltage of gate edge Lg	V	0.8
Pb	bottom-junction grading coefficient	None	0.5
Ps	sidewall-junction grading coefficient	None	0.5
Pg	gate-edge-junction grading coefficient	None	0.5
Nb	emission coefficient of bottom forward current	None	1.0
Ns	emission coefficient of sidewall forward current	None	1.0
Ng	emission coefficient of gate-edge forward current	None	1.0
wVsubfwd	substrate junction forward bias (warning)	V	None
wBvsub	substrate junction reverse breakdown voltage (warning)	V	None
wBvg	gate oxide breakdown voltage (warning)	V	None
wBvds	drain-source breakdown voltage (warning)	V	None
wIdsmax	maximum drain-source current (warning)	A	None
wPmax	maximum power dissipation (warning)	W	None
The3Clipping	flag for The3 clipping	None	no
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to the *Design Kit Development* (dkarch).

```
model modelname MOS9 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the

modelname that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOS9*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model  Nch11 MOS9 \
 Vtor=0.7 Etabet=0.4 NMOS=yes
```

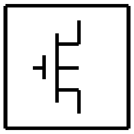
Notes/Equations/References

1. This model supplies values for an MM9 device.
2. Information about this model is available at

   http://www.nxp.com/models/mos_models/model9/
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MOS_Model11_Binned (Philips MOS Model 11, Binned)

Symbol



Parameters

Model parameters must be specified in SI units.

Parameter	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Level	Philips Level Name (1101=Electrical 11010=Physical 11011=Binned)	None	11011
Lvar	Difference between the actual and the programmed poly-silicon gate length	m	0.0
Lap	Effective channel length reduction per side due to the lateral diffusion of the source/drain dopant ions	m	4.0e-8
Wvar	Difference between the actual and the programmed field-oxide opening	m	0.0
Wot	Effective reduction of the channel width per side due to the lateral diffusion of the channel-stop dopant ions	m	0.0
Tr (Tref, Tnom)	Temperature at which the parameters for the reference transistor have been determined	°C	25
Vfb	Flat-band voltage for the reference transistor at the reference temperature	V	-1.05
Poko	Coefficient for the geometry independent part of KO	$V^{(1/2)}$	0.5
Plko	Coefficient for the length dependence of KO	$V^{(1/2)}$	0.0
Pwko	Coefficient for the width dependence of KO	$V^{(1/2)}$	0.0
Plwko	Coefficient for the length times width dependence of KO	$V^{(1/2)}$	0.0
Kpinv	Inverse of body-effect factor of the poly-silicon gate	$V^{(-1/2)}$	0.0
Pophib	Coefficient for the geometry independent part of PHIB	V	0.95
Plphib	Coefficient for the length dependence of PHIB	V	0.0
Pwphib	Coefficient for the width dependence of PHIB	V	0.0
Plwphib	Coefficient for the length times width dependence of PHIB	V	0.0
Pobet	Coefficient for the geometry independent part of BET	A/V^2	1.922e-3 (NMOS)
Plbet	Coefficient for the length dependence of BET	A/V^2	0.0

Pwbet	Coefficient for the width dependence of BET	A/V^2	0.0
Plwbet	Coefficient for the width over length dependence of BET	A/V^2	0.0
Pothesr	Coefficient for the geometry independent part of THES	V^{-1}	0.3562 (NMOS)
Plthesr	Coefficient for the length dependence of THES	V^{-1}	0.0
Pwthesr	Coefficient for the width dependence of THES	V^{-1}	0.0
Plwthesr	Coefficient for the length times width dependence of THES	V^{-1}	0.0
Potheph	Coefficient for the geometry independent part of THEPH	V^{-1}	1.0e-3 (NMOS)
Pltheph	Coefficient for the length dependence of THEPH	V^{-1}	0.0
Pwtheph	Coefficient for the width dependence of THEPH	V^{-1}	0.0
Plwtheph	Coefficient for the length times width dependence of THEPH	V^{-1}	0.0
Poetamob	Coefficient for the geometry independent part of ETAMOB	None	1.4 (NMOS)
Pletamob	Coefficient for the length dependence of ETAMOB	None	0.0
Pwetamob	Coefficient for the width dependence of ETAMOB	None	0.0
Plwetamob	Coefficient for the length times width dependence of ETAMOB	None	0.0
Pother	Coefficient for the geometry independent part of THER	V^{-1}	8.12e-2 (NMOS)
Plther	Coefficient for the length dependence of THER	V^{-1}	0.0
Pwther	Coefficient for the width dependence of THER	V^{-1}	0.0
Plwther	Coefficient for the length times width dependence of THER	V^{-1}	0.0
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0.0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	1.0
Pothesat	Coefficient for the geometry independent part of THESAT	V^{-1}	0.2513 (NMOS)
Plthesat	Coefficient for the length dependence of THESAT	V^{-1}	0.0
Pwthesat	Coefficient for the width dependence of THESAT	V^{-1}	0.0
Plwthesat	Coefficient for the length times width dependence of THESAT	V^{-1}	0.0
Potheth	Coefficient for the geometry independent part of THETH	V^{-3}	1.0e-5 (NMOS)
Pltheth	Coefficient for the length dependence of THETH	V^{-3}	0.0
Pwtheth	Coefficient for the width dependence of THETH	V^{-3}	0.0
Plwtheth	Coefficient for the length times width dependence of THETH	V^{-3}	0.0
Posdibl	Coefficient for the geometry independent part of SDIBL	$V^{(-1/2)}$	8.53e-4 (NMOS)
Plsdibl	Coefficient for the length dependence of SDIBL	$V^{(-1/2)}$	0.0
Pwsdibl	Coefficient for the width dependence of SDIBL	$V^{(-1/2)}$	0.0
Plwsdibl	Coefficient for the length times width dependence of SDIBL	$V^{-1/2}$	0.0
Pomo	Coefficient for the geometry independent part of MO	None	0.0
Plmo	Coefficient for the length dependence of MO	None	0.0
Pwmo	Coefficient for the width dependence of MO	None	0.0
Plwmo	Coefficient for the length times width dependence of MO	None	0.0
Possf	Coefficient for the geometry independent part of SSF	$V^{(-1/2)}$	0.012 (NMOS)
Plssf	Coefficient for the length dependence of SSF	$V^{(-1/2)}$	0.0
Pwssf	Coefficient for the width dependence of SSF	$V^{(-1/2)}$	0.0
Plwssf	Coefficient for the length times width dependence of SSF	$V^{(-1/2)}$	0.0

Poalp	Coefficient for the geometry independent part of ALP	None	0.025
Plalp	Coefficient for the length dependence of ALP	None	0.0
Pwalp	Coefficient for the width dependence of ALP	None	0.0
Plwalp	Coefficient for the length times width dependence of ALP	None	0.0
VP	Characteristic voltage of channel length modulation	V	0.05
Pomexp	Coefficient for the geometry independent part of 1/m	1/m	0.2
Plmexp	Coefficient for the length dependence of 1/m	1/m	0.0
Pwmexp	Coefficient for the width dependence of 1/m	1/m	0.0
Plwmexp	Coefficient for the length times width dependence of 1/m	1/m	0.0
Poa1	Coefficient for the geometry independent part of A1	None	6.022 (NMOS)
Pla1	Coefficient for the length dependence of A1	None	0.0
Pwa1	Coefficient for the width dependence of A1	None	0.0
Plwa1	Coefficient for the length times width dependence of A1	None	0.0
Poa2	Coefficient for the geometry independent part of A2	V	38.02 (NMOS)
Pla2	Coefficient for the length dependence of A2	V	0.0
Pwa2	Coefficient for the width dependence of A2	V	0.0
Plwa2	Coefficient for the length times width dependence of A2	V	0.0
Poa3	Coefficient for the geometry independent part of A3	None	0.6407 (NMOS)
Pla3	Coefficient for the length dependence of A3	None	0.0
Pwa3	Coefficient for the width dependence of A3	None	0.0
Plwa3	Coefficient for the length times width dependence of A3	None	0.0
Poiginv	Coefficient for the geometry independent part of IGINV	A/V	0.0
Pliginv	Coefficient for the length dependence of IGINV	None	0.0
Pwiginv	Coefficient for the width dependence of IGINV	None	0.0
Plwiginv	Coefficient for the length times width dependence of IGINV	None	0.0
Pobinv	Coefficient for the geometry independent part of BINV	V	48.0
Plbinv	Coefficient for the length dependence of BINV	V	0.0
Pwbinv	Coefficient for the width dependence of BINV	V	0.0
Plwbinv	Coefficient for the length times width dependence of BINV	V	0.0
Poigacc	Coefficient for the geometry independent part of IGACC	A/V^2	0.0
Pligacc	Coefficient for the length dependence of IGACC	A/V^2	0.0
Pwigacc	Coefficient for the width dependence of IGACC	A/V^2	0.0
Plwigacc	Coefficient for the length times width dependence of IGACC	A/V^2	0.0
Pobacc	Coefficient for the geometry independent part of BACC	V	48.0 (NMOS)
Plbacc	Coefficient for the length dependence of BACC	V	0.0
Pwbacc	Coefficient for the width dependence of BACC	V	0.0
Plwbacc	Coefficient for the length times width dependence of BACC	V	0.0
Vfbov	Flat-band voltage for source/drain overlap extension	V	0.0
Kov	Body-effect factor for source/drain overlap extension	$V^{(1/2)}$	2.5
Poigov	Coefficient for the geometry independent part of IGOV	A/V^2	0.0
Pligov	Coefficient for the length dependence of IGOV	A/V^2	0.0
Pwigov	Coefficient for the width dependence of IGOV	A/V^2	0.0
Plwigov	Coefficient for the width over length dependence of IGOV	A/V^2	0.0
Tox	Thickness of gate oxide layer	m	3.2e-9
Pocox	Coefficient for the geometry independent part of COX	F	2.980e-14 (NMOS)

Plcox	Coefficient for the length dependence of COX	F	0.0
Pwcox	Coefficient for the width dependence of COX	F	0.0
Plwcox	Coefficient for the width over length dependence COX	F	0.0
Pocgdo	Coefficient for the geometry independent part of CGDO	F	6.392e-15 (NMOS)
Plcgdo	Coefficient for the length dependence of CGDO	F	0.0
Pwcgdo	Coefficient for the width dependence of CGDO	F	0.0
Plwcgdo	Coefficient for the width over length dependence CGDO	F	0.0
Pocgso	Coefficient for the geometry independent part of CGSO	F	6.392e-15 (NMOS)
Plcgso	Coefficient for the length dependence of CGSO	F	0.0
Pwcgso	Coefficient for the width dependence of CGSO	F	0.0
Plwcgso	Coefficient for the width over length dependence CGSO	F	0.0
Gatenoise	Flag for in/exclusion of induced gate thermal noise	None	0
Nt	coefficient of thermal noise at actual temperature	J	1.656e-20
Ponfa	Coefficient for the geometry independent part of NFA	$V^{-1}\times m^{-1}$	8.323e+22 (NMOS)
Plnfa	Coefficient for the length dependence of NFA	$V^{-1}\times m^{-1}$	0.0
Pwnfa	Coefficient for the width dependence of NFA	$V^{-1}\times m^{-1}$	0.0
Plwnfa	Coefficient for the length times width dependence of NFA	$V^{-1}\times m^{-1}$	0.0
Ponfb	Coefficient for the geometry independent part of NFB	$V^{-1}\times m^{-2}$	2.514e7 (NMOS)
Plnfb	Coefficient for the length dependence of NFB	$V^{-1}\times m^{-2}$	0.0
Pwnfb	Coefficient for the width dependence of NFB	$V^{-1}\times m^{-2}$ 2	0.0
Plwnfb	Coefficient for the length times width dependence of NFB	$V^{-1}\times m^{-2}$	0.0
Ponfc	Coefficient for the geometry independent part of NFC	V^{-1}	0.0 (NMOS)
Plnfc	Coefficient for the length dependence of NFC	V^{-1}	0.0
Pwnfc	Coefficient for the width dependence of NFC	V^{-1}	0.0
Plwnfc	Coefficient for the length times width dependence of NFC	V^{-1}	0.0
Potvfb	Coefficient for the geometry independent part of STVFB	V/K	0.5e-3
Pltvfb	Coefficient for the length dependence of STVFB	V/K	0.0
Pwtvfb	Coefficient for the width dependence of STVFB	V/K	0.0
Plwtvfb	Coefficient for the length times width dependence of STVFB	V/K	0.0
Potphib	Coefficient for the geometry independent part of STPHIB	V/K	-0.85e-3
Pltphib	Coefficient for the length dependence of STPHIB	V/K	0.0
Pwtphib	Coefficient for the width dependence of STPHIB	V/K	0.0
Plwtphib	Coefficient for the length times width dependence of STPHIB	V/K	0.0
Potetabet	Coefficient for the geometry independent part of ETABET	None	1.3 (NMOS)
Pltetabet	Coefficient for the length dependence of ETABET	None	0.0
Pwtetabet	Coefficient for the width dependence of ETABET	None	0.0
Plwtetabet	Coefficient for the length times width dependence of ETABET	None	0.0

Potetasr	Coefficient for the geometry independent part of ETASR	None	0.65 (NMOS)
Pltetasr	Coefficient for the length dependence of ETASR	None	0.0
Pwtetasr	Coefficient for the width dependence of ETASR	None	0.0
Plwtetasr	Coefficient for the length times width dependence of ETASR	None	0.0
Potetaph	Coefficient for the geometry independent part of ETAPH	None	1.35 (NMOS)
Pltetaph	Coefficient for the length dependence of ETAPH	None	0.0
Pwtetaph	Coefficient for the width dependence of ETAPH	None	0.0
Plwtetaph	Coefficient for the length times width dependence of ETAPH	None	0.0
Potetamob	Coefficient for the geometry independent part of ETAMOB	K^{-1}	0.0
Pltetamob	Coefficient for the length dependence of ETAMOB	K^{-1}	0.0
Pwtetamob	Coefficient for the width dependence of ETAMOB	K^{-1}	0.0
Plwtetamob	Coefficient for the length times width dependence of ETAMOB	K^{-1}	0.0
Nu	Exponent of the field dependence of the mobility model minus 1 at the reference temperature	None	2.0
Potnuexp	Coefficient for the geometry independent part of NUEXP	None	5.25 (NMOS)
Pltnuexp	Coefficient for the length dependence of NUEXP	None	0.0
Pwtnuexp	Coefficient for the width dependence of NUEXP	None	0.0
Plwtnuexp	Coefficient for the length times width dependence of NUEXP	None	0.0
Potetar	Coefficient for the geometry independent part of ETAR	None	0.95 (NMOS)
Pltetar	Coefficient for the length dependence of ETAR	None	0.0
Pwtetar	Coefficient for the width dependence of ETAR	None	0.0
Plwtetar	Coefficient for the length times width dependence of ETAR	None	0.0
Potetasat	Coefficient for the geometry independent part of ETASAT	None	1.04 (NMOS)
Pltetasat	Coefficient for the length dependence of ETASAT	None	0.0
Pwtetasat	Coefficient for the width dependence of ETASAT	None	0.0
Plwtetasat	Coefficient for the length times width dependence of ETASAT	None	0.0
Pota1	Coefficient for the geometry independent part of STA1	K^{-1}	0.0
Plta1	Coefficient for the length dependence of STA1	K^{-1}	0.0
Pwta1	Coefficient for the width dependence of STA1	K^{-1}	0.0
Plwta1	Coefficient for the length times width dependence of STA1	K^{-1}	0.0
wVsubfwd	Substrate junction forward bias (warning)	V	None
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	None
wBvg	Gate oxide breakdown voltage (warning)	V	None
wBvds	Drain-source breakdown voltage (warning)	V	None
wIdsmax	Maximum drain-source current (warning)	A	None
wPmax	Maximum power dissipation (warning)	W	None
AllParams	DataAccessComponent-based parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOS11 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the

modelname that will be used by mosfet components to refer to the model.The third parameter indicates the type of model; for this model it is *MOS11*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
model Nch12 MOS11 \
 Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

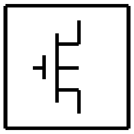
Notes/Equations

1. This model supplies values for an MM11 device.

   http://www.nxp.com/models/mos_models/model11/
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MOS_Model11_Electrical (Philips MOS Model 11, Electrical)

Symbol



Parameters

Model parameters must be specified in SI units.

Parameter	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Level	Philips Level Name (1101=Electrical 11010=Physical 11011=Binned)	None	1101
Tr (Tref, Tnom)	Temperature at which the parameters for the reference transistor have been determined	°C	25
Vfb	Flat-band voltage for the reference transistor at the reference temperature	V	-1.05
Stvfb	Coefficient of the temperature dependence of VFB	V/K	0.5e-3
Ko	Low-back-bias body factor	$V^{(1/2)}$	0.5
Kpinv	Inverse of body-effect factor of the poly-silicon gate	$V^{(-1/2)}$	0.0
Phib	Surface potential at the onset of strong inversion	V	0.95
Stphib	Coefficient of the temperature dependence of PHIB	V/K	-8.5e-4
Bet	Gain factor for an infinite square transistor	A/V^2	1.9215e-3 (NMOS),
Etabet	Exponent of the temperature dependence of the gain factor	None	1.3 (NMOS)
Thesrr	Coefficient of the mobility reduction due to surface roughness scattering for the reference transistor at the reference temperature	V^{-1}	0.3562 (NMOS), 0.73 (PMOS)
Etasr	Exponent of the temperature dependence of THESR for the reference transistor	None	0.65 (NMOS)
Theph	Coefficient of the mobility reduction due to phonon scattering	V^{-1}	1.29e-2 (NMOS)
Etaph	Exponent of the temperature dependence of THESR for the reference transistor	None	1.35 (NMOS)
Etamob	Effective field parameter for dependence on depletion/inversion charge	None	1.4 (NMOS)
Stetamob	Coefficient of the temperature dependence of ETAMOB	K^{-1}	0.0
Nu	Exponent of the field dependence of the mobility model minus 1 at the reference temperature	None	2.0

Nuexp	Exponent of the temperature dependence of NU	None	5.25 (NMOS)
Ther	Coefficient of the series resistance	V^{-1}	8.12e-2 (NMOS)
Etar	Exponent of the temperature dependence of ETA	None	0.95 (NMOS)
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0.0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	1.0
Thesat	Velocity saturation parameter due to optical/acoustic phonon scattering	V^{-1}	0.2513 (NMOS), 0.1728 (PMOS)
Etasat	Exponent of the temperature dependence of THESAT	None	1.04 (NMOS)
Theth	Coefficient on self-heating	V^{-3}	1.0e-5 (NMOS), 0.0 (PMOS)
Sdibl	Drain-induced barrier-lowering parameter	$V^{(-1/2)}$	8.53e-4 (NMOS), 3.551e-5 (PMOS)
Mo	Parameter fr short-channel subthreshold slope	None	0.0
Ssf	Static feedback parameter	$V^{(-1/2)}$	0.012 (NMOS), 0.01 (PMOS)
Alp	Factor of the channel-length modulation	None	0.025
Vp	Characteristic voltage of channel length modulation	V	0.05
Mexp	Smoothing factor for the actual transistor	None	5.0
A1	Factor of the weak-avalanche current	None	6.0221 (NMOS)
Sta1	Coefficient of the temperature dependence of A1	K^{-1}	0.0
A2	Exponent of the weak-avalanche current	V	38.017 (NMOS)
A3	Factor of the drain-source voltage above which weak-avalanche occurs	None	0.6407 (NMOS)
Iginv	Gain factor for intrinsic gate tunneling current in inversion	A/V^2	0.0
Binv	Probability factor for intrinsic gate tunneling current in inversion	V	48.0 (NMOS)
Igacc	Gain factor for intrinsic gate tunneling current in accumulation	A/V^2	0.0
Bacc	Probability factor for intrinsic gate tunneling current in accumulation	V	48.0
Vfbov	Flat-band voltage for the source/drain overlap extension	V	0.0
Kov	Body-effect factor for the source/drain overlap extension	$V^{(1/2)}$	2.5
Igov	Gain factor for source/drain overlap gate tunneling current	A/V^2	0.0
Cox	Gate-to-channel capacitance	F	2.980e-14 (NMOS)
Cgdo	G-D overlap capacitance	F	6.392e-15 (NMOS) 6.358e-15 (PMOS)
Cgso	G-S overlap capacitance	F	6.392e-15 (NMOS)
Gatenoise	Flag for in/exclusion of induced gate thermal noise	None	0
Nt	Coefficient of the thermal noise at the actual temperature	J	1.656e-20
Nfa	First coefficient of the flicker noise	$V^{-1}\times m^{-1}$	8.323e+22 (NMOS)
Nfb	Second coefficient of the flicker noise	$V^{-1}\times m^{-2}$	2.514e+7 (NMOS)
Nfc	Second coefficient of the flicker noise	$V^{-1}\times m^{-2}$	0.0 (NMOS)
Tox	Thickness of the gate oxide layer	m	3.2e-9
wVsubfwd	Substrate junction forward bias (warning)	V	None
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	None
wBvg	Gate oxide breakdown voltage (warning)	V	None

wBvds	Drain-source breakdown voltage (warning)	V	None
wIdsmax	Maximum drain-source current (warning)	A	None
wPmax	Maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOS11 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model. The third parameter indicates the type of model; for this model it is *MOS11*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
modelNch12 MOS11 \
 Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

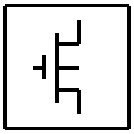
Notes/Equations

1. This model supplies values for an MM11 device.
2. Information about this model is available at

   http://www.nxp.com/models/mos_models/model11/
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MOS_Model11_Physical (Philips MOS Model 11, Physical)

Symbol



Parameters

Model parameters must be specified in SI units.

Parameter	Description	Units	Default
NMOS	Model type: yes or no	None	yes
PMOS	Model type: yes or no	None	no
Level	Philips Level Name (1101=Electrical 11010=Physical 11011=Binned)	None	11010
Lvar	Difference between the actual and the programmed poly-silicon gate length	m	0.0
Lap	Effective channel length reduction per side due to the lateral diffusion of the source/drain dopant ions	m	4.0e-8
Wvar	Difference between the actual and the programmed field-oxide opening	m	0.0
Wot	Effective reduction of the channel width per side due to the lateral diffusion of the channel-stop dopant ions	m	0.0
Tr (Tref, Tnom)	Temperature at which the parameters for the reference transistor have been determined	°C	21
Vfb	Flat-band voltage for the reference transistor at the reference temperature	V	-1.05
Stvfb	Coefficient of the temperature dependence of VFB	V/K	0.5e-3
Kor	Low-back-bias body factor for the reference transistor	V$^{(1/2)}$	0.5
Slko	Coefficient of the length dependence of KO	m×V$^{(1/)2}$	0.0
Sl2ko	Second coefficient of the length dependence of KO	m×V$^{(1/)2}$	0.0
Swko	Coefficient of the width dependence of KO	m×V$^{(1/)2}$	0.0
Kpinv	Inverse of body-effect factor of the poly-silicon gate	V$^{(-1/2)}$	0.0
Phibr	Surface potential at the onset of strong inversion at the reference temperature	V	0.95
Stphib	Coefficient of the temperature dependence of PHIB	V/K	-8.5e-4
Slphib	Coefficient of the length dependence of PHIB	V×m	0.0
Sl2phib	Second coefficient of the length dependence of PHIB	V×m^2	0.0

Swphib	Coefficient of the width dependence of PHIB	V×m	0.0
Betsq	Gain factor for an infinite square transistor at the reference temperature	A/V^2	3.709e-4 (NMOS),
Etabetr	Exponent of the temperature dependence of the gain factor	None	1.3 (NMOS)
Sletabet	Coefficient of the length dependence of ETABET	m	0.0
Fbet1	Relative mobility decrease due to first lateral profile	None	0.0
Lp1	Characteristic length of first lateral profile	m	0.8e-6
Fbet2	Relative mobility decrease due to second lateral profile	None	0.0
Lp2	Characteristic length of second lateral profile	m	0.8e-6
Thesrr	Coefficient of the mobility reduction due to surface roughness scattering for the reference transistor at the reference temperature	V^{-1}	0.4 (NMOS),
Etasr	Exponent of the temperature dependence of THESR for the reference transistor	None	0.65 (NMOS)
Swthesr	Coefficient of the width dependence of THESR	m	0.0
Thephr	Coefficient of the mobility reduction due to phonon scattering for the reference transistor at the reference temperature	V^{-1}	1.29e-2 (NMOS)
Etaph	Exponent of the temperature dependence of THESR for the reference transistor	None	1.35 (NMOS)
Swtheph	Coefficient of the width dependence of THEPH	m	0.0
Etamobr	Effective field parameter for dependence on depletion/inversion charge for the reference transistor	None	1.4 (NMOS)
Stetamob	Coefficient of the temperature dependence of ETAMOB	K^{-1}	0.0
Swetamob	Coefficient of the width dependence of ETAMOB	m	0.0
Nu	Exponent of the field dependence of the mobility model minus 1 at the reference temperature	None	2.0
Nuexp	Exponent of the temperature dependence of NU	None	5.25 (NMOS)
Therr	Coefficient of the series resistance for the reference transistor at the reference temperature	V^{-1}	0.155 (NMOS),
Etar	Exponent of the temperature dependence of ETA	None	0.95 (NMOS)
Swther	Coefficient of the width dependence of THER	m	0.0
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0.0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	1.0
Thesatr	Velocity saturation parameter due to optical/acoustic phonon scattering for the reference transistor at the reference temperature	V^{-1}	0.5 (NMOS),
Etasat	Exponent of the temperature dependence of THESAT	None	1.04 (NMOS)
Slthesat	Coefficient of the length dependence of THESAT	None	1.0
Thesatexp	Exponent of the length dependence of THESAT	None	1.0
Swthesat	Coefficient of the width dependence of THESAT	m	0.0
Thethr	Coefficient on self-heating for the reference transistor at the reference temperature	V^{-3}	1.0e-3 (NMOS)
Thethexp	Exponent of the length dependence of THETH	None	1.0
Swtheth	Coefficient of the width dependence of THETH	m	0.0
Sdiblo	Drain-induced barrier-lowering parameter for the reference transistor	V$^{(-1/2)}$	1.0e-4
Sdiblexp	Exponent of the length dependence of SDIBLO	None	1.35
Mor	Parameter fr short-channel subthreshold slope for the reference transistor	None	0.0
Moexp	Exponent of the length dependence of MO	None	1.34
Ssfr	Static feedback parameter for the reference transistor	V$^{(-1/2)}$	6.25e-3

Slssf	Coefficient of the length dependence of SSF	m	1.0
Swssf	Coefficient of the width dependence of SSF	m	0.0
Alpr	Factor of the channel-length modulation for the reference transistor	None	0.01
Slalp	Coefficient of the length dependence of ALP	None	1.0
Alpexp	Exponent of the length dependence of ALP	None	1.0
Swalp	Coefficient of the width dependence of SSF	m	0.0
Vp	Characteristic voltage of channel length modulation	V	0.05
Lmin	Minimum effective channel length in technology, used for calculation of smoothing factor m	m	1.5e-7
A1r	Factor of the weak-avalanche current for the reference transistor at the reference temperature	None	6.0
Sta1	Coefficient of the temperature dependence of A1	K^{-1}	0.0
Sla1	Coefficient of the length dependence of A1	m	0.0
Swa1	coefficient of the width dependence of A1	m	0.0
A2r	Exponent of the weak-avalanche current for the reference transistor at the reference temperature	V	38.0
Sla2	Coefficient of the length dependence of A2	V×m	0.0
Swa2	Coefficient of the width dependence of A2	V×m	0.0
A3r	Factor of the drain-source voltage above which weak-avalanche occurs, for the reference transistor	None	1.0
Sla3	Coefficient of the length dependence of A3	m	0.0
Swa3	Coefficient of the width dependence of A3	m	0.0
Iginvr	Gain factor for intrinsic gate tunneling current in inversion for the reference transistor	A/V^2	0.0
Binv	Probability factor for intrinsic gate tunneling current in inversion	V	48.0 (NMOS)
Igaccr	Gain factor for intrinsic gate tunneling current in accumulation for the reference transistor	A/V^2	0.0
Bacc	Probability factor for intrinsic gate tunneling current in accumulation	V	48.0
Vfbov	Flat-band voltage for the source/drain overlap extension	V	0.0
Kov	Body-effect factor for the source/drain overlap extension	$V^{(1/2)}$	2.5
Igovr	Gain factor for source/drain overlap gate tunneling current for the reference transistor	A/V^2	0.0
Tox	Thickness of the gate oxide layer	m	3.2e-9
Col	Gate overlap capacitance per unit channel width	F	3.2e-16
Gatenoise	Flag for in/exclusion of induced gate thermal noise	None	0
Nt	Coefficient of the thermal noise at the actual temperature	J	1.656e-20
Nfar	First coefficient of the flicker noise for the reference transistor	$V^{-1}\times m^{-1}$	1.573e+23 (NMOS)
Nfbr	Second coefficient of the flicker noise for the reference transistor	$V^{-1}\times m^{-2}$	4.752e9 (NMOS)
Nfcr	Second coefficient of the flicker noise for the reference transistor	$V^{-1}\times m^{-2}$	0.0 (NMOS)
wVsubfwd	Substrate junction forward bias (warning)	V	None
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	None
wBvg	Gate oxide breakdown voltage (warning)	V	None
wBvds	Drain-source breakdown voltage (warning)	V	None
wIdsmax	Maximum drain-source current (warning)	A	None
wPmax	Maximum power dissipation (warning)	W	None
AllParams	Data Access Component (DAC) Based Parameters	None	None

Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelname MOS11 [parm=value]*
```

The model statement starts with the required keyword *model*. It is followed by the *modelname* that will be used by mosfet components to refer to the model.The third parameter indicates the type of model; for this model it is *MOS11*. Use either parameter NMOS=yes or PMOS=yes to set the transistor type. The rest of the model contains pairs of model parameters and values, separated by an equal sign. The name of the model parameter must appear exactly as shown in the parameters table-these names are case sensitive. Some model parameters have aliases, which are listed in parentheses after the main parameter name; these are parameter names that can be used instead of the primary parameter name. Model parameters may appear in any order in the model statement. Model parameters that are not specified take the default value indicated in the parameters table. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim) in Using Circuit Simulators.

Example:

```
modelNch12 MOS11 \
 Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

Notes/Equations

1. This model supplies values for an MM11 device.

   http://www.nxp.com/models/mos_models/model11/
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to *DataAccessComponent* (ccsim) in *Introduction to Circuit Components*). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MOSVAR_1_1 (PSP-Based MOS Varactor Version 1.1 Model and Instance)

Note
For detailed information please refer to the MOSVAR 1.1 manual provided by the Arizona State University at http://pspmodel.asu.edu/downloads/MOSVAR1p1p0.pdf .

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to Design Kit Development.

```
model modelName mosvar_1_1 [parm=value]*
```

Example:

```
model Nch mosvar_1_1 TOXO=2.15e-9
```

Model Parameters

Name (Alias)	Description	Units	Default
Gender	+1=N-type, -1=P-type		1(n),-1(p)
Tnom (TR)	Parameter measurement temperature	deg C	21
Secured	Secured model parameters		0
VERSION	model version		1.1
SUBVERSION	model subversion		0
REVISION	model revision		0
LEVEL	model level		1000
TMIN	minimum reference/ambient temperature		-100
TMAX	maximum reference/ambient temperature		500
VMAX	maximum voltage applied between nodes g and b		10000
LMIN	minimum allowed drawn length		1e-08
LMAX	maximum allowed drawn length		9.9e+09
WMIN	minimum allowed drawn width		1e-08
WMAX	maximum allowed drawn width		9.9e+09
SWRES	switch to control series resistance: 0=exclude and 1=include		1
TYPE	substrate doping TYPE: -1=n-TYPE and +1=p-TYPE		-1
TYPEP	polysilicon doping TYPE: -1=n-TYPE and +1=p-TYPE		-1
TOXO	oxide thickness		2e-09
TAU	time constant for inversion charge recombination/generation		0.1
VFBO	flatband voltage (for p-TYPE substrate)		0
NSUBO	substrate doping level		3e+23
MNSUBO	maximum change in absolute doping, limited to 1 order of mag up		1
DNSUBO	doping profile slope parameter		0
VNSUBO	doping profile corner voltage parameter		0
NSLPO	doping profile smoothing parameter		0.1
NPO	polysilicon doping level		1e+27
QMC	quantum mechanical correction factor		1
DLQ	length delta for capacitor size		0

DWQ	width delta for capacitor size		0
DWR	width delta for substrate resistance calculation		0
CFRL	fringing capacitance in length direction		0
CFRW	fringing capacitance in width direction		0
RSHG	gate sheet resistance		1
RPV	vertical resistance down through gate in units of ohm*m^2		0
REND	end resistance (extrinsic well res. plus vertical contact res. to well) per width		0.0001
RSHS	substrate sheet resistance		1000
UAC	accumulation layer zero bias mobility		0.05
UACRED	accumulation layer mobility degradation factor		0
STVFB	temperature dependence of VFB		0
STRSHG	temperature dependence of RSHG		0
STRPV	temperature dependence of RPV		0
STREND	temperature dependence of REND		0
STRSHS	temperature dependence of RSHS		0
STUAC	temperature dependence of UAC		0
FETA	Effective field parameter		1
SWIGATE	flag for gate current: 0=turn off and 1=turn on		0
CHIBO	tunneling barrier height for electrons		3.1
CHIBPO	tunneling barrier height for holes		4.5
STIG	temperature dependence for gate current densities of ECB, HVB		2
LOV	overlap length		0
NOVO	effective doping level of overlap regions		5e+25
IGINVLW	ECB gate channel current pre-factor for 1 um^2 channel area		0
IGOVW	ECB gate overlap current pre-factor for 1 um wide gate overlap region		0
GCOO	ECB gate tunneling energy adjustment		0
GC2O	ECB gate current slope factor		0.375
GC3O	ECB gate current curvature factor		0.063
IGCHVLW	HVB gate channel current pre-factor for 1 um^2 channel area		0
IGOVHVW	HVB gate overlap current pre-factor for 1 um wide gate overlap region		0
GCOHVO	HVB gate tunneling energy adjustment		0
GC2HVO	HVB gate current slope factor		0.375
GC3HVO	HVB gate current curvature factor		0.063
IGMAX	maximum gate tunneling current		1e-05

Instance Netlist Format

```
modelName [:Name] d g s b
```

Example

```
Nch:M1 2 1 0 W=10u L=0.9u
```

Instance Parameters

Name (Alias)	Description	Units	Default
Temp	Device operating temperature	deg C	25
Trise (DTA)	Temperature rise over ambient	deg C	0
Mode	Nonlinear spectral model on/off		1
Noise	Noise generation on/off		1
m	multiplicity factor		1
W	design width of varactor		1e-06
L	design length of varactor		1e-06
NGCON	number of gate contacts		1

DC Operating Point Information

Name	Description	Units
I	Current	A
V	Voltage	V
Cap	Capacitance	F

MOSVAR (PSP-Based MOS Varactor Model)

Instance Parameters

Name	Description	Unit	Default	Min	Max
m	Multiplicity factor		1	0	
W	Design width of varactor	m	1.0e-6	0.0	
L	Design length of varactor	m	1.0e-6	0.0	
NGCON	Number of gate contacts		1	1	2
DTA	Local temperature delta to ambient	°C	0.0		

Model Parameters

Name	Description	Units	Default	Min	Max
VERSION	Model version		1.0		
SUBVERSION	Model subversion		0.0		
REVERSION	Model reversion		0.0		
LEVEL	Model level		1000		
TMIN	Minimum reference/ambient temperature	°C	-100.0	-250.0	21.0
TMAX	Maxinum reference/ambient temperature	°C	500.0	21.0	1000.0
VMAX	Maximum voltage applied between nodes g and b	V	10000.0	0.5	
TR	Nominal (reference) temperature	°C	21.0	-250.0	1000.0
LMIN	Minimum allowed drawn length	m	1.0e-8	0.0	
LMAX	Maximum allowed drawn length	m	9.9e9	0.0	
WMIN	Minimum allowed drawn width	m	1.0e-8	0.0	
WMAX	Maximum allowed drawn width	m	9.9e9	0.0	
SWRES	Switch to control series resistance: 0=exclude and 1=include		1		
TYPE	Substrate doping TYPE: -1=n-TYPE and +1=p-TYPE		-1		
TYPEP	Polysilicon doping TYPE: -1=n-TYPE and +1=p-TYPE		-1		
TOXO	Oxide thickness	m	2.0e-9	5.0e-10	2.0e-8
TAU	Time constant for inversion charge recombination/generation	s	0.1	0	10.0
VFBO	Flatband voltage (for p-TYPE substrate)	V	0.0		
NSUBO	Substrate doping level	$/m^3$	3.0e23	1.0e22	1.0e25
MNSUBO	Maximum change in absolute doping, limited to 1 order of mag up		1.0	1.0	10.0
DNSUBO	Doping profile slope parameter		0.0	0.0	100.0
VNSUBO	Doping profile corner voltage parameter		0.0	-5.0	5.0
NSLPO	Doping profile smoothing parameter		0.1	0.1	1.0
NPO	Doping profile corner voltage parameter	$/m^3$	1.0e27	1.0e24	1.0e27
QMC	Quantum mechanical correction factor		1.0	0.0	
DLQ	Length delta for capacitor size	m	0.0		

DWQ	Width delta for capacitor size	m	0.0		
DWR	Width delta for substrate resistance calculation	m	0.0		
CFRL	Fringing capacitance in length direction	F/m	0.0	0.0	
CFRW	Fringing capacitance in width direction	F/m	0.0	0.0	
RSHG	Gate sheet resistance	Ω / sq	1.0	0.0	
RPV	Vertical resistance down through gate in units of Ω × m^2	Ω × m^2	0.0	0.0	
REND	End resistance (extrinsic well res. plus vertical contact res. to well) per width	Ω × m	1.0e-4	0.0	
RSHS	Substrate sheet resistance	Ω / sq	1000.0	0.0	10000.0
UAC	Accumulation layer zero bias mobility	m^2 / V / s	5.0e-2	0.0	
UACRED	Accumulation layer mobility degradation factor	/V	0.0	0.0	
STVFB	Temperature dependence of VFB	V / K	0.0		
STRSHG	Temperature dependence of RSHG		0.0		
STRPV	Temperature dependence of RPV		0.0		
STREND	Temperature dependence of REND		0.0		
STRSHS	Temperature dependence of RSHS		0.0		
STUAC	Temperature dependence of UAC		0.0		
STETA	Effective field parameter		1.0	0.0	
SWIGATE	Flag for gate current: 0=turn off and 1=turn on		0		
CHIBO	Tunneling barrier height for electrons	V	3.1	1.0	
CHIBOP	Tunneling barrier height for holes	V	4.5	1.0	
STIG	Common temperature coefficient for gate currents (ECB, HVB and HVB)		2.0		
LOV	Overlap length	m	0.0	0.0	
NOVO	Effective doping level of overlap regions	/m^3	5.0e25	1.0e22	1.0e26
IGINVLW	ECB gate channel current pre-factor for 1 μm^2 channel area	A	0.0	0.0	
IGOVW	ECB gate overlap current pre-factor for 1 μm wide gate overlap region	A	0.0	0.0	
GCOO	ECB gate tunneling energy adjustment		0.0	-10.0	10.0
GC2O	ECB gate current slope factor		0.375	0.0	10.0
GC3O	ECB gate current curvature factor		0.063	-10.0	10.0
IGCHVLM	HVB gate channel current pre-factor for 1 μm^2 channel area	A	0.0	0.0	
IGOVHVW	HVB gate overlap current pre-factor for 1 μm wide gate overlap region	A	0.0	0.0	
GCOHVO	HVB gate tunneling energy adjustment		0.0	-10.0	10.0
GC2HVO	HVB gate current slope factor		0.375	0.0	10.0
GC3HVO	HVB gate current curvature factor		0.063	-10.0	10.0
IGCEVLM	EVB gate channel current pre-factor for 1 μm^2 channel area	A	0.0	0.0	
IGOVEVW	EVB gate overlap current pre-factor for 1 μm wide gate overlap region	A	0.0	0.0	
GCOEVO	EVB gate tunneling energy adjustment		0.0	-10.0	10.0
GC2EVO	EVB gate current slope factor		0.375	0.0	10.0
GC3EVO	EVB gate current curvature factor		0.063	-10.0	10.0

Instance Netlist Format

```
modelName:instanceName g bi b [parm=value]
```

Example:

```
amos:X1 1 2 3 w=10 um l=10 um
```

Model Netlist Format

Model statements for the ADS circuit simulator may be stored in an external file. This is typically done with foundry model kits. For more information on how to set up and use foundry model kits, refer to *Design Kit Development* (dkarch).

```
model modelName mosvar [parm=value]
```

The model statement starts with the required keyword model. It is followed by the modelName that will be used by components to refer to the model. The third parameter indicates the type of model; for this model it is mosvar. Use the parameter gender to set the model parameters. Model parameters that are not specified take the default value. For more information about the ADS circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to *ADS Simulator Input Syntax* (cktsim).

Example:

```
model model amos mosvar SWRES=1 TOXO=3.6e-9 VFBO=6.0e-2
```

Notes/Equations

1. Please see the following PDF document for detailed information: http://pspmodel.asu.edu/downloads/MOSVAR1p0p0.pdf

Devices and Models, NXP SiMKit

The ADS circuit simulator supports the transistor models developed by NXP Semiconductors, called SiMKit. Version 3.4 of SiMKit is currently shipped with the circuit simulator, older versions of SiMKit are available from the NXP website. Please refer to the following website for more information on SiMKit:

http://www.nxp.com/models/source/

The simulator will recognize these models and instances at the netlist level. Schematic level support for ADS is available by downloading the SiMKit design kit from the NXP website. Please refer to the following website for support documentation for the SiMKit 3.4 components and models in ADS:

SiMKit 3.4 Components and Models
(located at http://www.agilent.com/find/eesof in the Support and Services Knowledge Center)

Model Category	**Netlist Model Names**
BJT 3500	bjt3500, bjt3500t, bjtd3500, bjtd3500t
BJT 500	bjt500, bjt500t
BJT 504 (Mextram)	bjt504, bjt504t, bjtd504, bjtd504t
Juncap	juncap, juncap200
MOS 11	mos1100, mos1100e, mos11010, mos11010t, mos11011, mos11011t, mos1101e, mos1101et, mos11020, mos11020t, mos11021, mos11021t mos1102e, mos1102et
MOS 20	mos2001, mos2001e, mos2001et, mos2001t, mos2002, mos2002e, mos2002t, mos2002et
MOS 31	mos3100, mos3100t
MOS 40	mos4000, mos4000t
PSP	psp103, pspnqs103, psp102e, psp1020, psp1021, pspnqs102e, pspnqs1020, pspnqs1021

For detailed information about NXP SiMKit, refer to http://www.nxp.com/models/source/ .

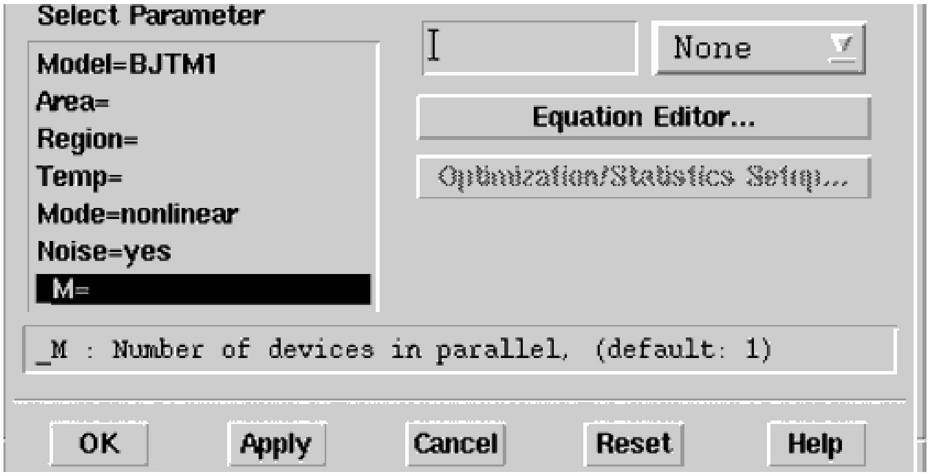
Equation-Based Non-Linear Components

- *FDD1P to FDD10P (1- to 10-Port Frequency-Domain Defined Devices)* (ccnld)
- *NonlinC (Nonlinear Capacitor)* (ccnld)
- *NonlinCCCS (Nonlinear Current-Controlled Current Source)* (ccnld)
- *NonlinCCVS (Nonlinear Current-Controlled Voltage Source)* (ccnld)
- *NonlinL (Nonlinear Inductor)* (ccnld)
- *NonlinVCCS (Nonlinear Voltage-Controlled Current Source)* (ccnld)
- *NonlinVCVS (Nonlinear Voltage-Controlled Voltage Source)* (ccnld)
- *SDD14P (Symbolically Defined Devices, 1-12 and 14 Ports)* (ccnld)

Multiplicity Parameter _M

The multiplicity feature provides a way to scale components or entire sub-circuits containing many components and sub-circuits. Given a component with a multiplicity value *M* , the simulator treats this component as if there were *M* such components all connected in parallel. Sub-circuits within sub-circuits will be appropriately scaled.

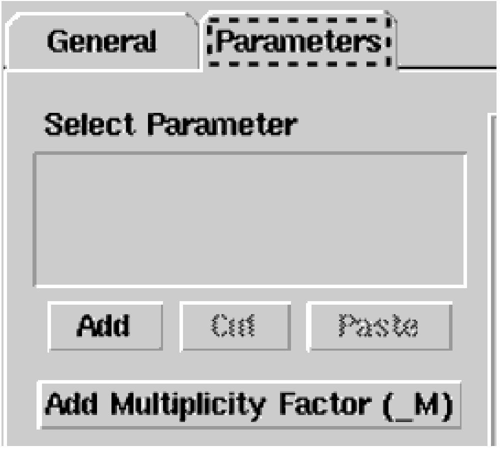
The _M parameter is available at the component level as shown here. (For components that do not explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



Model=BJTM1
Area=
Region=
Temp=
Mode=nonlinear
Noise=yes
_M=

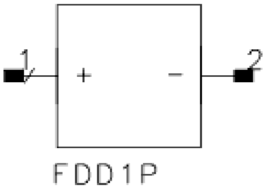
_M : Number of devices in parallel, (default: 1)

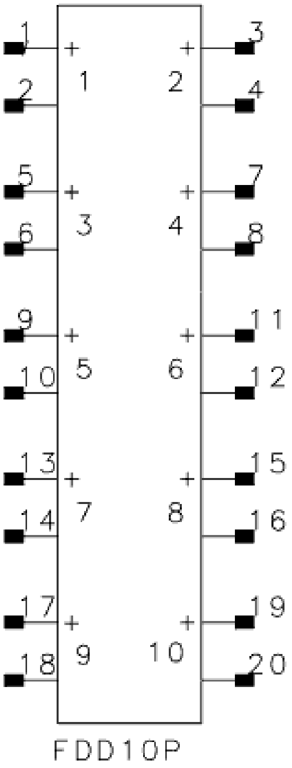
For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameters** from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor_M**.



FDD1P to FDD10P (1- to 10-Port Frequency-Domain Defined Devices)

Symbol





Parameters

Name	Description	Units	Default
I[i, j]	current equation that describes spectral current. *i* refers to the port number. *j* refers to a frequency index	None	None
V[i, j]	voltage equation that describes spectral voltage. *i* refers to the port number. *j* refers to a frequency index		
Freq[k]	carrier frequency	F	Hz
Trig[k]	trigger event		
Ce[k]	clock enable definiiton		

Range of Usage

$0 \le i \le 10$

Notes/Equations

1. The frequency-domain defined (FDD) device enables you to create equation-based, user-defined, nonlinear components. The FDD is a multi-port device that describes current and voltage spectral values in terms of algebraic relationships of other voltage and current spectral values. It is for developing nonlinear, behavioral models that are more easily defined in the frequency domain.
2. For more information on how to use these devices and application examples, refer to *Custom Modeling with Frequency-Domain Defined Devices* (modbuild) in *User-Defined Models*.
3. Equations that relate to port spectral voltages and currents are described in the frequency domain. The two basic types of equations are current equations and voltage equations. Their format is:

   I[port, findex] = f(_sv(),_sv_d(),_si(),_si_d())
   V[port, findex] = f(_sv(),_sv_d(),_si(),_si_d())

   where *port* is the port number and *findex* is a frequency index.
   The equations can be listed in any order; more than one equation can be used for a single port, but each port must have at least one equation.
   The variables of interest at a given port are the port spectral voltages and currents. Spectral voltages and currents can be obtained using the functions:

   _sv(), _si(), *_sv_d()*, and *_si_d()*.
4. The Freq parameter enables you to define one or more carrier frequencies.
5. The FDD device enables you to define up to 31 trigger events. Any time the value of the trigger expression is equal to a number other than 0, a trigger event is declared for the corresponding trigger.
6. Clock enables specify that the output of a given port can change only when a specified trigger, or a set of specified triggers, occurs.

NonlinC (Nonlinear Capacitor)

Symbol

Parameters

Name	Description	Units	Default
Coeff	list of coefficients that describe a polynomial that defines capacitance as a function of voltage v across the capacitor where: cap = Coeff[0] + Coeff[1] × v + Coeff[2] × v^2 +, ... , + Coeff[n] × v^n and coefficients are entered using the list function: Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])	None	list(1,1)

Notes/Equations

1. The coefficients of the polynomial are specified in the dialog box for this component. Enter the values for each coefficient in a single line.

   units of Coeff[0] = farads
   units of Coeff[1] = farads/volt
   units of Coeff[2] = farads/volt^2

   Coefficients are entered using the list function. For example, if

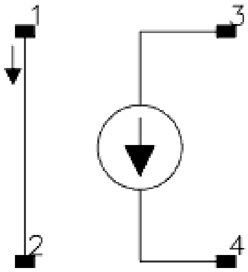
   $C = 5V^2 + 4V^4$

   the parameter entry is:

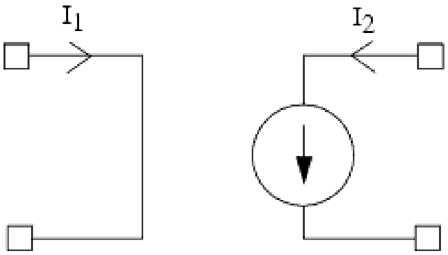
   Coeff = list(0,0,5,0,4)
2. The controlling voltage V is the voltage across the capacitor, with pin 1 being positive and pin 2 being negative.
3. This component has no default artwork associated with it.
4. For linear analyses DC, AC and S_Param, the behavior of this component is linearized around its DC operating point, so the effective value of cap=Coeff[0].

NonlinCCCS (Nonlinear Current-Controlled Current Source)

Symbol



Illustration



Parameters

Name	Description	Units	Default
Coeff	list of coefficients that describe a polynomial that defines output current I_2 as a function of input current I_1:if only one coefficient is specified: I_2 = Coeff[0] × I_1^2 the coefficient is entered using the list function: Coeff = list(Coeff[0]) Otherwise: I_2 Coeff[0] + Coeff[1] × I_1 + Coeff[2] × I_1^2 +, ... , + Coeff[n] × I_1^n and coefficients are entered as: Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])	None	list(1,1)

Notes/Equations

1. The coefficients of polynomial are specified in the dialog box for this component. Enter values for each coefficient in a single line using the list function. For example, if:

$I_2 = 3 - 2I_1^2 + 5I_1^6$

the parameter entry is:

Coeff = list(3,0,-2,0,0,0,5)

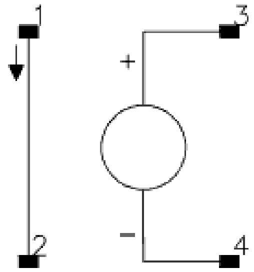
If $I_2 = 5I_1$, then Coeff = list(5)

If $I_2 = 5$, then Coeff = list(5,0)

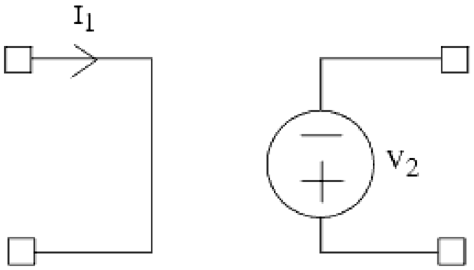
2. This component has no default artwork associated with it.
3. Output current is in Amperes.

NonlinCCVS (Nonlinear Current-Controlled Voltage Source)

Symbol



Illustration



Parameters

Name	Description	Units	Default
Coeff	a list of coefficients that describe a polynomial that defines output voltage V_2 as a function of input current I_1: if only one coefficient is specified V_2 = Coeff[0] × I_1 the coefficient is entered using the list function: Coeff = list(Coeff[0]) otherwise: V_2 = Coeff[0] + Coeff[1] × I_1 + Coeff[2] × I_1^2 +, ... , + Coeff[n] × I_1^n and coefficients are entered as: Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])	None	list(1,1)

Coeff = a list of coefficients that describe a polynomial that defines output voltage V_2 as a function of input current I_1:

if only one coefficient is specified

V_2 = Coeff[0] × I_1

the coefficient is entered using the list function:

Coeff = list(Coeff[0])

otherwise:

V_2 = Coeff[0] + Coeff[1] × I_1 + Coeff[2] × I_1^2 +, ... , + Coeff[n] × I_1^n

and coefficients are entered as:

Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])

Notes/Equations

1. The coefficients of polynomial are specified in the dialog box for this component. Enter values for each coefficient in a single line. Enter values for each coefficient in a single line using the list function. For example, if:

   $V_2 = 3 - 2I_1^2 + 5I_1^6$

   the parameter entry is:

   Coeff = list(3,0,-2,0,0,0,5)

   If $V_2 = 5I_1$, then Coeff = list(5)

   If $V_2 = 5$, then Coeff = list(5,0)
2. This component has no default artwork associated with it.
3. Output voltage is in volts.

NonlinL (Nonlinear Inductor)

Symbol

Parameters

Name	**Description**	**Units**	**Default**
Coeff	a list of coefficients that describe a polynomial that defines inductance as a function of current through the inductor: $L= Coeff[0] + Coeff[1] \times I + Coeff[2] \times I^2 +, \ldots , +Coeff[n] \times I^n$ and coefficients are entered using the list function: Coeff = list(Coeff[0],Coeff[1],Coeff[2] , ... , Coeff[n])	None	list(1,1)

Notes/Equations

1. The coefficients of the polynomial are specified in the dialog box for this component. Enter the values for each coefficient in a single line.

   units of Coeff[0] = henries
   units of Coeff[1] = henries/amp
   units of Coeff[2] = henries/amp^2

   Coefficients are entered using the list function. For example, if:

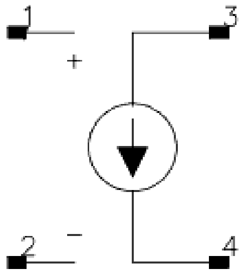
   $L= 5I^2 + 4I^4$

   the parameter entry is:

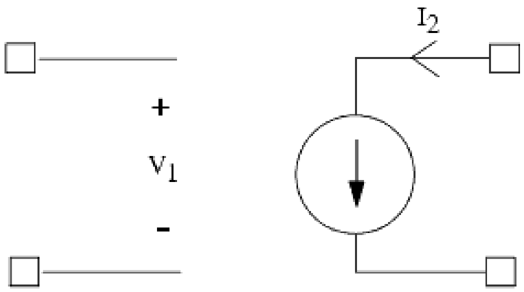
   Coeff = list(0,0,5,0,4)
2. The controlling current I is the current flowing from pin 1 to pin 2.
3. This component has no default artwork associated with it.
4. For linear analyses DC, AC and S_Param, the behavior of this component is linearized around its DC operating point, so the effective value of L=Coeff[0].

NonlinVCCS (Nonlinear Voltage-Controlled Current Source)

Symbol



Illustration



Parameters

Name	Description	Units	Default
Coeff	a list of coefficients that describe a polynomial that defines output current I_2 as a function of input voltage V_1: if only one coefficient is specified: I_2 = Coeff[0] × V_1 the coefficient is entered using the list function: Coeff = list(Coeff[0]) otherwise: I_2 = Coeff[0] + Coeff[1] × V1 + Coeff[2] × V_1^2 +, ... , +Coeff[n] × V_1^n and coefficients are entered as: Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])	None	list(1,1)

Notes/Equations

1. The coefficients of polynomial are specified in the dialog box for this component. Enter values for each coefficient in a single line. Enter values for each coefficient in a single line using the list function. For example, if:

$I_2 = 3 - 2V_1^2 + 5V_1^6$

the parameter entry is:

Coeff = list(3,0,-2,0,0,0,5)

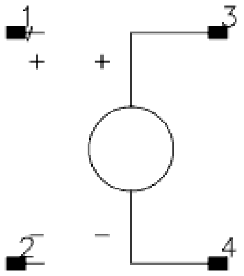
If $I_2 = 5V_1$, then Coeff = list(5)

If $I_2 = 5$, then Coeff = list(5,0)

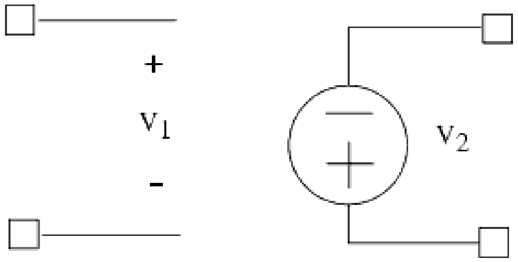
2. This component has no default artwork associated with it.
3. Output current is in amperes.

NonlinVCVS (Nonlinear Voltage-Controlled Voltage Source)

Symbol



Illustration



Parameters

Name	Description	Units	Default
Coeff	a list of coefficients that describe a polynomial that defines output voltage V_2 as a function of input voltage V_1: If only one coefficient is specified: V_2 = Coeff [0] × V_1 the coefficient is entered using the list function: Coeff = list(Coeff[0]) otherwise, V_2 = Coeff[0] + Coeff[1] × V1 + Coeff[2] × V12 +, ... , +Coeff[n] × V_1^n and coefficients are entered as: Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])	None	list(1,1)

Notes/Equations

1. The coefficients of polynomial are specified in the dialog box for this component. Enter values for each coefficient in a single line. Enter values for each coefficient in a single line using the list function. For example, if:

$V_2 = 3 - 2V_1^2 + 5V_1^6$

the parameter entry is:

Coeff = list(3,0,-2,0,0,0,5)

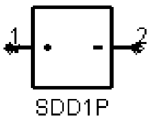
If $V_2 = 5V_1$, then Coeff = list(5)

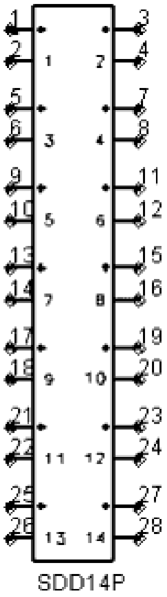
If $V_2 = 5$, then Coeff = list(5,0)

2. This component has no default artwork associated with it.
3. Output voltage is in volts.

SDD1P to SDD12P, SDD14P (Symbolically Defined Devices, 1-12 and 14 Ports)

Symbol





Parameters

Name	Description	Units	Default
I[p,w]	explicit equation that describes port current in terms of voltage. *p* refers to the port number. *w* refers to the weighting function (0,1, or user defined).	None	I[1,0]=(_v1)/50.0
C[n]	controlling current device name (repeatable). *n* is index of list of controlling currents	None	None
Cport[n]	port number on controlling current device to use (repeatable). *n* is index of port number associated with current source C[n]	None	1
_M	number of devices in parallel	None	1
F[p,w]	implicit equation defining a nonlinear relationship of port voltages and port currents (or the currents of certain other devices) that is equal to 0. *p* refers to the port number. *w* refers to the weighting function (0, 1, or user defined).		
H[w]	user-defined weighting function		
In[p,w]	equation that specifies the noise current squared. *p* refers to the port number. *w* refers to the weighting function (0, 1, or user defined).		
Nc[p,q]	complex noise correlation coefficient between ports *p* and *q*.		

Range of Usage

1 ≤ p ≤ 60
1 ≤ q ≤ 60
1 ≤ n
0 ≤ w, but H[w] is internally pre-defined for *w*={0,1}, use only 2 ≤ w for H[].

Notes/Equations

1. The symbolically-defined device (SDD) enables you to create equation based, user-defined, nonlinear components. The SDD is a multi-port device which is defined by specifying algebraic relationships that relate the port voltages, currents, and their derivatives, plus currents from certain other devices.
2. Devices SDD1P through SDD10P are available from the component palette and library browser. Two additional devices, SDD12P and SDD14P are only available by typing their exact names into the Component History box, pressing Enter, and moving the cursor to the drawing area to place the components.
3. The port index *p* starts at 1 and should go no higher than the number of ports on the SDD. SDD1P through SDD10P are available from the *Devices - Nonlinear Equation* palette; SDD12P and SDD14P are available for direct placement.
4. Port variables, *_in* and *_vn* , contain the current and voltage values of a port, respectively. The suffix *n* specifies the port number, for example, the current and voltage variables for port 1 are *_i1* and *_v1* , respectively.
5. Equations that relate port currents and voltages are specified in the time domain. These constitutive relationships may be specified in either *explicit* or *implicit* representations.
   With the *explicit* representation, the current at port *k* is specified as a function of port voltages:

   $$i_k = func(v_1, v_2, \cdots, v_n)$$

   The *implicit* representation uses an implicit relationship between any of the port currents and any of the port voltages:

   $$f_k(v_1, v_2, \cdots, v_n, i_1, i_2, \cdots, i_n) = 0$$

   Using the implicit representation, you can also reference current flowing in another device by using controlling currents.
   Different types of expressions cannot be mixed-that is, a single port must be described by either implicit or explicit expressions. Every port must have at least one equation.
   By convention, a positive port current flows into the terminal marked + .
6. A *weighting function* H[w] is a frequency-dependent expression used to scale the spectrum of a port current. Weighting functions are evaluated in the frequency domain. There are two predefined weighting functions. Weighting function 0 is defined to be identically one; it is used when no weighting is desired. Weighting function 1 is defined as jω and is used when a time derivative is desired. Other weighting functions can be defined, starting with 2. H[w] can be made dependent on frequency by using the global variable *freq*.
7. An SDD can also be set up to reference the current flowing in another device. The devices that can be referenced are limited to:
   - independent voltage sources
   - current probes and shorts
   - inductors (L and L_Model)
   - hybrid (primary current only)

- SnP S-parameter devices
- ZnP Z-parameter devices
- SDD (implicit voltage ports only)
  To specify a current as a control current, you enter the instance name of the device in the C[n] parameter of the SDD. For devices with more than one port (SnP, ZnP, SDD), the port number whose current is to be measured must be specified with Cport[n]. These currents can then be referred to using the variable _*cn* for the *n* th referenced current. The variables _*cn* can be used in the SDD equations along with the SDD port voltages _*vn* and port currents _*in* .

8. In[*p*,*w*] specifies the short-circuit noise current squared, in units of amperes squared at port *p* , with weighting function *w*. This expression should not have a negative value:

   $$< i_p, i_p^* >$$

   When user-defined weighting function H[*w*] are used with noise, they should be real and non-negative. Only one In[*p*,*w*] can be defined for each port *p*. If there is a need to define two noise currents at one port with different weighting factors, introduce one of them through an additional SDD port that is used only for noise. For example, on a two port SDD the expressions on the left-hand are not legal. Instead, creating a new third port and using the expressions on the right-hand solves the problem:

Incorrect	**Correct**
SDD2P In[1,0]=funcA(_v1) In[1,2]=funcB(_v1) H[2]=freq**2	SDD3P In[1,0]=funcA(_v1) I[3,0]=0 In[3,2]=funcB(_v1) H[2]=freq**2

9. Nc[*p*,*q*] specifies the complex noise correlation coefficient between ports *p* and *q*. It should be a complex number with a magnitude ≤ 1, Nc[*p*,*q)] and Nc[_q*,*p*] should be complex conjugates of each other. If only one is specified, the other term is assumed since the noise correlation matrix is assumed to be Hermitian. Nc[*p*,*q*] should be a constant for harmonic balance noise analysis. This parameter is not used during Transient Circuit Envelope noise analysis.

   $$Nc[p,q] = \frac{<i_p, i_q^*>}{\sqrt{<i_p, i_p^*> * <i_q, i_q^*>}}$$

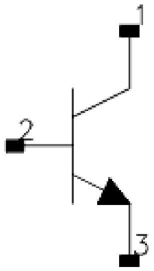
10. For more information on how to use these devices and application examples, refer to *Custom Modeling with Symbolically-Defined Devices* (modbuild) in *User-Defined Models*.

Linear Devices

- *BIP (Bipolar Transistor with Alpha Current Gain)* (ccnld)
- *BIPB (Bipolar Transistor, with Beta Current Gain)* (ccnld)
- *DFET (Dual-Gate Field Effect Transistor)* (ccnld)
- *FET2 (Field Effect Transistor with Source Resistance)* (ccnld)
- *FET (Field Effect Transistor)* (ccnld)
- *FETN1 (FET Noise Model (Van der Ziel))* (ccnld)
- *FETN2 (FET Noise Model (Statz, et al))* (ccnld)
- *FETN3 (FET Noise Model (Fukui))* (ccnld)
- *FETN4 (FET Noise Model (Podell))* (ccnld)
- *FETN4a (FET Noise Model (Podell))* (ccnld)
- *FETN5 (FET Noise Model Gupta, et al))* (ccnld)
- *HYBPI (Hybrid-Pi Bipolar Transistor with Alpha Current Gain)* (ccnld)
- *PIN2 (PIN Diode, Packaged Model)* (ccnld)
- *PIN (PIN Diode, Chip Model)* (ccnld)

BIP (Bipolar Transistor with Alpha Current Gain)

Symbol



Parameters

Name	Description	Units	Default
A	magnitude of current gain (alpha) at DC	None	0.99
T	time delay associated with current gain	nsec	1.0
F	-3 dB frequency for current gain	GHz	0.1
Cc	collector capacitance	pF	10.0
Gc	collector conductance	uS	1.0
Rb	base resistance	Ohm	2.0
Lb	base inductance	nH	1.0
Ce	emitter capacitance	pF	10.0
Re	emitter resistance	Ohm	2.0
Le	emitter inductance	nH	1.0

Range of Usage

$0 < A < 1.0$

Notes/Equations

1. $A(f) = A \times \frac{e^{-(j2\pi fT)}}{1+j\left(\frac{f}{F}\right)}$ (for F > 0)

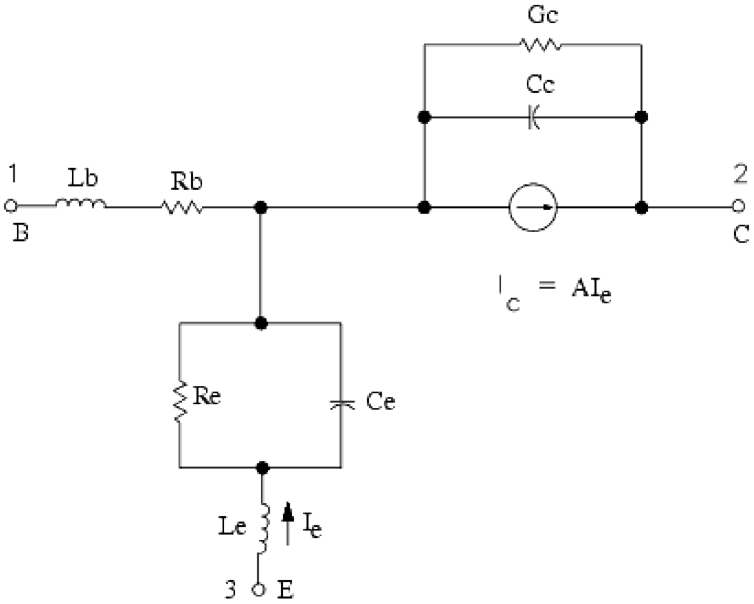
   $A(f) = A \times e^{-(j2\pi fT)}$ (for F = 0)

   where:

   f = simulation frequency
   F = reference frequency

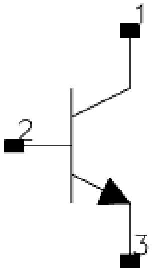
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



BIPB (Bipolar Transistor, with Beta Current Gain)

Symbol



Parameters

Name	Description	Units	Default
B	magnitude of current gain (Beta) at DC	None	20.0
A	phase offset of current gain	deg	0.0
T	time delay associated with current gain	nsec	1.0
Cc	collector capacitance	pF	10.0
Gc	collector conductance	uS	1.0
Rb	base resistance	Ohm	2.0
Lb	base inductance	nH	1.0
Ce	emitter capacitance	pF	10.0
Re	emitter resistance	Ohm	2.0
Le	emitter lead inductance	nH	1.0
Rel	emitter lead resistance	Ohm	0.2

Range of Usage

$B > 0$

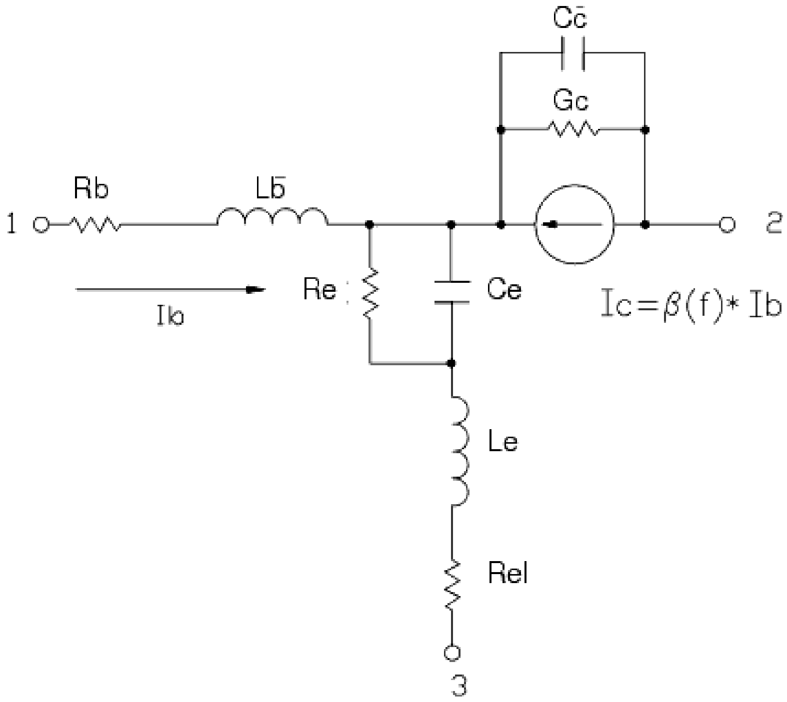
Notes/Equations

1. $\beta(f) = B \times e^{-j(2\pi f T_{sec} - A_{radians})}$

   where:

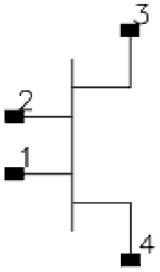
   f = simulation frequency in Hz
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



DFET (Dual-Gate Field Effect Transistor)

Symbol



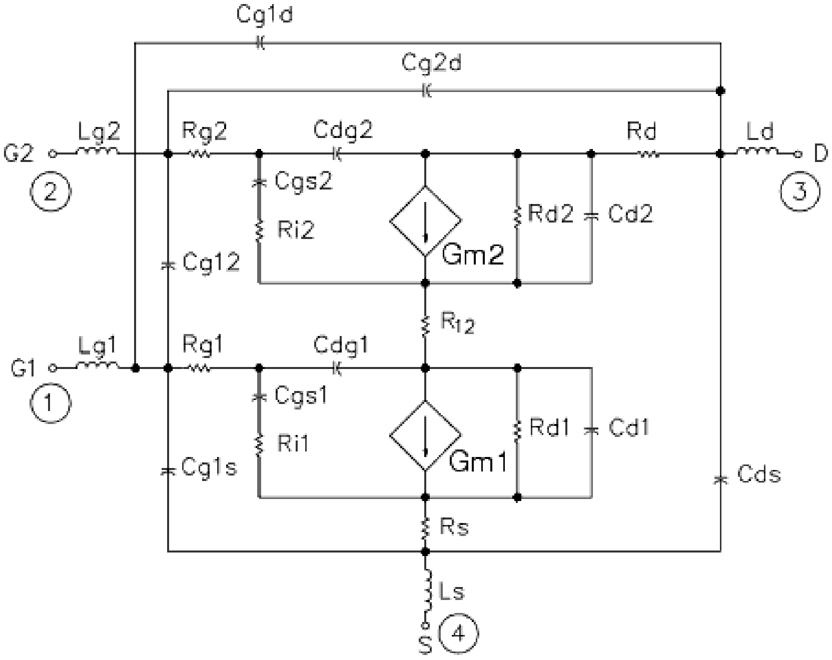
Parameters

Name	Description	Units	Default
Gm1	DC transconductance at gate 1	uS	20.0
T1	time delay of Gm1	nsec	1.0
F1	-3 dB frequency for Gm1	GHz	1.0
Cgs1	gate-to-source capacitance - gate 1	pF	10.0
Ri1	input resistance - gate 1	Ohm	0.1
Cdg1	drain-to-gate capacitance - gate 1	pF	10.0
Cds1	drain-to-source capacitance - gate 1	pF	10.0
Rds1	drain-to-source resistance - gate 1	Ohm	500.0
Rg1	gate1 resistance	Ohm	0.1
Lg1	gate1 inductance	nH	10.0
Gm2	dc transconductance - gate 2	uS	20.0
T2	time delay of Gm2	nsec	1.0
F2	−3 dB frequency for Gm2	GHz	1.0
Cgs2	gate-to-source capacitance - gate 2	pF	10.0
Ri2	input resistance - gate 2	Ohm	0.1
Cdg2	drain-to-gate capacitance - gate 2	pF	10.0
Cds2	drain-to-source capacitance - gate 2	pF	10.0
Rds2	drain-to-source resistance - gate 2	Ohm	500.0
Rg2	gate 2 resistance	Ohm	0.1
Lg2	gate 2 inductance	nH	10.0
Rd	drain resistance	Ohm	25.0e-6
Ld	drain inductance	nH	1.0
Rs	source resistance	Ohm	1.0
Ls	source inductance	nH	10.0
Cg1s	gate1-to-source capacitance	pF	10.0
Cg12	gate1-to-gate2 capacitance	pF	5.0
Cg1d	gate1-to-drain capacitance	pF	10.0
Cg2d	gate2-to-drain capacitance	pF	1.0
Cds	drain-to-source capacitance	pF	1.0
R12	resistance between drain 1 and source 2	Ohm	1.0

Notes/Equations

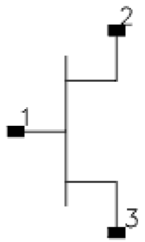
1. For time-domain analysis, the frequency-domain analytical model is used.
2. This component is assumed to be noiseless.
3. This component has no default artwork associated with it.

Equivalent Circuit


Cg1d
Cg2d
G2
Lg2
Rg2
Cdg2
Rd
Ld
D
②
③
Cgs2
Ri2
Gm2
Rd2
Cd2
Cg12
R12
G1
Lg1
Rg1
Cdg1
①
Cgs1
Ri1
Gm1
Rd1
Cd1
Cg1s
Cds
Rs
Ls
S
④

FET2 (Field Effect Transistor with Source Resistance)

Symbol



Parameters

Name	Description	Units	Default
G	magnitude of transconductance at DC	uS	20.0
T	time delay associated with transconductance	nsec	1.0
F	transconductance roll-off frequency	GHz	1.0
Cgs	gate-to-source capacitance	pF	10.0
Ggs	gate-to-source conductance	uS	1.0
Ri	channel resistance	Ohm	0.1
Cdg	drain-to-gate capacitance	pF	10.0
Cdc	dipole layer capacitance	pF	10.0
Cds	drain-to-source capacitance	pF	10.0
Rds	drain-to-source resistance	Ohm	500.0
Rs	source resistance	Ohm	0.1

Notes/Equations

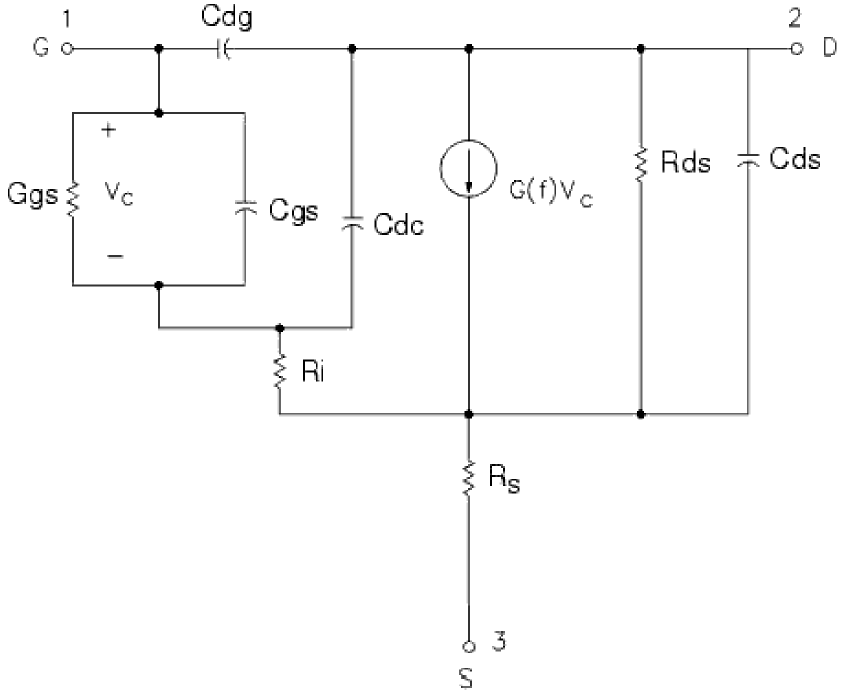
1. Setting F = 0 gives constant transconductance magnitude with respect to frequency:

   Transconductance = G(f) = G × $\left(\frac{e^{-(j2\pi fT)}}{1 + j\frac{f}{F}}\right)$ (for F > 0)

   Transconductance = G(f) = G × $e^{-(j2\pi fT)}$ (for F = 0)

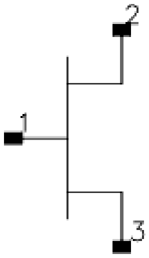
   where:
   f = simulation frequency, in Hz
   F = reference frequency, in Hz
   T = time delay, in seconds
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



FET (Field Effect Transistor)

Symbol



Parameters

Name	Description	Units	Default
G	magnitude of transconductance at DC	uS	20.0
T	time delay associated with transconductance	nsec	1.0
F	transconductance roll-off frequency	GHz	1.0
Cgs	gate-to-source capacitance	pF	10.0
Ggs	gate-to-source conductance	uS	1.0
Ri	channel resistance	Ohm	0.1
Cdg	drain-to-gate capacitance	pF	10.0
Cdc	dipole layer capacitance	pF	10.0
Cds	drain-to-source capacitance	pF	10.0
Rds	drain-to-source resistance	Ohm	500.0

Notes/Equations

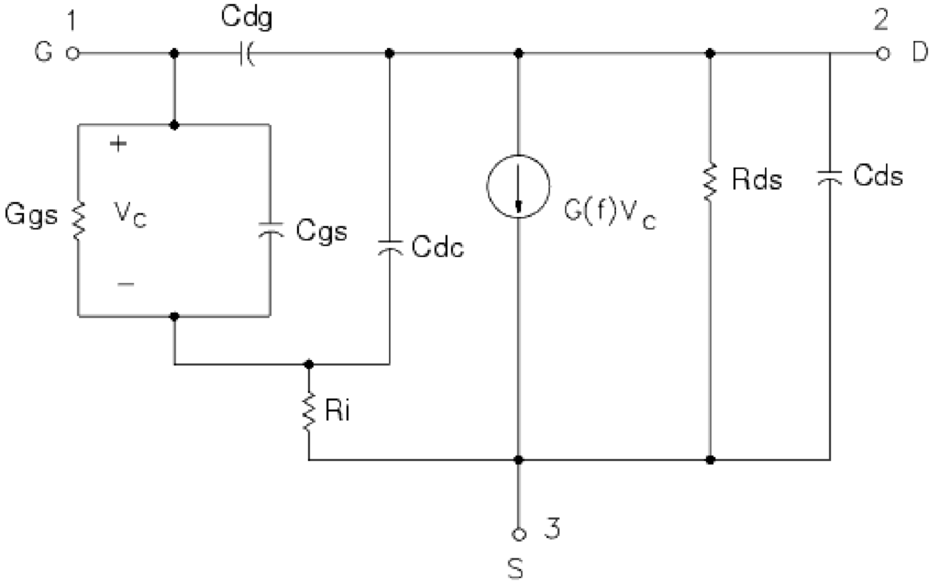
1. Setting F = 0 gives constant transconductance magnitude with respect to frequency:

   $$\text{Transconductance} = G(f) = G \times \left(\frac{e^{-(j2\pi fT)}}{1 + j\frac{f}{F}}\right) \quad \text{(for F > 0)}$$

   $$\text{Transconductance} = G(f) = G \times e^{-(j2\pi fT)} \quad \text{(for F = 0)}$$

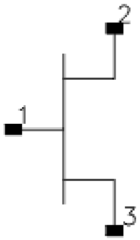
   where:
   f = simulation frequency, in Hz
   F = reference frequency, in Hz
   T = time delay, in seconds
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



FETN1 (FET Noise Model (Van der Ziel))

Symbol



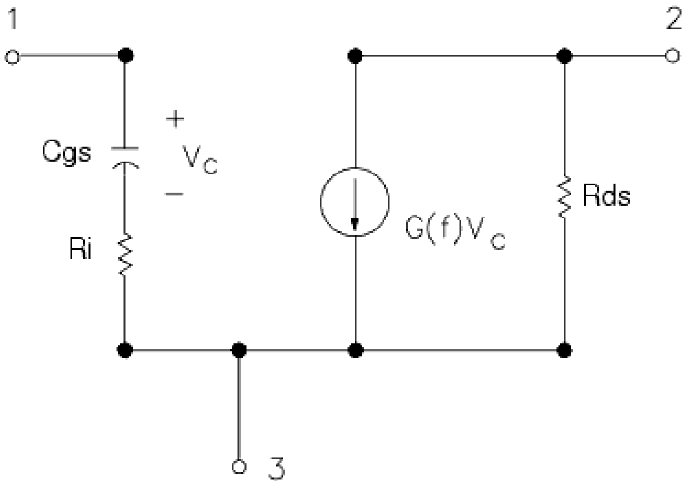
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cg	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rds	drain-to-source resistance	Ohm	300.0
P	noise parameter P (see references)	None	0.8
R	noise parameter R (see references)	None	1.2
C	noise parameter C (see references)	None	0.90

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by A. Van der Ziel) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN1 is determined by connecting appropriate circuit components externally to FETN1.
3. For time-domain analysis, the frequency-domain analytical model is used.
4. This component has no default artwork associated with it.

Equivalent Circuit

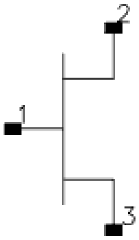


References

1. C. Liechti "Microwave Field Effect Transistors-1976," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-24, June 1976, pp. 279-300.
2. A. Van der Ziel, "Gate Noise in Field Effect Transistors at Moderately High Frequencies," *Proceedings of the IEEE,* Vol. 51, March 1963, pp. 461-467.
3. A. Van der Ziel, "Thermal Noise in Field Effect Transistors," *Proceedings of the IRE,* Vol. 50, August 1962, pp. 1808-1812.

FETN2 (FET Noise Model (Statz, et al))

Symbol



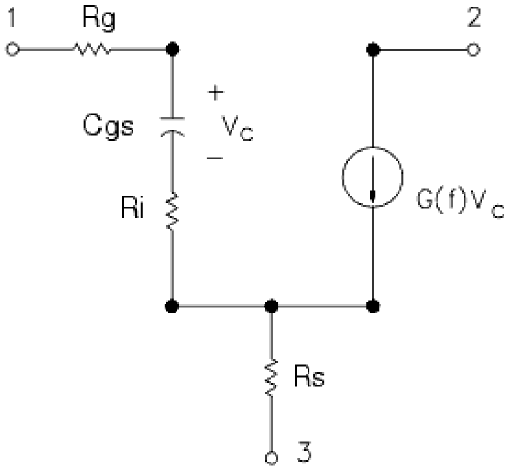
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cgs	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rs	drain-to-source resistance	Ohm	3.70
Rg	gate resistance	Ohm	0.80
Kr	noise parameter Kr (see references)	None	0.050
Kc	noise parameter Kc (see references)	None	1.4
Kg	noise parameter Kg (see references)	None	1.50

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by Statz, et al.) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN2 is determined by connecting appropriate circuit components externally to FETN2.
3. For time-domain analysis, the frequency-domain analytical model is used.
4. This component has no default artwork associated with it.

Equivalent Circuit

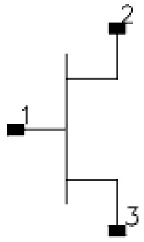


References

1. R. Pucel, H. Haus, and H. Statz. "Signal and Noise Properties of Gallium Arsenide Microwave Field-Effect Transistors," *Advances in Electronics and Electron Physics* , Vol. 38. New York: Academic Press, 1975, pp. 195-265.
2. R. Pucel, D. Masse, and C. Krumm. "Noise Performance of Gallium Arsenide Field-Effect Transistors," *IEEE Journal of Solid-State Circuits,* Vol. SC-11, April 1976, pp. 243-255.
3. H. Statz, H. Haus, and R. Pucel. "Noise Characteristics of Gallium Arsenide Field-Effect Transistors," *IEEE Transactions on Electron Devices,* Vol. ED-21, September 1974, pp. 549-562.

FETN3 (FET Noise Model (Fukui))

Symbol



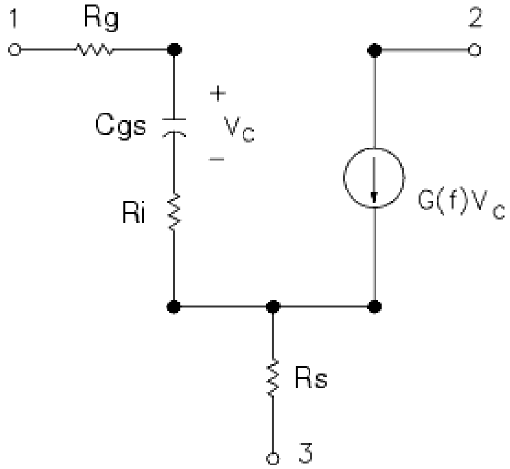
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cgs	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rs	source resistance	Ohm	3.70
Rg	gate resistance	Ohm	0.80
K1	noise parameter K1 (see references)	None	0.020
K2	noise parameter K2 (see references)	None	0.800
K3	noise parameter K3 (see references)	None	2.2
K4	noise parameter K4 (see references)	None	160.0

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by Fukui) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN3 is determined by connecting appropriate circuit components externally to FETN3.
3. The expressions that relate the noise parameters to the model components (G, Cgs, for example) and the K1-K4 parameters use the model components in specific units. The values of K1-K4 should conform to these units of the model components. (See references.)
4. For time-domain analysis, the frequency-domain analytical model is used.
5. This component has no default artwork associated with it.

Equivalent Circuit

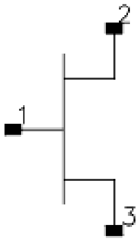


References

1. H. Fukui, "Design of Microwave GaAs MESFET's for Broad-Band Low-Noise Amplifiers," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-27, July 1979, pp. 643-650.
2. H. Fukui, Addendum to "Design of Microwave GaAs MESFET's for Broad-Band Low-Noise Amplifiers," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-29, October 1981.

FETN4 (FET Noise Model (Podell))

Symbol



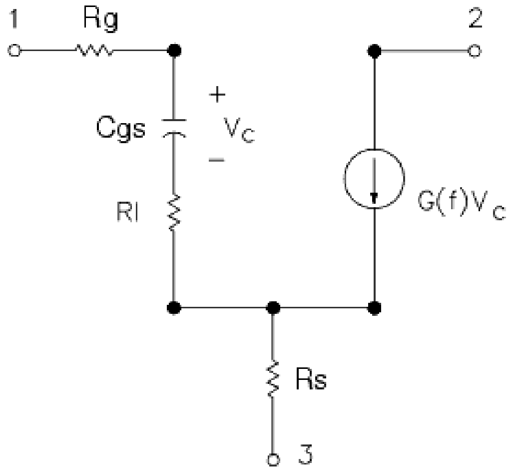
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cgs	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rs	source resistance	Ohm	3.70
Rg	gate resistance	Ohm	0.80
NFmin	minimum noise figure	dB	2.0
FRef	reference frequency at which NFMin is measured	GHz	10.0

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by Podell) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN4 is determined by connecting appropriate circuit components externally to FETN4.
3. For time-domain analysis, the frequency-domain analytical model is used.
4. This component has no default artwork associated with it.

Equivalent Circuit

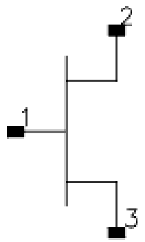


References

1. A. Podell, "A Functional GaAs FET Noise Model," *IEEE Transactions on Electron Devices* , Vol. ED-28, No. 5, May 1981, pp. 511-517.

FETN4a (FET Noise Model (Podell))

Symbol



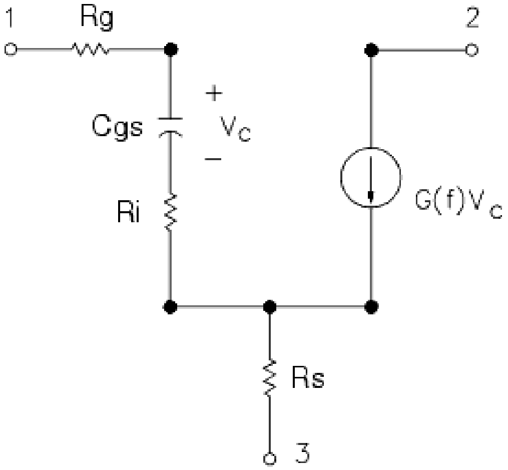
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cgs	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rs	source resistance	Ohm	3.70
Rg	gate resistance	Ohm	0.80
K	noise parameter K (see references)	None	1.0

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by Podell) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. This model is the same as FETN4 except that the input parameter related to the noise performance for FETN4a is K, whereas FETN4 uses NFMin and FRef. Specifying K instead of NFMin and FRef is an alternate way to describe the same model.
3. The effect of feedback or parasitics on the noise performance of FETN4a is determined by connecting appropriate circuit components externally to FETN4a.
4. For time-domain analysis, the frequency-domain analytical model is used.
5. This component has no default artwork associated with it.

Equivalent Circuit

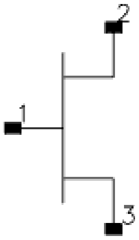


References

1. A. Podell, "A Functional GaAs FET Noise Model," *IEEE Transactions on Electron Devices,* Vol. ED-28, No. 5, May 1981, pp. 511-517.

FETN5 (FET Noise Model Gupta, et al))

Symbol



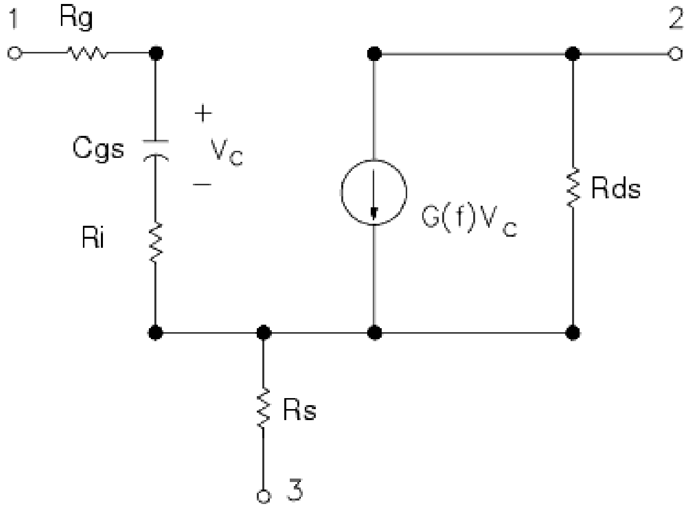
Parameters

Name	Description	Units	Default
G	magnitude of transconductance	S	0.03
T	time delay associated with transconductance	psec	3.0
Cgs	gate-to-source capacitance	pF	0.40
Ri	channel resistance	Ohm	3.0
Rds	drain-to-source resistance	Ohm	450.0
Rs	source resistance	Ohm	3.70
Rg	gate resistance	Ohm	0.80
Sio	noise parameter Sio	picoamperes squared per Hz (see references)	710

Notes/Equations

1. This component provides a linear bias-independent FET noise model (by Gupta, et al.) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN5 is determined by connecting appropriate circuit components externally to FETN5.
3. For time-domain analysis, the frequency-domain analytical model is used.
4. This component has no default artwork associated with it.

Equivalent Circuit

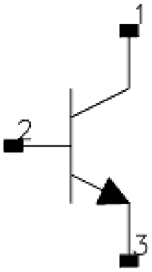


References

1. M. Gupta, O. Pitzalis, S. Rosenbaum, and P. Greiling. "Microwave Noise Characterization of GaAs MESFET's: Evaluation by On-Wafer Low-Frequency Output Noise Current Measurement," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-35, No. 12, December 1987, pp. 1208-1217.
2. M. Gupta and P. Greiling. "Microwave Noise Characterization of GaAs MESFET's: Determination of Extrinsic Noise Parameters," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 36, No. 4, April 1988, pp. 745-751.

HYBPI (Hybrid-Pi Bipolar Transistor with Alpha Current Gain)

Symbol



Parameters

Name	Description	Units	Default
G	transconductance	uS	20.0
T	transit time	nsec	1.0
Cpi	base-emitter (pi) capacitance	pF	10.0
Rpi	base-emitter (pi) resistance	Ohm	0.01
Cmu	base-collector (mu) capacitance	pF	5.0
Rmu	base-collector (mu) resistance	Ohm	1000.0
Rb	base resistance	Ohm	0.02
Rc	collector resistance	Ohm	500.0
Re	emitter resistance	Ohm	0.04

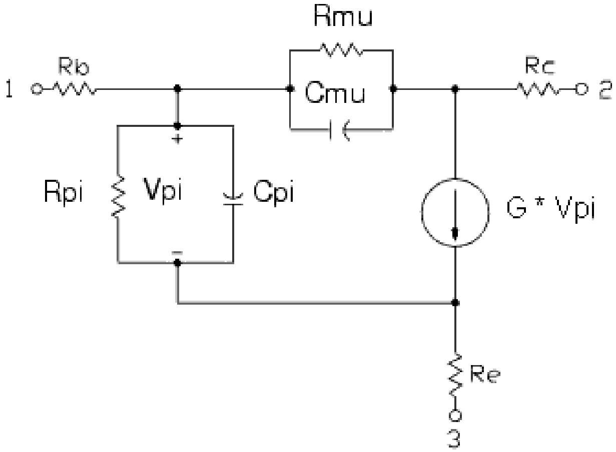
Range of Usage

Rpi > 0
Rmu > 0

Notes/Equations

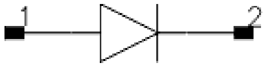
1. For time-domain analysis, the frequency-domain analytical model is used.
2. This component is assumed to be noiseless.
3. This component has no default artwork associated with it.

Equivalent Circuit


Rmu
1
Rb
Cmu
Rc
2
+
Rpi
Vpi
Cpi
G * Vpi
-
Re
3

PIN2 (PIN Diode, Packaged Model)

Symbol



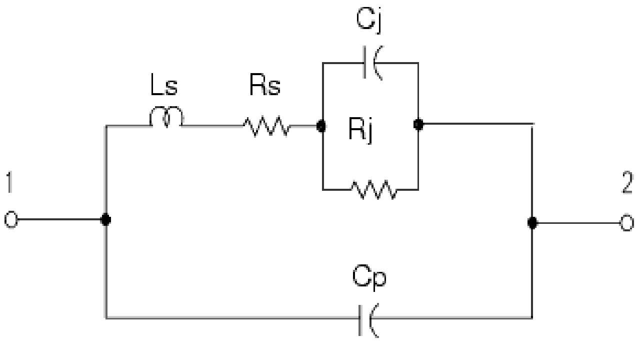
Parameters

Name	Description	Units	Default
Cj	junction capacitance	nF	0.01
Rj	junction resistance	Ohm	0.01
Rs	series resistance	Ohm	0.01
Ls	series inductance	nH	1.0
Cp	package capacitance	nF	0.1

Notes/Equations

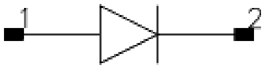
1. This component is assumed to be noiseless.
2. This component has no default artwork associated with it.

Equivalent Circuit



PIN (PIN Diode, Chip Model)

Symbol



Parameters

Name	Description	Units	Default
Cj	junction capacitance	nF	0.1
Rj	junction resistance	Ohm	0.01
Rs	diode series resistance	Ohm	0.01
Ls	bond wire inductance	nH	1.0
Cb	by-pass capacitance	nF	0.1
Cg	capacitance of gap across which diode is connected	nF	0.1

Notes/Equations

1. This component is assumed to be noiseless.
2. This component has no default artwork associated with it.

Equivalent Circuit