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Nonlinear Devices

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Chapter 1: Devices and Models, Diode

Bin Model

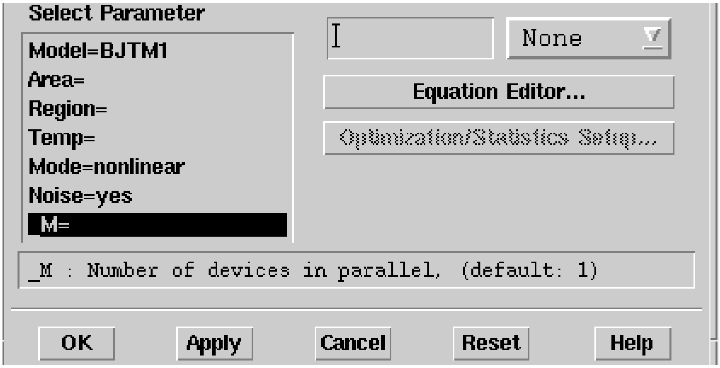
The BinModel in the Diodes library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to BinModel documentation in Chapter 1 of *Introduction and Simulation 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 don't 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.)

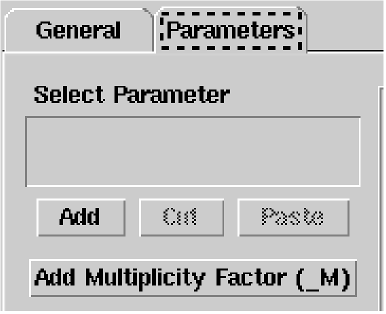


Select Parameter

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 Parameter**s 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 circuit simulator netlist format, including scale factors, subcircuits, variables and equations, refer to Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

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 book 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 25ºC. 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

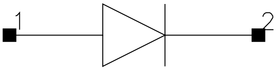
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp,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

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
```

Diode (PN-Junction Diode)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of Diode_Model		
Area	scaling factor that scales certain parameter values of Diode_Model		1.0
Periph (Perim)	scaling factor that affects the sidewall parameters of the Diode_Model		0
Width (W)	geometric width of diode junction		0
Length (L)	geometric length of diode junction		0
Scale	scaling factor that scales Area, Periph, Width, and Length		1
Region	state of the diode: off, on gives the DC simulator a good initial guess to enhance its convergence properties		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear (refer to Note 3)		nonlinear
Noise	noise generation: yes, no		yes
_M	number of devices in parallel		1

Range of Usage

$\text{Area} > 0$

$\text{Periph} \geq 0$

$\text{Scale} > 0$

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 to see which parameter values are scaled).
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, simulation time may be decreased. Devices with Mode=linear are linearized about their DC operating point.
4. Table 1-1 lists the DC operating point parameters that can be sent to the dataset.

Table 1-1. DC Operating Point Information

Name	Description	Units
Id	Diode current	A
Power	DC power dissipated	W
Rd	Junction series resistance	Ohms
Rdsw	Sidewall series resistance	Ohms
Cd	Junction capacitance	F
Cdsw	Sidewall capacitance	F
Vd	Anode-cathode voltage	V

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

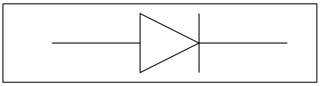
References

[1] *SPICE2: A Computer Program to Simulate Semiconductor Circuits*, University of California, Berkeley.

[2] P. Antognetti and G. Massobrio. *Semiconductor 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	Unit	Default
Level	model level selector (1=standard, 3=Hspicegeometry, 11=Spectre)		1
Is (Js)[†, ††]	saturation current (with N, determines diode DC characteristics)	A	10^{-14}
Rs[†††]	ohmic resistance	ohm	0.0
Gleak[†]	bottom junction leakage conductance	S	0
N	emission coefficient (with Is, determines diode DC characteristics)		1.0
Tt	transit time	sec	0.0
Cd[†]	linear capacitance	F	0
Cjo[†, ††]	zero-bias junction capacitance	F	0.0
Vj (Pb) [††]	junction potential	V	1.0 V
M	grading coefficient		0.5
Fc	forward-bias depletion capacitance coefficient		0.5
Imax	explosion current beyond which diode junction current is linearized	A	1.0
Imelt	(similar to Imax; refer to Note 4)	A	1.0
Isr[†, ††]	recombination current parameter	A	0.0
Nr	emission coefficient for Isr		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		1
Bv	reverse breakdown voltage	V	infinity[‡]

Name	Description	Unit	Default
Ibv†	current at reverse breakdown voltage	A	0.001
Nbv (Nz)	reverse breakdown ideality factor		1.0
Ibvl†	low-level reverse breakdown knee current	A	0.0
Nbvl	low-level reverse breakdown ideality factor		1.0
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Ffe	flicker noise frequency exponent		1.0
Jsw (Isw)††, ‡‡	sidewall saturation current	A	0.0
Rsw‡‡‡	sidewall series resistance	ohm	0
Gleaksw‡‡	sidewall junction leakage conductance	S	0
Ns	sidewall emission coefficient		I (when Level=11) N (when Level ≠ 11
Ikp‡‡	high-injection knee current for sidewall	A	Ikf
Cjsw††, ‡‡	sidewall zero-bias capacitance	F	0.9
Msw (Mjsw)	sidewall grating coefficient		0.33
Vjsw (Pbsw)††	sidewall junction potential	V	Vj 1 (when Level=11)
Fcsw	sidewall forward-bias depletion capacitance coefficient		0.5 Fc (when Level = 11)
Area	default area for diode		1
Periph (Perim)	default periphery for diode	m	0
Width	default width for diode	m	0
Length	default length for diode	m	0
Etch	narrowing due to etching per side	m	0
Etchl	length reduction due to etching per side	m	Etch
Dwl	geometry width and length addition	m	0
Shrink	geometry shrink factor		1.0

Name	Description	Unit	Default
AllowScaling	allow instance Scale parameter to affect diode instance geometry parameters: yes or no		no
Tnom	temperature at which parameters were extracted	°C	25
Trise	temperature rise above ambient	°C	0
Tlev	temperature equation selector (0/1/2)		0
Tlevc	temperature equation selector for capacitance (0/1/2/3)		0
Xti	saturation-current temperature exponent (with Eg, helps define the dependence of Is on temperature)		3.0 PN junction diode 2.0 Schottky barrier diode
Eg	energy gap (with Xti, helps define the dependence of Is on temperature)	eV	1.11 0.69 Schottky barrier diode 0.67 Ge 1.43 GaAs
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	1/°C	0
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

Name	Description	Unit	Default
Tbv2	Bv quadratic temperature coefficient	$1/(^oC)^2$	0
wBv (Bvj)	reverse breakdown voltage (warning)	W	0.0
wPmax	maximum power dissipation (warning)	W	0.0
AllParams	name of DataAccessComponent for file-based parameter values		

† 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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model SimpleDiode Diode \
  Is=1e-9 Rs=4 Cjo=1.5e-12
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

1. This model supplies values for a Diode device.
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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

   $Area = w \times l$
   $Periph = 2 \times (w + l)$
   where $w = Width \times Shrink + Dwl$
   $= Length \times Shrink + Dwl$
   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.

   $Area = area\ (from\ device/model) \times Shrink^2$
   $Periph = periph\ (from\ device/model) \times Shrink$

   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 - Etch1

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 - Etch1

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 mutiplied by 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 (vd+ 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 × Nbvl × 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 (vd + 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

$$idh = iexp\frac{1}{1 + \sqrt{\frac{iexp}{Ikf}}}$$

$$gdh = gexp\left(\frac{1}{1 + \sqrt{\frac{iexp}{Ikf}}}\right) \times \left(1 - \frac{\sqrt{\frac{iexp}{Ikf}}}{2\left(1 + \sqrt{\frac{iexp}{Ikf}}\right)}\right)$$

Otherwise if Ikr is not equal to zero and iexp < 0

$$idh = iexp \frac{1}{1 + \sqrt{\frac{-iexp}{Ikr}}}$$

$$gdh = gexp\left(\frac{1}{1 + \sqrt{\frac{-iexp}{Ikr}}}\right) \times \left(1 - \frac{\sqrt{\frac{-iexp}{Ikr}}}{2\left(1 + \sqrt{\frac{-iexp}{Ikr}}\right)}\right)$$

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 $\neq$ 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 $\neq$ 0 and iexp > 0

$$idsw = iexpsw\frac{1}{1 + \sqrt{\dfrac{iexpsw}{Ikp}}}$$

$$gdsw = gexpsw\left(\frac{1}{1 + \sqrt{\dfrac{iexpsw}{Ikp}}}\right) \times \left(1 - \frac{\sqrt{\dfrac{iexpsw}{Ikp}}}{2\left(1 + \sqrt{\dfrac{iexp}{Ikp}}\right)}\right)$$

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

$$Cjsw = Periph \times Cjsw \times 1 - \left(\frac{vdsw}{Vjsw}\right)^{-Msw}$$

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:

$$E_G(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108} \text{ if } Tlev = 0, 1$$

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

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 Δf 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.

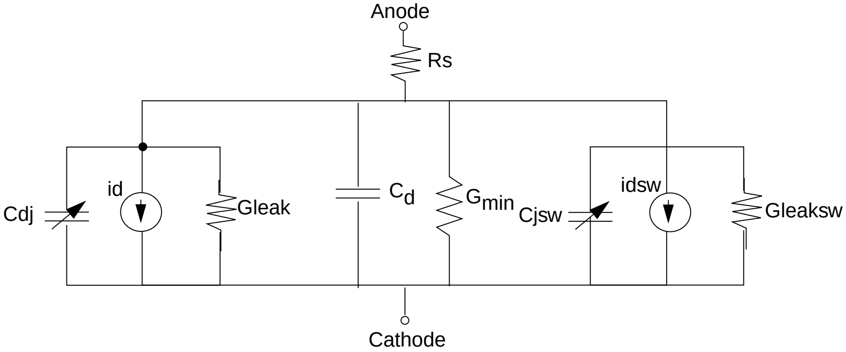
10. To model a Zener diode, the model parameters Bv and Ibv can be used. Bv should be set to the Zener reverse breakdown voltage as a positive number. Ibv is set to the breakdown current that flows at that voltage as a positive number; typically this is in the range of 1 to 10 mA. The series resistance Rs should also be set; a typical value is 1 Ohm.

References

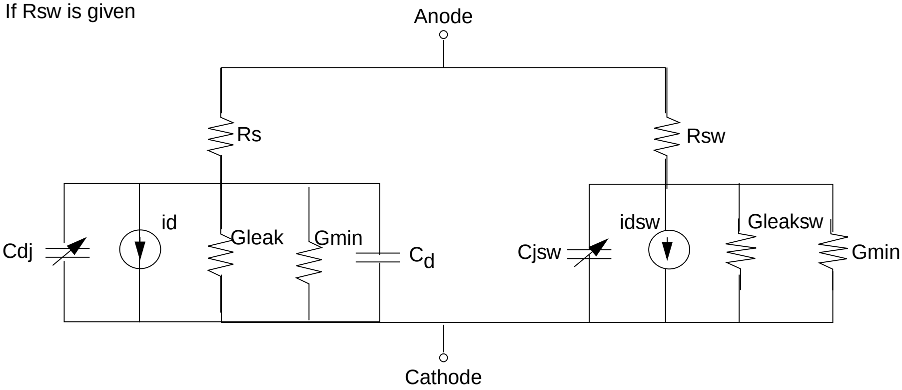
[1] Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE*, New York: McGraw-Hill, Second Edition 1993.

Equivalent Circuit

If Rsw is not given

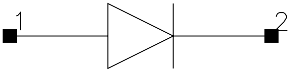


If Rsw is given



HPDiode (HP_Root Diode)

Symbol



Parameters

Name	Description	Default
Model	name of model instance	
Area	junction	1.0
_M	number of devices in parallel	1

Range of Usage

Area > 0

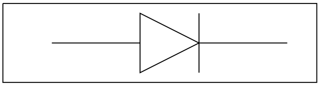
1. Table 1-2 lists the DC operating point parameters that can be sent to the dataset.

Table 1-2. DC Operating Point Information

Name	Description	Units
Id	Diode current	A
Power	DC power dissipated	W
Rd	Series resistance	Ohms
Cd	Junction capacitance	F
Vd	Anode-cathode voltage	V

HP_Diode_Model (HP_Root Diode Model)

Symbol



Parameters

Name	Description	Default
File	name of rawfile	
Rs	series resistance	0
Ls	parasitic inductance	0
Tt	transit time, in seconds	0.0
All Params	DataAccessComponent-based parameters	

Notes/Equations

1. This model supplies values for an HPDiode device.
2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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. 15th 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.

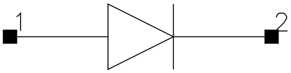
[4] D. E. Root and B. Hughes, “Principles of nonlinear active device modeling for circuit simulation,” in *32nd ARFTG Conf. Dig.*, Tempe, AZ, 1988, pp. 3-26.

[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.

JUNCAP (Philips JUNCAP Device)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a Juncap model		
Ab	diffusion area	m^2	1.0e-12
Ls	length of sidewall of the diffusion area that is not under the gate	um, mm, cm, meter, mil, in	1.0e -6 m
Lg	length of sidewall of the diffusion area that is under the gate	um, mm, cm, meter, mil, in	1.0e -6 m
Region	DC operating region; 0=off, 1=on, 2=rev, 3=sat		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode: linear, nonlinear		nonlinear
Noise	noise generation; yes, no		yes
_M	number of devices in parallel		1

Notes/Equations

1. Table 1-3 lists the DC operating point parameters that can be sent to the dataset.

Table 1-3. DC Operating Point Information

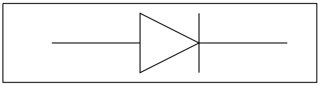
Name	Description	Units
Id	Diode current	A
Power	DC power dissipated	W
Rd	Series resistance	Ohms
Cd	Junction capacitance	F
Vd	Anode-cathode voltage	V

2. Additional information about this device is available from the website:

http://www.semiconductors.com/Philips_Models/documentation/add_models/

Juncap_Model (Philips JUNCAP Model)

Symbol



Parameters

Name	**Description**	**Unit**	**Default**
Tr (Tnom)	temperature at which the parameters for the reference transistor have been determined, in Celsius	°C	25
Trise	temperature rise above ambient	°C	0
Vr	voltage at which parameters have been determined	volts	0.0
Jsgbr	bottom saturation-current density due to electron-hole generation at V = Vr	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 at V =Vr	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 due to electron-hole generation at V =Vr	A/m^2	1.0e-3
Jsdgr	gate-edge saturation-current density due to diffusion from back contact	A/m	1.0e-3
Cjbr	bottom-junction capacitance at V = Vr	F/m^2	1.0e-12
Cjsr	sidewall-junction capacitance at V = Vr	F/m	1.0e-12
Cjgr	gate-edge junction capacitance at V = Vr	F/m	1.0e-12
Vdbr	diffusion voltage of the bottom junction at T = Tr		1.0
Vdsr	diffusion voltage of the sidewall junction at T = Tr		1.0
Vdgr	diffusion voltage of the gate-edge junction at T = Tr		1.0
Pb	bottom-junction grading coefficient		0.4
Ps	sidewall-junction grading coefficient		0.4
Pg	gate-edge-junction grading coefficient		0.4
Nb	emission coefficient of the bottom forward current		1.0
Ns	emission coefficient of the sidewall forward current		1.0
Ng	emission coefficient of the gate-edge forward current		1.0

Name	Description	Unit	Default
Gmin	minimum conductance added in parallel to the P-N junction	Siemens	1.0e-15
Imax	explosion current beyond which diode junction current is linearized	A	1.0
All Params	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  DSpar  Juncap \
  Jsbgr=3e-4  Cjbr=1e-4  Tr=25
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

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.

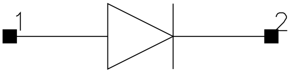
2. More information about the model can be obtained from:

   http://www.semiconductors.com/Philips_Models/documentation/add_models/

3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those via AllParams.

PinDiode (PIN Diode)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a PinDiodeModel		
Area	junction area		1
Region	state of the diode: off, on		on
Temp	default operating temperature	°C	25
Mode	simulation mode for this device: nonlinear, linear		nonlinear
_M	number of devices in parallel		1

Range of Usage

Area > 0

Notes/Equations

1. The Region parameter is used to give the DC simulator a good initial guess to enhance its convergence properties.
2. The Temp parameter is used to calculate the noise performance of this device only. Temperature scaling of model parameters is not performed for this device.
3. The Mode parameter is used during harmonic balance, oscillator, or large-signal S-parameter analysis only. 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. Table 1-4 lists the DC operating point parameters that can be sent to the dataset.

Table 1-4. DC Operating Point Information

Name	Description	Units
Id	Diode current	A
Power	DC power dissipated	W

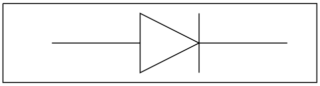
Table 1-4. DC Operating Point Information (continued)

Name	Description	Units
Rd	Series resistance	Ohms
Cd	Junction capacitance	F
Vd	Anode-cathode voltage	V

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

PinDiodeModel (PIN Diode Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
Is†	saturation current	A	10^{-14}
Vi	I-region forward bias voltage drop	V	0
Un	electron mobility	$cm^2/(V \times S)$	900
Wi	I-region width	m	10^{-6}
Rr†	I-region reverse bias resistance	ohm	0
Cmin†	P-I-N punchthrough capacitance	F	0
Tau	ambipolar lifetime within I region	sec	10^{-7}
Rs†	ohmic resistance	ohm	0
Cjo†	zero-bias junction capacitance	F	0
Vj	junction potential	V	1.0
M	grading coefficient		0.5
Fc	coefficient for forward-bias depletion capacitance		0.5
Imax	explosion current	A/m^2	1.0
Imelt	(similar to Imax; refer to Note 7)	A	1.0
Kf	flicker-noise coefficient		0
Af	flicker-noise exponent		1.0
Ffe	flicker noise frequency exponent		1.0
wBv	diode reverse breakdown voltage (warning)	V	0.0
wPmax	maximum power dissipation warning	W	0.0
AllParams	DataAccessComponent-based parameters		
† Parameter value is scaled by Area specified with the PinDiode device.			

Notes/Equations

1. This model supplies values for a PinDiode device.
2. PinDiodeModel is based on its high-frequency characteristics. The following assumptions have been made in this model derivation and, therefore, its usefulness.
   - You must first bias the PIN diode in either forward or reverse condition and determine its characteristic.
   - Periods of all time-variant signals applied to the circuit in transient analysis are much shorter than the ambipolar lifetime in the I-region.
   - In reverse bias, the I-region is punchthrough.
3. Limitations of PinDiodeModel:
   - After the DC condition of the diode model has been determined (that is, under forward or reverse bias condition), the PIN diode intrinsic resistance R is fixed for all subsequent analyses.
   - For subsequent analyses, the depletion capacitance is not fixed at DC bias; it will vary with its voltage (Vc). However, the pin diode DC condition determines whether depletion capacitance or Cmin will be used in subsequent analyses.
   - Periods of all time variant signals applied to the circuit in transient analysis must be shorter compared to the ambipolar lifetime in the I-region; otherwise, a regular diode should be used.
   - The model does not vary with temperature.
4. The equivalent circuit of the intrinsic PIN diode:
   - R=Ri, C=depletion capacitance if forward bias
   - R=Rr, C=Cmin if reverse bias

   where

   Ri=Vi/Idc

   Idc is the DC current through the pin diode when R is replaced by a DC voltage source with Vi volt.

   If the I-region forward bias voltage drop Vi is not specified or equal to zero,

$$Vi = \frac{3}{4} \times \frac{Wi^2}{Un \times 10^{-4} \times Tau}$$

In DC sweep analysis under forward bias, because Vi remains constant and Idc varies with the sweep source, the intrinsic resistance R will vary; however, the dI/dV term will remain constant.

5. Depletion capacitance:

   If

   $$Vc < Fc \times Vj$$

   $$C = Cjo \times \left(1 - \frac{Vc}{Vj}\right)^{-M}$$

   If

   $$Vc \geq Fc \times Vj$$

   $$C = Cjo \times \left(\frac{1 - Fc(1 + M) + M\left(\frac{Vc}{Vj}\right)}{(1 - Fc)^{(1 + M)}}\right)$$

6. Noise Model

   Thermal noise generated by resistor Rs is characterized by the spectral density:

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

   Shot noise and flicker noise (Kf, Af, Ffe) generated by DC current flow through the diode is characterized by the spectral density:

   $$\frac{< i^2_{ds} >}{\Delta f} = 2qI_D + \mathrm{k}_f \frac{I_D^{a_f}}{f^{f_{fe}}}$$

   In the preceding expressions, k is Boltzmann's constant, T is the operating temperature in Kelvin, q is the electron charge, k_{f}, $a_{\mathrm{f},}$ and f_{fe} are model parameters, f is the simulation frequency, and Δf is the noise bandwidth.

7. 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).

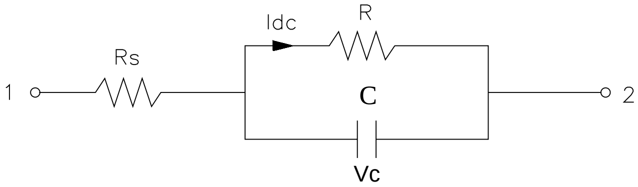
8. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those via AllParams.

References

[1] Joseph F. White, Ph.D., Microwave Semiconductor Engineering, Van Nostrand Reinhold Publishing Company, 1982.

[2] S.M. Sze, Physics of Semiconductor Devices, second edition, John Wiley & Sons, 1981.

Equivalent Circuit



Chapter 2: Devices and Models, BJT

Bin Model

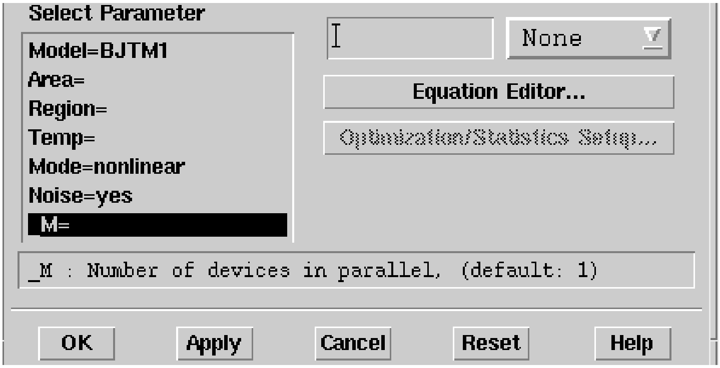
The BinModel in the BJT library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to BinModel documentation in Chapter 1 of *Introduction and Simulation 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 don't 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.)

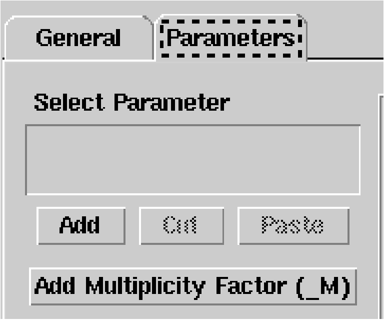


Select Parameter

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 Parameter**s 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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* manual.

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 manual 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 25ºC. 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

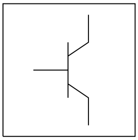
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp,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

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
```

BJT_Model (Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NPN	NPN bipolar transistor		yes
PNP	PNP bipolar transistor		no
Is (Js)	saturation current	A	
Bf	forward beta		100
Nf	forward emission coefficient		1.0
Vaf (Vbf)	forward early voltage	V	
Ikf (Jbf)	High current corner for forward beta	A	infinity†
Ise (Jle)	base-emitter leakage saturation current	A	1.5
C2	forward leakage saturation current coefficient. If Ise is not given, Ise= C2 x Is		0
Ne (Nle)	base-emitter leakage emission coefficient		1.5
Br††	reverse beta		1.0††
Nr	reverse emission coefficient		infinity†
Var (Vbr)	reverse early voltage	V	infinity†
Ikr (Jbr)	high current corner for reverse beta	A	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.		0
Nc (Nlc)	base-collector leakage emission coefficient		2.0
Cbo†††	extrapolated 0-vdt base-collector leakage current	A	0.0

Name	Description	Unit	Default
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)	ohms	0.0
Irb (Jrb)	Current for base resistance midpoint	A	
Rbm	Minimum base resistance for high currents	ohms	
Rbnoi	effective base noise resistance	ohms	Rb
Re‡	emitter resistance	ohms	fixed at 0
Rc‡	collector resistance	ohms	fixed at 0
Rcv‡	variable collector resistance	ohms	0.0
Rcm‡	minimum collector resistance	ohms	0.0
Dope	collector background doping concentration	1/cm^3	1e15
Cex	current crowding exponent		1.0
Cco†††	current crowding normalization constant	A	1.0
Imax	explosion current	A	1.0
Imelt	(similar to Imax; refer to Note 3)	A	1.0
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)		0.33
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)		0.33

Name	Description	Unit	Default
Xcjc (Cdis)	fraction of Cjc that goes to internal base pin		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)		0.0
Fc	forward-bias depletion capacitance coefficient		0.5
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
Xtf	coefficient of bias-dependence for Tf		0.0
Vtf	voltage dependence of Tf on base-collector voltage	V	infinity‡
Itf (Jtf) †††	high-current effect on Tf	A	0.0
Ptf	excess phase at frequency = 1 / (Tf × 2π)	degrees	0.0
Tr	ideal reverse transit time (Tr, Tf, and depletion-layer capacitances model base charge storage effects)	sec	0.0
Kf	flicker-noise coefficient		0.0
Af	flicker-noise exponent		1.0
Kb (Bnoisefc)	burst noise coefficient		0.0
Ab	burst noise exponent		1.0
Fb	burst noise corner frequency	hertz	1.0
Iss ††, †††	collector-substrate P-N junction saturation current	A	0.0
Ns	collector-substrate P-N junction emission coefficient		1.0
Nk	high-current roll-off coefficient		0.5
Ffe	flicker noise frequency exponent		1.0
Lateral	lateral substrate geometry type		no
RbModel	base resistance model: Spice=1, MDS=0		MDS
Approxqb	use approximation for Qb vs early voltage		yes
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0

Name	Description	Unit	Default
Tlev	temperature equation selector (0/1/2/3)		0
Tlevc	temperature equation selector for capacitance (0/1/2/3)		0
Eg	energy gap for temperature effect on Is	eV	1.11
EgAlpha (Gap1)	energy gap temperature coefficient alpha	V/°C	7.02e-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

Name	Description	Unit	Default
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

Name	Description	Unit	Default
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.		0.0
Xti (Pt)	temperature exponent for saturation current		3.0
wVsubfwd (Vsubfwd)	substrate junction forward bias (warning)	V	
wBvsub (Bvsub)	substrate junction reverse breakdown voltage (warning)	V	
wBvbe (Bvbe)	base-emitter reverse breakdown voltage (warning)	V	
wBvbc (Bvbc)	base-collector reverse breakdown voltage (warning)	V	
wVbcfwd (Vbcfwd)	base-collector forward bias (warning)	V	
wIbmax	maximum base current (warning)	A	
wIcmax	maximum collector current (warning)	A	

Name	Description	Unit	Default
wPmax	maximum power dissipation (warning)	W	
†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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Npn1  BJT  \
  NPN=yes Is=1.5e-15 Cjc=2.0e-13
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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

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

$Vbe \geq$ 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

$$Cbediff = \frac{2Qbediff}{2Vbe}$$

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

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

$Vbc \geq$ 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

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

$VBc \geq$ 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

$$Cbcdiff = \frac{2Qbcdiff}{2Vbc}$$

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 frequent 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):

$$Ibei = \frac{3Wo^2}{S^2 + 3Wos + 3Wo^2} \times Ibei$$

where

$$Wo = \frac{1}{Ptf \times Tf \times \frac{Tc}{180}}$$

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:

$$E_G(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108} \quad Tlev = 0, 1, 3$$

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

The intrinsic carrier concentration n_i for silicon varies as:

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

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

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

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

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

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

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

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

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:

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

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:

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

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 Δf 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:

ls = ls × AREA
lse = lse × AREA
lsc = lsc × AREA
lkf = lkf × AREA
lkr = lkr × AREA

$$lrb = lbr \times AREA$$
$$ltf = ltf \times AREA$$

$$Cjc(0) = Cjc(0) \times AREA$$
$$Cje(0) = Cje(0) \times AREA$$
$$Cjs(0) = Cjs(0) \times AREA$$

$$Rb = Rb/AREA$$
$$Rbm = Rbm/AREA$$
$$Rbnoi = Rbnoi/AREA$$
$$Re = Re/AREA$$
$$Rc = Rc/AREA$$

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

$$Ib = \text{sign(ib) x Max (Abs(Ib), ie-20)}$$

$$Gm = \frac{dIce}{dVbe} + \frac{dIce}{dVbc}$$

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

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

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

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

$$Vbe = \nu(B) - \nu(E)$$

$$Vbc = \nu(B) - \nu(C)$$

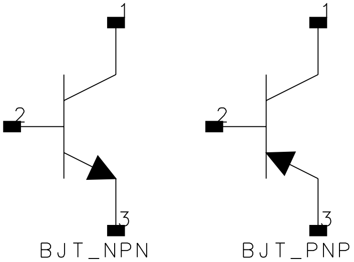
$$Vce = \nu(BC) - \nu(E)$$

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	Unit	Default
Model	name of BJT_Model, EE_BJT2_Model, STBJT_Model, or MEXTRAM_Model		
Area	factor that scales certain parameter values of the model		1
Region	dc operating region: 0 = off, 1 = on, 2 = rev, 3 = sat		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear		nonlinear
_M	number of devices in parallel		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 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.
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” for the BJT_Model component.
5. DC operating point parameters that can be sent to the dataset are listed in the following tables according to model.

Table 2-1. DC Operating Point Information
Model = BJT_Model or EE_BJT2_Model

Name	Description	Units
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipation	W
BetaDc	DC current gain	
Gm	Forward transconductance (dIce/dVbe)	S
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	F
Cmu	Base-internal collector capacitance	F
Cbx	Base-external collector capacitance	F
Ccs	Substrate capacitance	F
BetaAc	AC current gain	
Ft	Unity current gain frequency	Hz
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

Table 2-2. DC Operating Point Information
Model = STBJT_Model

Name	Description	Units
Ic	Collector current	A
Is	Substrate current	A
Ib	Base current	A
Ie	Emitter current	A
Power	DC power dissipation	W
BetaDc	DC current gain	
BetaAc	AC current gain	
fTreal	Unity current gain frequency	Hz
fTappr	Unity current gain frequency	Hz
Gm	Forward transconductance (dIce/dVbe)	S
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	F
Cmu	Base-internal collector capacitance	F
Cbx	Base-external collector capacitance	F
Ccs	Internal collector-substrate capacitance	F
Cbs	Internal base-substrate capacitance	F
Cxs	External base-substrate capacitance	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

Table 2-3. DC Operating Point Information
Model = MEXTRAM_Model (503)

Name	Description	Units
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipated	W
dIc2e1_dVb2e1	(dIc2e1/dVb2e1)	S
Gb2e1	(dIb2e1/dVb2e1)	S
Gb1b2	(dIb1b2/dVb1b2)	S
Gb1c1	(dIb1c1/dVb1c1)	S
Gbc1	(dIbc1/dVbc1)	S
Gb2c2	(dIb2c2/dVb2c2)	S
Cb2e1	(dIb2e1/dVb2e1)	S
Cb2c2	(dIb2c2/dVb2c2)	S
Gb1e1	(dIb1e1/dVb1e1)	S
Gc1s	(dIc1s/dVc1s)	S
dIc2e1_dVb2c2	(dIc2e1/dVb2c2)	S
dIc2e1_dVb2c1	(dIc2e1/dVb2c1)	S
dIc1c2_dVb2e1	(dIc1c2/dVb2e1)	S
dIc1c2_dVb2c2	(dIc1c2/dVb2c2)	S
dIc1c2_dVb2c1	(dIc1c2/dVb2c1)	S
dIb2c2_dVb2e1	(dIb2c2/dVb2e1)	S
dIb2c2_dVb2c1	(dIb2c2/dVb2c1)	S
dIb1b2_dVb2e1	(dIb1b2/dVb2e1)	S
dIb1b2_dVb2c2	(dIb1b2/dVb2c2)	S
dIb1b2_dVb2c1	(dIb1b2/dVb2c1)	S
dIc1s_dVb1c1	(dIc1s/dVb1c1)	S
dIc1s_dVbc1	(dIc1s/dVbc1)	S
Cb1b2	(dQb1b2/dVb1b2)	F

Table 2-3. DC Operating Point Information (continued)
Model = MEXTRAM_Model (503)

Name	**Description**	**Units**
Cc1s	(dQc1s/dVc1s)	F
Cb1c1	(dQb1c1/dVb1c1)	F
Cbc1	(dQbc1/dVbc1)	F
dQb2e1_dVb2c2	(dQb2e1/dVb2c2)	F
dQb2e1_dVb2c1	(dQb2e1/dVb2c1)	F
dQc2b2_dVb2e1	(dQc2b2/dVb2e1)	F
dQb2c2_dVb2c1	(dQb2c2/dVb2c1)	F
dQb1b2_dVb2e1	(dQb1b2/dVb2e1)	F
dQb1e1_dVb2e1	(dQb1e1/dVb2e1)	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

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

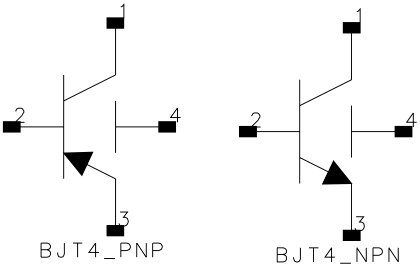
References

[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.

BJT4_NPN, BJT4_PNP (Bipolar Junction Transistors w/Substrate Terminal, NPN, PNP)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of BJT_Model or MEXTRAM_Model		
Area	factor that scales certain parameter values of the model		1
Region	dc operating region: off=0, on=1, rev=2, sat=3		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear (refer to Note 2)		linear
Noise	noise generation option: yes=1, no=0		yes
_M	number of devices in parallel		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 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.
3. The fourth terminal (substrate) is available for connection to an external circuit.

4. Table 2-4 lists the DC operating point parameters that can be sent to the dataset.

Table 2-4. DC Operating Point Information

Name	Description	Units
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Power	DC power dissipation	W
BetaDc	DC current gain	
BetaAc	AC current gain	
fTreal	Unity current gain frequency	Hz
fTappr	Unity current gain frequency	Hz
Gm	Forward transconductance (dIce/dVbe)	S
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	F
Cmu	Base-internal collector capacitance	F
Cbx	Base-external collector capacitance	F
Ccs	Internal collector-substrate capacitance	F
Cbs	Internal base-substrate capacitance	F
Cxs	External base-substrate capacitance	F

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

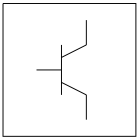
References

[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.

EE_BJT2_Model (EEsof Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
Type	NPN or PNP		NPN
Nf	forward-current emission coefficient		1.0
Ne	base-emitter leakage emission coefficient		1.5
Nbf	forward base emission coefficient		1.06
Vaf	forward Early voltage	V	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	infinity†
Xtf	coefficient of bias-dependence for Tf		0.0
Vtf	voltage dependence of Tf on base-collector voltage	V	infinity†
Itf	parameter for high-current effect on Tf	A	0.0
Nbr	reverse base emission coefficient		1.04
Nr	reverse-current emission coefficient		1.0
Nc	base-collector leakage emission coefficient		2.0
Isc	base-collector leakage saturation current	A	0.0
Ikr	corner for reverse-beta high-current roll-off	A	infinity†
Var	reverse Early voltage	V	infinity†
Tr	ideal reverse transit time (Tr and Tf, along with the depletion-layer capacitances, model base charge storage effects)	sec	0.0
† A value of 0.0 is interpreted as infinity			

Name	Description	Unit	Default
Isf	forward saturation current	A	9.53×10^{-15}
Ibif	forward base saturation current	A	1.48×10^{-16}
Isr	reverse saturation current	A	1.01×10^{-14}
Ibir	reverse base saturation current	A	6.71×10^{-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)		0.33
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)		0.33
Rb	base resistance	ohms	10^{-4}
Re	emitter resistance	ohms	10^{-4}
Rc	collector resistance	ohms	10^{-4}
Fc	forward-bias depletion capacitance coefficient		0.5
wVsubfwd	substrate junction forward bias (warning)	V	
wBvsub	substrate junction reverse breakdown voltage (warning)	V	
wBvbe	base-emitter reverse breakdown voltage (warning)	V	
wBvbc	base-collector reverse breakdown voltage (warning)	V	
wVbcfwd	base-collector forward bias (warning)	V	
wIbmax	maximum base current (warning)	A	
wIcmax	maximum collector current (warning)	A	

† A value of 0.0 is interpreted as infinity

Name	Description	Unit	Default
wPmax	maximum power dissipation (warning)	W	
AllParams	name of DataAccessComponent for file-based model parameter values		
† 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 since 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 $\geq 10^{-4}$
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). 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).

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

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:

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

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

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

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

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 $Vbc \le Fc \times Vjc$

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

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 $Vbc > Fc \times Vjc$

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

for $Vbe \le Fc \times Vje$

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

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 Δf 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

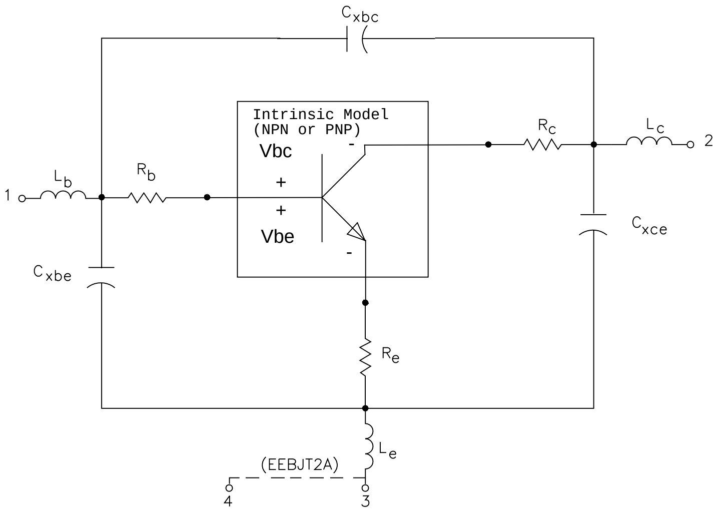
[1] J. J. Ebers and J. L. Moll. "Large Signal Behaviour of Junction Transistors," Proc. I.R.E. 42, 1761 (1954).

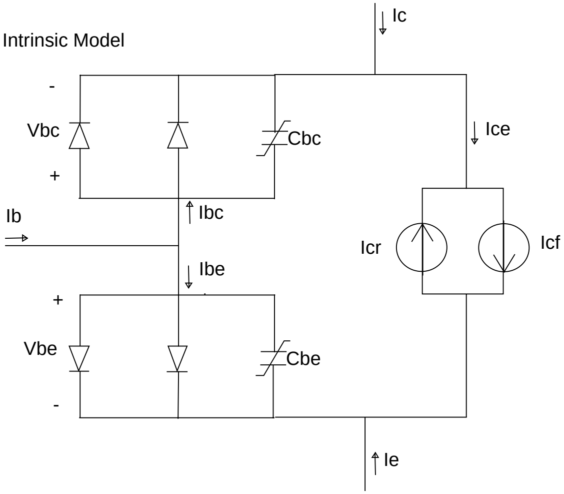
[2] H. K. Gummel and H. C. Poon. "An Integral Charge-Control Relation for Bipolar Transistors," Bell Syst. Techn. J. 49, 115 (1970).

[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.

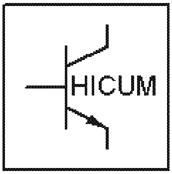
Equivalent Circuit




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

HICUM_Model (Bipolar Transistor Model)

Symbol



Parameters

Name	Description	Units	Default
NPN	NPN model type: yes, no		yes
PNP	PNP model type: yes, no		no
C10	ICCR constant (=$I_S Q_{p0}$)	A^2s	2e-30
Qp0	zero-bias hole charge	As	2.0e-14
Ich	high-current correction for 2D/3D-ICCR	amperes	1e20
Hfe	GICCR weighing factor for Q_{Ef} in HBTs		1
Hfc	GICCR weighing factor for Q_{fc} (mainly for HBTs)		1
Hjei	GICCR weighing factor for Q_{jei} in HBTs		1
Hjci	GICCR weighing factor for Q_{jci} in HBTs		1
Mcf	GICCR weighing factor for Q_{jci} in HBTs		1
Alit	factor for additional delay time of iT		0.0
Cjei0	zero-bias value	farads	0.0
Vdei	built-in voltage	volts	0.9
Zei	exponent coefficient		0.5
Aljei	factor for adjusting maximum value of Cjei0		2.5
Cjci0	zero-bias value	farads	0.0
Vdci	built-in voltage	volts	0.7
Zci	exponent coefficient		0.4
Vptci	punch-through voltage (=$qN_{Ci} w^2_{Ci}/(2\varepsilon)$)	volts	1e20
T0	low-current transit time at $V_{B'C'}$=0	seconds	0
Dt0h	time constant for base and BC SCR width modulation	seconds	0.0

Name	Description	Units	Default
Tbvl	voltage for modeling carrier jam at low Vces	seconds	0.0
Tef0	neutral emitter storage time	seconds	0.0
Gtfe	exponent factor for current dependent emitter storage time		1
Thcs	saturation time constant at high current densities	seconds	0.0
Alhc	smoothing factor for current dependent C and B transit time	seconds	0.1
Fthc	partitioning factor for base and collector portion		0.0
Alqf	factor for additional delay time of Qf		0.0
Rci0	low-field resistance of internal collector region (including scaling)	ohms	150
Vlim	limitation voltage separating ohmic and SCR regime	volts	0.5
Vpt	punch-through voltage of BC SCR through (epi) collector	volts	3
Vces	internal CE saturation voltage	volts	0.1
Tr	time constant for inverse operation	seconds	0 sec
Ibeis	BE saturation current	amperes	1e-18
Mbei	BE non-ideality factor		1.0
Ireis	BE recombination saturation current	amperes	0.0
Mrei	BE recombination non-ideality factor		2.0
Ibcis	BC saturation current	amperes	1e-16
Mbci	BC non-ideality factor		1.0
Favl	pre-factor for CB avalanche effect	1/V	0
Qavl	exponent factor for CB avalanche effect		0
Rbi0	value at zero-bias	ohms	0
Fdqr0	correction factor for modulation by BE and BC SCR		0.0
Fgeo	geometry factor (default value corresponds to long emitter stripe)		0.6557
Fqi	ratio of internal to total minority charge		1.0
Fcrbi	ration of h.f. shunt to total internal capacitance		0.0
Latb	scaling factor for Q_{fC} in b_E direction		0
Latl	scaling factor for Q_{fC} in l_E direction		0
Cjep0	zero-bias value	farads	0
Vdep	built-in voltage	volts	0.9
Zep	depletion coefficient		0.5

Name	Description	Units	Default
Aljep	factor for adjusting maximum value of Cjep0		2.5
Ibeps	saturation current	amperes	0.0
Mbep	non-ideality factor		1.0
Ireps	recombination saturation current	amperes	0.0
Mrep	recombination non-ideality factor		2.0
Ibets	saturation current	amperes	0
Abet	exponent coefficient		40
Cjcx0	zero-bias depletion value	farads	0
Vdcx	built-in voltage	volts	0.7
Zcx	exponent coefficient		0.4
Vptcx	punch-through voltage	volts	1.0e20
Ccox	collector-oxide capacitance	farads	0
Fbc	partitioning factor for Ccbx=Cjcx0+Ccox		0.0
Ibcxs	saturation current	amperes	0.0
Mbcx	non-ideality factor		1.0
Ceox	emitter oxide (overlap) capacitance	farads	0
Rbx	external base series resistance	ohms	0
Re	emitter series resistance	ohms	0
Rcx	external collector series resistance	ohms	0
Itss	transfer saturation current	amperes	0.0
Msf	non-ideality factor for forward transfer current		1.0
Msr	non-ideality factor for inverse transfer current component		1.0
Iscs	saturation current of CS diode (latch-up modeling)	amperes	0.0
Msc	non-ideality factor of CS diode		1
Tsf	storage time (constant) for minority charge	seconds	0.0
Cjs0	zero-bias value of CS depletion capacitance	farads	0
Vds	built-in voltage	volts	0.6
Zs	exponent coefficient		0.5
Vpts	punch-through voltage	volts	1.0e20
Rsu	substrate series resistance	ohms	0
Csu	substrate capacitance given by permittivity of bulk material	farads	0

Name	Description	Units	Default
Kf	flicker noise factor (no unit only for a_F=2!)		0
Af	flicker noise exponent factor		2.0
Krbi	factor for internal base resistance		1
Vgb	bandgap voltage	volts	1.17
Alb	relative temperature coefficient of forward current gain	1/K	5e-3
Zetaci	temperature coefficient (mobility) for epi collector		0.0
Alvs	relative temperature coefficient of saturation drift velocity	1/K	0.0
Alt0	temperature coefficient for low-current transmit time t0 (linear term)	1/K	8.25e-4
Kt0	temperature coefficient for low-current transmit time t0 (quad. term)	1/K	0.0
Alces	relative temperature coefficient of Vces	1/K	0.0
Zetarbi	temperature coefficient (mobility) for internal base resistance		0.0
Zetarbx	temperature coefficient (mobility) for external base resistance		0.0
Zetarcx	temperature coefficient (mobility) external collector resistance		0.0
Zetare	temperature coefficient (mobility) emitter resistance		0.0
Alfav	relative temperature coefficient for avalanche breakdown	1/K	0.0
Alqav	relative temperature coefficient for avalanche breakdown	1/K	0.0
Tnom	temperature for which parameters are valid	^oC	25
Trise	temperature rise above ambient	°C	0
Rth	thermal resistance	ohms	0
Cth	thermal capacitance	farads	0
Imax	explosion current	A	1e4
Imelt	(similar to Imax; refer to Note 4)	A	Imax
AcModel	selects which small signal models to use for ac and S-parameter analyses (1 or 2); refer to Note 5		1
SelfheatingModel	selects which power dissipation equations to use for modeling self-heating effect (1 or 2); refer to Note 6		1
wVsubfwd	substrate junction forward bias (warning)	V	
wBvsub	substrate junction reverse breakdown voltage (warning)	V	
wBvbe	base-emitter reverse breakdown voltage (warning)	V	
wBvbc	base-collector reverse breakdown voltage (warning)	V	
wVbcfwd	base-collector forward bias (warning)	V	

Name	Description	Units	Default
wIbmax	maximum base current (warning)	A	
wIcmax	maximum collector current (warning)	A	
wPmax	maximum power dissipation (warning)	W	
AllParams	name of DataAccessComponent for file-based model parameter values		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

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

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

1. This model (version 2.1) supplies values for a HICUM device.

2. More information about this model is available at

   http://www.iee.et.tu-dresden.de/iee/eb/comp_mod.html

3. 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 the detailed physical and electrical effects, as well as model equations, refer to the document *HICUM, A scalable physics-based compact bipolar transistor model, description of model version 2.1*, December, 2000 authored by Michael Schroter.

4. Constant transit time Tf (at dc bias) is used in harmonic balance analysis for It current delay.

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. 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.

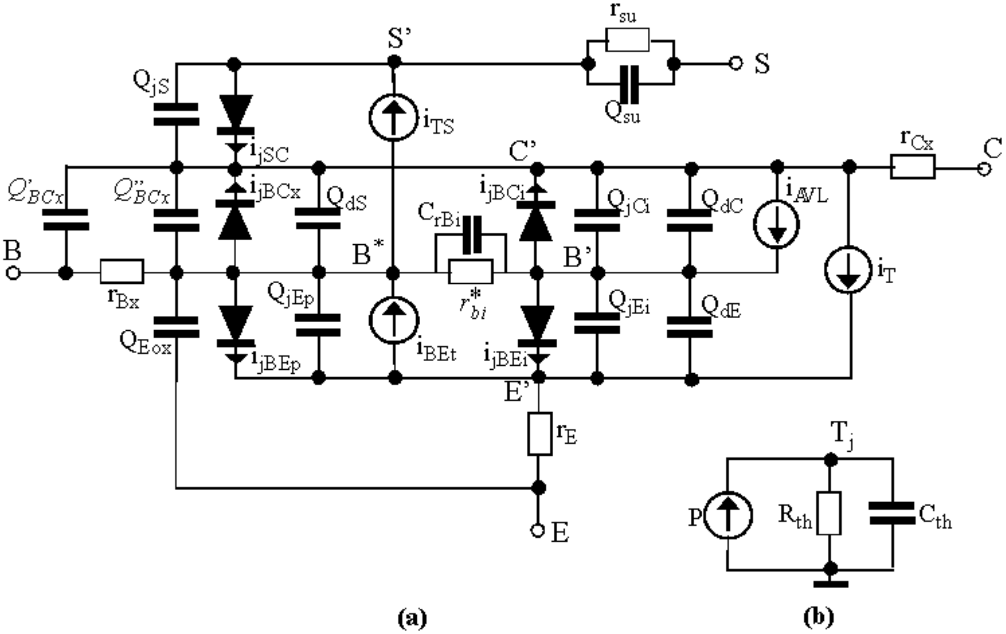
7. Two power dissipation formulas for modeling the self-heating effect have been implemented in ADS.

   - When SelfheatingModel = 1, the simplified formula power = It × vce - Iave × vbc will be used.
   - When SelfheatingModel = 2, the formula 2.1.16-1 from the reference document cited in Note 1 will be used.

   The simplified formula is implemented in Dr. Schroter's DEVICE program.

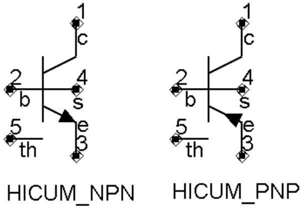
8. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those specified via AllParams.

Equivalent Circuit



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

Symbol



Parameters

Name	Description	Unit	Default
Mode	name of a HICUM_Model		
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear		nonlinear
Noise	noise generation option: yes=1, no=0		yes
Selfheating	turn on the self-heating effect on this device: yes, no (refer to Note 3)		
_M	number of devices in parallel		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 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.
3. When Selfheating = no, the self-heating effect on this device will be turned off if model parameter Rth is not equal to zero. If Selfheating is not specified or is set to yes, then the Rth value given in the model will be used for modeling the self-heating effect of this device.

4. Table 2-5 lists the DC operating point parameters that can be sent to the dataset.

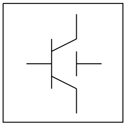
Table 2-5. DC Operating Point Information

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

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

MEXTRAM_Model (MEXTRAM Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NPN	NPN model type		yes
PNP	PNP model type		no
Release	model level		503
Exmod	flag for extended modeling of reverse current gain		yes
Exphi	flag for distributed high-frequency effects in transient		yes
Exavl	flag for extended modeling of avalanche currents		yes
Is	collector-emitter saturation current	A/m^2	9.6369×10^{-18}
Bf	ideal forward current gain		138.9
Xibi	fraction of ideal base current that belongs to sidewall		0.0
Ibf	saturation current of non-ideal forward base current	A/m^2	2.7223×10^{-15}
Vlf	crossover voltage of non-ideal forward base current	V	0.6181
Ik	high-injection knee current	A/m^2	1.5×10^{-2}
Bri	ideal reverse current gain		6.243
Ibr	saturation current of non-ideal reverse base current	A	4.6066×10^{-14}
Vlr	crossover voltage of non-ideal reverse base current	V	0.5473
Xext	part of I_{EX}, Q_{EX}, Q_{TEX} and I_{SUB} that depends on base-collector voltage V_{BC1}		0.5358
Qb0	base charge at zero bias		9.3424×10^{-14}
Eta	factor of built-in field of base (= η)		4.8
Avl	weak avalanche parameter		76.43
Efi	electric field intercept (with Exavl=1)		0.7306

Name	**Description**	**Unit**	**Default**
Ihc	critical current for hot carriers	A/m^2	5.8359×10^{-4}
Rcc	constant part of collector resistance	Ω/m^2	11.09
Rcv	resistance of unmodulated epilayer	Ω/m^2	981.9
Scrcv	space charge resistance of epilayer	Ω/m^2	1769
Sfh	current spreading factor epilayer		0.3556
Rbc	constant part of base resistance	Ω/m^2	134.4
Rbv	variable part of base resistance at zero bias	Ω/m^2	307.7
Re	emitter series resistance	Ω/m^2	1.696
Taune	minimum delay time of neutral and emitter charge	sec	6.6626×10^{-12}
Mtau	non-ideality factor of the neutral and emitter charge	S	1
Cje	zero bias base-emitter depletion capacitance	F/m^2	4.9094×10^{-14}
Vde	base-emitter diffusion voltage	V	0.8764
Pe	base-emitter grading coefficient		0.3242
Xcje	fraction of base-emitter depletion capacitance that belongs to sidewall		0.26
Cjc	zero bias base-collector depletion capacitance	F/m^2	8.7983×10^{-14}
Vdc	base-collector diffusion voltage	V	0.6390
Pc	base-collector grading coefficient variable part		0.6135
Xp	constant part of Cjc		0.5
Mc	collector current modulation coefficient		0.5
Xcjc	fraction of base-collector depletion capacitance under emitter area		2.7018×10^{-2}
Tref (Tnom)	reference temperature	°C	25
Dta (Trise)	difference of device temperature to ambient temperature ($T_{Device}=T_{Ambient}+Dta$)	°C	0
Vge	emitter bandgap voltage	V	1.129
Vgb	base bandgap voltage	V	1.206
Vgc	collector bandgap voltage	V	1.120
Vgj	emitter-base junction band-gap voltage	V	1.129

Name	Description	Unit	Default
Vi	ionization voltage base dope	V	2.1×10^{-2}
Na	maximum base dope concentration	cm^{-3}	4.4×10^{17}
Er	temperature coefficient of Vlf and Vlr		2×10^{-3}
Ab	temperature coefficient resistivity base		1.0
Aepi	temperature coefficient resistivity of the epilayer		1.9
Aex	temperature coefficient resistivity of the extrinsic base		0.31
Ac	temperature coefficient resistivity of the buried layer		0.26
Kf	flicker noise coefficient ideal base current		0
Kfn	flicker noise coefficient non-ideal base current		0
Af	flicker noise exponent		1.0
Iss	base-substrate saturation current	A/m^2	5.8602×10^{17}
Iks	knee current of the substrate	A/m^2	6.7099×10^{-6}
Cjs	zero bias collector-substrate depletion capacitance	F/m^2	2.2196×10^{-13}
Vds	collector-substrate diffusion voltage	V	0.5156
Ps	collector-substrate grading coefficient		0.3299
Vgs	substrate bandgap voltage	V	1.12
As	for closed buried or an open buried layer		1.9
wVsubfwd	substrate junction forward bias (warning)	V	
wBvsub	substrate junction reverse breakdown voltage (warning)	V	
wBvbe	base-emitter reverse breakdown voltage (warning)	V	
wBvbc	base-collector reverse breakdown voltage (warning)	V	
wVbcfwd	base-collector forward bias (warning)	V	
wIbmax	maximum base current (warning)	A	
wIcmax	maximum collector current (warning)	A	
wPmax	maximum power dissipation (warning)	W	
AllParams	name of DataAccessComponent for file-based model parameter values		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Npn4 MextramBJT  \
  NPN=yes Ibf=3e-15 Qb0=1e-13
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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). 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:

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

$$Qb_e = f_1(n_o) \tag{2-2}$$

$$Qb_c = f_2(n_b) \tag{2-3}$$

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:

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

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 XIb_1. This factor can be determined by analyzing the maximum current gain of transistors with different geometries.

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

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:

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

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.

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

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:

$$Ct_c = Xcjc \times Cjc \times \left(\frac{(1 - Xp) \times f(Vc_1 c_2)}{1 - ((Vb_2 \times c_2)/(Vdc))^{Pc}} + Xp \right) \tag{2-8}$$

$$f(Vc_1 \times c_2) = \left(1 - \frac{Vc_1 c_2}{Vc_1 c_2 + Ihc \times Rcv} \right)^{Mc} \tag{2-9}$$

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 ($0.3 < m_c < 0.5$)

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:

$$Q_n = Qn_0 \times \left(\exp\left(\frac{Vb_2 e_1}{Mtau \times V_t} \right) - 1 \right) \tag{2-10}$$

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.

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

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

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 ($n \ll N_{epi}$), and space-charge-limited if the carrier density exceeds the doping level (N_{epi}).
- 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:

$$J_{hc} = q \times N_{epi} \times v_{sat} \tag{2-13}$$

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:

$$Ic_1c_2 = \frac{E_c + Vb_2c_2 - Vb_2c_1}{Rcv} \tag{2-14}$$

$$E_c = V_t \times \left[K_0 - K_w - \ln\left(\frac{K_0 + 1}{K_w + 1}\right)\right] \tag{2-15}$$

$$K_0 = \sqrt{1 + 4 \times \exp[(Vb_2c_2 - Vd_c)/V_t]} \tag{2-16}$$

$$K_w = \sqrt{1 + 4 \times \exp[(Vb_2c_1 - Vd_c)/V_t]} \tag{2-17}$$

$$V_t = k \times \frac{T}{q} \tag{2-18}$$

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 (Vb_2c_1 - Vd_c 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:

$$\frac{X_i}{W_{epi}} = \frac{E_c}{Ic_1c_2 \times Rcv} \tag{2-19}$$

$$I_{low} = \frac{Ihc \times Vc_1c_2}{Vc_1c_2 + Ihc \times Rcv \times (1 - X_i / W_{epi})} \tag{2-20}$$

$$Ic_1c_2 = (I_{low} + S_f) \times \frac{Vc_1c_2 - I_{low} \times Rcv \times (1 - X_i / W_{epi})}{Scrcv \times (1 - X_i / W_{epi})^2} \tag{2-21}$$

Where X_i/W_{epi} 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 (Ic_1c_2) 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:

$$Ihc = q \times N_{epi} \times A_{em} \times v_{sat} \times \frac{1 + Sf_l}{\alpha_{cf}} \tag{2-22}$$

$$Rcv = \frac{W_{epi}}{q \times N_{epi} \times \mu \times A_{em}} \times \frac{\alpha_{cf}}{1 + Sf_l} \tag{2-23}$$

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

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

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

where

$$A_{em} = H_e \times L_e, \tag{2-27}$$

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

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

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

α_{cf} = 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. SF_1 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):

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

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

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

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}:

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

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

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

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]:

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

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

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

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:

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

λ = 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 (λ) 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

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.

No additional parameters.

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 Ps 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 Circuit

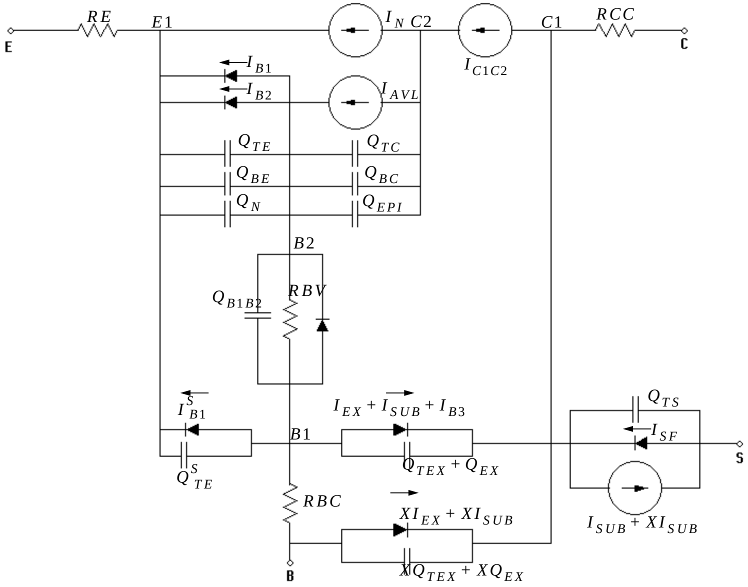


Figure 2-1. Equivalent Circuit for Vertical NPN Transistor

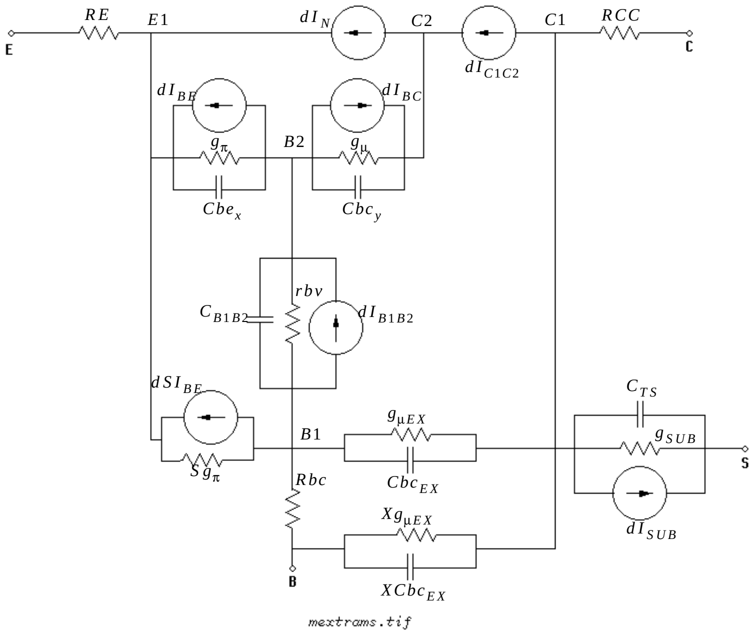


Figure 2-2. Small Signal Equivalent Circuit for Vertical NPN Transistor

References

[1] G. M. Kull, L. W. Nagel, S. Lee, P. L. Loyd, E. J. Prendergast, H. Dirks: “A Unified Circuit Model for Bipolar Transistors Including Quasi-Saturation Effects.” IEEE Transaction on Electron devices, Vol. ED-32, No. 6, June 1985.

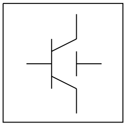
[2] H.C. de Graaff and W.J. Kloosterman: “Modeling of the collector Epilayer of a Bipolar Transistor in the Mextram Model.” IEEE Transaction on Electron devices, Vol. ED-42, p. 274, February 1995.

[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. 1537, 1958.

MEXTRAM_504_Model (MEXTRAM 504 Model)

Symbol



Parameters

Name	Description	Unit	Default
NPN	NPN bipolar transistor		yes
PNP	PNP bipolar transistor		no
Level (Release)	model level (must be set to 504)		504
Tref (Tnom)	Reference temperature	°C	25
Dta (Trise)	Difference between the device and ambient temperature	°C	0
Exmod	Flag for the extended modeling of the reverse current gain		1
Exphi	Flag for high-frequency effects in transient		1
Exavl	Flag for extended modeling of avalanche currents		0
Is	Collector-emitter saturation current	A	22.0e-18
Ik	Collector-emitter high injection knee current	A	0.1
Ver	Reverse Early voltage	V	2.5
Vef	Forward Early voltage	V	44
Bf	Ideal forward current gain		215
Ibf	Saturation current of the non-ideal forward base current	A	2.7e-15
Mlf	Non-ideality factor of the forward base current		2.0
Xibi	Part of the ideal base current that belongs to the sidewall		0
Bri	Ideal reverse current gain		7
Ibr	Saturation current of the non-ideal reverse base current	A	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		0.63
Wavl	Epilayer thickness used in weak-avalanche model	m	1.1e-6
Vavl	Voltage determining curvature of avalanche current	V	3

Name	Description	Unit	Default
Sfh	Current spreading factor of avalanche model (when EXAVL=1)		0.3
Re	Emitter resistance	Ohms	5
Rbc	Constant part of the base resistance	Ohms	23
Rbv	Zero-bias value of the variable part of the base resistance	Ohms	18
Rcc	Constant part of the collector resistance	Ohms	12
Rcv	Resistance of the un-modulated epilayer	Ohms	150
Scrcv	Space charge resistance of the epilayer	Ohms	1250
Ihc	Current for velocity saturation in the epilayer	A	4.0e-3
Axi	Smoothness parameter for the onset of quasi-saturation		0.3
Cje	Zero-bias emitter-base depletion capacitance	F	73.0e-15
Vde	Emitter-base diffusion voltage	V	0.95
Pe	Emitter-base grading coefficient		0.4
Xcje	Fraction of the emitter-base depletion capacitance that belongs to the sidewall		0.4
Cbeo (Cbe0)	Fixed capacitance between external base and emitter nodes	F	0
Cjc	Zero-bias collector-base depletion capacitance	F	78.0e-15
Vdc	Collector-base diffusion voltage	V	0.68
Pc	Collector-base grading coefficient		0.5
Xp	Constant part of Cjc		0.35
Mc	Coefficient for the current modulation of the collector-base capacitance		0.5
Xcjc	Fraction of the collector-base depletion capacitance under the emitter		32.0e-3
Cbco (Cbc0)	Fixed capacitance between external base and collector nodes	F	0
Mtau	Non-ideality factor of the emitter stored charge		1
Taue (Te)	Minimum transit time of stored emitter charge	sec	2.0e-12
Taub (Tb)	Transit time of stored base charge	sec	4.2e-12
Tepi	Transit time of stored epilayer charge	sec	41.0e-12
Taur (Tr)	Transit time of reverse extrinsic stored base charge	sec	520.0e-12
Deg	Bandgap difference over the base	eV	0

Name	Description	Unit	Default
Xrec	Pre-factor of the recombination part of Ib1		0
Aqbo (Aqb0)	Temperature coefficient of the zero-bias base charge		0.3
Ae	Temperature coefficient of the resistivity of the emitter		0
Ab	Temperature coefficient of the resistivity of the base		1
Aepi	Temperature coefficient of the resistivity of the epilayer		2.5
Aex	Temperature coefficient of the resistivity of the extrinsic base		0.62
Ac	Temperature coefficient of the resistivity of the buried layer		2
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		2.0
Kf	Flicker-noise coefficient of the ideal base current		2.0e-11
Kfn	Flicker-noise coefficient of the non-ideal base current		2.0e-11
Iss	Base-substrate saturation current	A	48.0e-18
Iks	Base-substrate high injection knee current	A	250.0e-6
Cjs	Zero-bias collector-substrate depletion capacitance	F	315.0e-15
Vds	Collector-substrate diffusion voltage	V	0.62
Ps	Collector-substrate grading coefficient		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		1.58
Rth	Thermal resistance		300
Cth	Thermal capacitance		3.0e-9
wVsubfwd	Substrate junction forward bias (warning)	V	
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	
wBvbe	Base-emitter reverse breakdown voltage (warning)	V	
wBvbc	Base-collector reverse breakdown voltage (warning)	V	

Name	Description	Unit	Default
wVbcfwd	Base-collector forward bias (warning)	V	
wIbmax	Maximum base current (warning)	A	
wIcmax	Maximum collector current (warning)	A	
wPmax	Maximum power dissipation (warning)	W	

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

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

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

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.

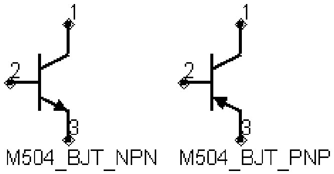
   Self-heating can be used with either an internal or external thermal node.

   - 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 Philips Semiconductors. Documentation is available on their website:

   http://www.semiconductors.philips.com/philips_models/newsflash/mextram504
4. ADS implements the complete MEXTRAM 504 model, as per the Philips document NL_UR 2000/811, issued April 2001. Differences between the ADS documentation and the Philips documentation are:
   - in equations (4.96) and (4.102), Rcvt is used and not Rcv.
   - resistances are limited to a lower value of 10^{-4} ohms, not 10^{-6} ohms

M504_BJT_NPN, M504_BJT_PNP (Mextram 504 Nonlinear Bipolar Transistors)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of MEXTRAM_504_Model		
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear (refer to Note 2)		nonlinear
Noise	noise generation option: yes=1, no=0		yes
Selfheating	include selfheating effects: no, yes		no
_M	number of devices in parallel		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 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.
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: $\Delta T = Pdiss \times Rth$. 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.

4. Table 2-6 lists the DC operating point parameters that can be sent to the dataset.

Table 2-6. DC Operating Point Information

Name	**Description**	**Units**
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipated	W
In	Main current from C2-E1	A
Ic1c2	Epilayer current from C1-C2	A
Ib1b2	Pinched-base current from B1-B2	A
Ib1	Ideal forward base current from B2-E1	A
SIb1	Ideal sidewall base current from B1-E1	A
Ib2	Nonideal forward base current from B2-E1	A
Ib3	Nonideal reverse base current from B1-C1	A
Iavl	Avalanche current from C2-B2	A
Iex	Extrinsic reverse base current from B1-C1	A
XIex	Extrinsic reverse base current from B-C1	A
Isub	Substrate current from B1-S	A
XIsub	Substrate current from B-S	A
Isf	Substrate failure current from S-C1	A

Table 2-6. DC Operating Point Information (continued)

Name	Description	Units
Ire	Emitter current from E1-E	A
Irbc	Base current from B-B1	A
Ircc	Collector current from C-C1	A
Vc	External collector voltage	V
Vc1	Internal collector1 voltage	V
Vc2	Internal collector2 voltage	V
Vb	External base voltage	V
Vb1	Internal base1 voltage	V
Vb2	Internal base2 voltage	V
Ve	External emitter voltage	V
Ve1	External emitter1 voltage	V
Vs	Substrate voltage	V
gx	Forward transconductance (dIn/dVb2e2)	S
gy	Reverse transconductance (dIn/dVb2c2)	S
gz	Reverse transconductance (dIn/dVb2c1)	S
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	S
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	S
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	S
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	S
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	S
gmuy	Avalanche current conductance (-dIavl/dVb2c2)	S
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	S
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	S
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	S
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	S
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	S
rbv	Base resistance (1/(dIb1b2/dVb1b2))	Ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	S
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	S
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	S

Table 2-6. DC Operating Point Information (continued)

Name	Description	Units
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	S
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	S
gsf	Substrate failure conductance (dIsf/dVsc1)	S
Qe	Emitter or emitter neutral charge	C
Qte	Base-emitter depletion charge	C
SQte	Sidewall base-emitter depletion charge	C
Qbe	Base-emitter diffusion charge	C
Qbc	Base-collector diffusion charge	C
Qtc	Base-collector depletion charge	C
Qepi	Epilayer diffusion charge	C
Qb1b2	AC current crowding charge	C
Qtex	Extrinsic base-collector depletion charge	C
XQtex	Extrinsic base-collector depletion charge	C
Qex	Extrinsic base-collector diffusion charge	C
XQex	Extrinsic base-collector diffusion charge	C
Qts	Collector-substrate depletion charge	C
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	F
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	F
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	F
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	F
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	F
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	F
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	F
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	F
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	F
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	F
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	F
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	F
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	F
Cts	Substrate-collector capacitance (dQts/dVsc1)	F

Table 2-6. DC Operating Point Information (continued)

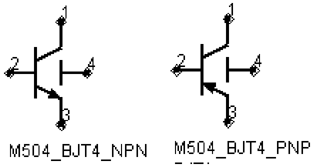
Name	**Description**	**Units**
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

5. This device has no default artwork associated with it.
6. This model was developed by Philips Semiconductors. Documentation is available on their website:

   http://www.semiconductors.philips.com/philips_models/newsflash/mextram504

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

Symbol



Parameters

Name	Description	Unit	Default
Model	name of MEXTRAM_504_Model		
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear (refer to Note 2)		nonlinear
Noise	noise generation option: yes=1, no=0		yes
Selfheating	include selfheating effects: no, yes		no
_M	number of devices in parallel		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 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.
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: $\Delta T = Pdiss \times Rth$. 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. Table 2-7 lists the DC operating point parameters that can be sent to the dataset.

Table 2-7. DC Operating Point Information

Name	Description	Units
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipated	W
In	Main current from C2-E1	A
Ic1c2	Epilayer current from C1-C2	A
Ib1b2	Pinched-base current from B1-B2	A
Ib1	Ideal forward base current from B2-E1	A
SIb1	Ideal sidewall base current from B1-E1	A
Ib2	Nonideal forward base current from B2-E1	A
Ib3	Nonideal reverse base current from B1-C1	A
Iavl	Avalanche current from C2-B2	A
Iex	Extrinsic reverse base current from B1-C1	A
XIex	Extrinsic reverse base current from B-C1	A
Isub	Substrate current from B1-S	A

Table 2-7. DC Operating Point Information (continued)

Name	Description	Units
XIsub	Substrate current from B-S	A
Isf	Substrate failure current from S-C1	A
Ire	Emitter current from E1-E	A
Irbc	Base current from B-B1	A
Ircc	Collector current from C-C1	A
Vc	External collector voltage	V
Vc1	Internal collector1 voltage	V
Vc2	Internal collector2 voltage	V
Vb	External base voltage	V
Vb1	Internal base1 voltage	V
Vb2	Internal base2 voltage	V
Ve	External emitter voltage	V
Ve1	External emitter1 voltage	V
Vs	Substrate voltage	V
gx	Forward transconductance (dIn/dVb2e2)	S
gy	Reverse transconductance (dIn/dVb2c2)	S
gz	Reverse transconductance (dIn/dVb2c1)	S
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	S
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	S
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	S
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	S
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	S
gmuy	Avalanche current conductance (-dIavl/dVb2c2)	S
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	S
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	S
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	S
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	S
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	S
rbv	Base resistance (1/(dIb1b2/dVb1b2))	Ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	S

Table 2-7. DC Operating Point Information (continued)

Name	Description	Units
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	S
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	S
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	S
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	S
gsf	Substrate failure conductance (dIsf/dVsc1)	S
Qe	Emitter or emitter neutral charge	C
Qte	Base-emitter depletion charge	C
SQte	Sidewall base-emitter depletion charge	C
Qbe	Base-emitter diffusion charge	C
Qbc	Base-collector diffusion charge	C
Qtc	Base-collector depletion charge	C
Qepi	Epilayer diffusion charge	C
Qb1b2	AC current crowding charge	C
Qtex	Extrinsic base-collector depletion charge	C
XQtex	Extrinsic base-collector depletion charge	C
Qex	Extrinsic base-collector diffusion charge	C
XQex	Extrinsic base-collector diffusion charge	C
Qts	Collector-substrate depletion charge	C
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	F
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	F
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	F
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	F
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	F
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	F
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	F
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	F
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	F
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	F
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	F
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	F

Table 2-7. DC Operating Point Information (continued)

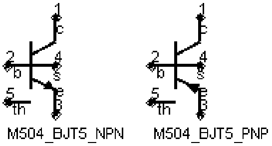
Name	**Description**	**Units**
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	F
Cts	Substrate-collector capacitance (dQts/dVsc1)	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

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

   http://www.semiconductors.philips.com/philips_models/newsflash/mextram504

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

Symbol



Parameters

Name	Description	Unit	Default
Model	name of MEXTRAM_504_Model		
Temp	device operating temperature	°C	25
Trise (Dta)	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear (refer to Note 2)		nonlinear
Noise	noise generation option: yes=1, no=0		yes
Selfheating	include selfheating effects: on/off		0
_M	number of devices in parallel		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 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.

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. Table 2-8 lists the DC operating point parameters that can be sent to the dataset.

Table 2-8. DC Operating Point Information

Name	**Description**	**Units**
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipated	W
In	Main current from C2-E1	A
Ic1c2	Epilayer current from C1-C2	A
Ib1b2	Pinched-base current from B1-B2	A
Ib1	Ideal forward base current from B2-E1	A
SIb1	Ideal sidewall base current from B1-E1	A
Ib2	Nonideal forward base current from B2-E1	A
Ib3	Nonideal reverse base current from B1-C1	A
Iavl	Avalanche current from C2-B2	A
Iex	Extrinsic reverse base current from B1-C1	A
XIex	Extrinsic reverse base current from B-C1	A
Isub	Substrate current from B1-S	A
XIsub	Substrate current from B-S	A

Table 2-8. DC Operating Point Information (continued)

Name	**Description**	**Units**
Isf	Substrate failure current from S-C1	A
Ire	Emitter current from E1-E	A
Irbc	Base current from B-B1	A
Ircc	Collector current from C-C1	A
Vc	External collector voltage	V
Vc1	Internal collector1 voltage	V
Vc2	Internal collector2 voltage	V
Vb	External base voltage	V
Vb1	Internal base1 voltage	V
Vb2	Internal base2 voltage	V
Ve	External emitter voltage	V
Ve1	External emitter1 voltage	V
Vs	Substrate voltage	V
gx	Forward transconductance (dIn/dVb2e2)	S
gy	Reverse transconductance (dIn/dVb2c2)	S
gz	Reverse transconductance (dIn/dVb2c1)	S
Sgpi	Base-emitter sidewall conductance (dSIb1/dVb1e1)	S
gpix	Base-emitter conductance (d(Ib1 + Ib2)/dVb2e1)	S
gpiy	Early effect on recombination base current (dIb1/dVb2c2)	S
gpiz	Early effect on recombination base current (dIb1/dVb2c1)	S
gmux	Early effect on avalanche current limiting (-dIavl/dVb2e1)	S
gmuy	Avalanche current conductance (-dIavl/dVb2c2)	S
gmuz	Avalanche current conductance (-dIavl/dVb2c1)	S
gmuex	Extrinsic base-collector conductance (d(Iex + Ib3)/dVb1c1)	S
Xgmuex	Extrinsic base-collector conductance (dXIex/dVbc1)	S
grcvy	Epilayer conductance (dIc1c2/dVb2c2)	S
grcvz	Epilayer conductance (dIc1c2/dVb2c1)	S
rbv	Base resistance (1/(dIb1b2/dVb1b2))	Ohms
grbvx	Early effect on base resistance (dIb1b2/dVb2e1)	S
grbvy	Early effect on base resistance (dIb1b2/dVb2c2)	S

Table 2-8. DC Operating Point Information (continued)

Name	Description	Units
grbvz	Early effect on base resistance (dIb1b2/dVb2c1)	S
gs	Parasitic PNP transistor conductance (dIsub/dVb1c1)	S
Xgs	Parasitic PNP transistor conductance (dXIsub/dVbc1)	S
gsf	Substrate failure conductance (dIsf/dVsc1)	S
Qe	Emitter or emitter neutral charge	C
Qte	Base-emitter depletion charge	C
SQte	Sidewall base-emitter depletion charge	C
Qbe	Base-emitter diffusion charge	C
Qbc	Base-collector diffusion charge	C
Qtc	Base-collector depletion charge	C
Qepi	Epilayer diffusion charge	C
Qb1b2	AC current crowding charge	C
Qtex	Extrinsic base-collector depletion charge	C
XQtex	Extrinsic base-collector depletion charge	C
Qex	Extrinsic base-collector diffusion charge	C
XQex	Extrinsic base-collector diffusion charge	C
Qts	Collector-substrate depletion charge	C
SCbe	Base-emitter sidewall capacitance (dSQte/dVb1e1)	F
Cbex	Base-emitter capacitance (d(Qte + Qbe + Qe)/dVb2e1)	F
Cbey	Early effect on base-emitter diffusion charge (dQbe/dVb2c2)	F
Cbez	Early effect on base-emitter diffusion charge (dQbe/dVb2c1)	F
Cbcx	Early effect on base-collector diffusion charge (dQbc/dVb2e1)	F
Cbcy	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c2)	F
Cbcz	Base-collector capacitance (d(Qtc + Qbc + Qepi)/dVb2c1)	F
Cbcex	Extrinsic base-collector capacitance (d(Qtex + Qex)/dVb1c1)	F
XCbcex	Extrinsic base-collector capacitance (d(XQtex + XQex)/dVbc1)	F
Cb1b2	AC current crowding capacitance (dQb1b2/dVb1b2)	F
Cb1b2x	AC current crowding transcapacitance (dQb1b2/dVb2e1)	F
Cb1b2y	AC current crowding transcapacitance (dQb1b2/dVb2c2)	F
Cb1b2z	AC current crowding transcapacitance (dQb1b2/dVb2c1)	F

Table 2-8. DC Operating Point Information (continued)

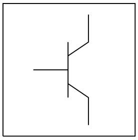
Name	Description	Units
Cts	Substrate-collector capacitance (dQts/dVsc1)	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

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

   http://www.semiconductors.philips.com/philips_models/newsflash/mextram504

STBJT_Model (ST Bipolar Transistor Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
Type	1 = NPN; 2 = PNP		1
Tmeas (Tnom)	measurement temperature	°C	25
Is	forward transport saturation current	A	1.0e-16
Isn	reverse transport saturation current	A	Is
Bf	ideal forward current gain		100.0
Nf	forward current emission coefficient		1.0
Br	ideal reverse current gain		1.0
Nr	reverse emission coefficient		1.0
Isf	ideal B-E junction saturation current	A	Is/Bf
Nbf	ideal B-E junction emission coefficient		Nf
Isr	ideal B-C junction saturation current	A	Isn/Br
Nbr	ideal B-C junction emission coefficient		Nr
Ise	B-E recombination saturation current	A	0.0
Ne	B-E recombination emission coefficient		2.0
Isc†, ††	B-C recombination saturation current	A	0.0
Nc	B-C recombination emission coefficient		1.5
Vaf	forward early voltage	V	0.0†††
Var	reverse early voltage	V	0.0†††
Enp	base push out exponent		2.0
Rp	BPO fitting parameter		1.0e-3
Rw	ratio of collector width to the base		0
Vij	modified B-C potential	V	0.8

Name	Description	Unit	Default
Vrp	voltage drop across vertical Rc	V	1.0e-9
Bvc	junction breakdown of C-B junction	V	0.0†††
Mf	exponent of B-C multiplication factor		0.0
Fa	Bvcbo/Bvc		0.95
Avc	fitting parameter		1.0
Bve	junction breakdown of the E-B junction	V	0†††
Mr	exponent of the E-B multiplication factor		0.0
Fb	Bvebo/Bve		0.95
Ave	fitting parameter		1.0
Rb	zero-bias base resistance	ohms	0.0
Irb	current when base resistance falls halfway to its minimum value	A	0.0†††
Rbm	minimum base resistance at high current (0 means Rb)	ohms	0.0
Re	emitter resistance	ohms	0.0
Rc	collector resistance under the emitter	ohms	0.0
Rcs	collector resistance in saturation	ohms	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		0.33
Fc	forward-bias depletion gap		1.0
Cjc	B-C zero-bias depletion gap	F	0.0
Vjc	B-C junction built-in potential	V	0.75
Mjc	junction grading coefficient		0.33
Xjbc	fraction of Cjc connected to B int node		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		0.33
Xjbs	fraction of B-S cap connected to B int node		1.0
Vert	1 = vertical structures; 0 = else		0
Subsn	N substrate if 1		0
Tf	ideal forward transit time	S	0.0

Name	Description	Unit	Default
Xtf	coefficient of bias dependence for TF		0.0
Vtf	voltage dependence of Tf on B-C voltage (0 means infinity)	V	0†††
Itf	parameter for Tf high currents roll off	A	0†††
Ptf	excess phase	degrees	0.0
Tfcc	Tf BPO model (1 if Spice)		0.0
Tr	ideal reverse transit time	S	0.0
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		0.0
Eg	bandgap voltage at OK	V	1.11
Xti	temperature exponent		3.0
Xtb	temperature exponent for gain currents		0.0
Trb1	linear temperature coefficient for Rb	1/°C	0.0
Trb2	quadratic temperature coefficient for Rb	$1/(°C)^2$	0.00
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	$1/(°C)^2$	0.0
Trc1	linear temperature coefficient for Rc	1/°C	0.0
Trc2	quadratic temperature coefficient for Rc	$1/(°C)^2$	0.0
Trcs1	linear temperature coefficient for Rcs	1/°C	0.0
Trcs2	quadratic temperature coefficient for Rcs	$1/(°C)^2$	0.0
Ikf	forward Ik (0 means infinity)	A	0†††
Ikr	reverse IK (0 means infinity)	A	0†††
Gmin	minimum conductance		1e-12
All Params	name of DataAccessComponent for file-based model parameter values		

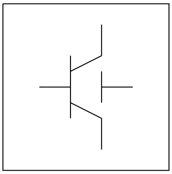
† This parameter value varies with temperature based on model Tnom and device Temp.

†† This parameter value scales with Area specified with the BJT or BJT4 model.

††† A value of 0.0 is interpreted as infinity.

VBIC_Model (VBIC Model)

Symbol



Parameters

Name	Definition	Unit	Default
NPN	N-channel model type		yes
PNP	P-channel model type		no
Tnom	nominal ambient temperature	°C	25
Trise	temperature rise above ambient	°C	0
Rcx†	extrinsic collector resistance	ohms	0.0
Rci†	intrinsic collector resistance	ohms	0.0
Vo†	epi drift saturation voltage	V	0.0
Gamm†	epi doping parameter		0.0
Hrcf	high-current RC factor		1.0
Rbx†	extrinsic base resistance	ohms	0.0
Rbi†	intrinsic base resistance	ohms	0.0
Re†	emitter resistance	ohms	0.0
Rs†	substrate resistance	ohms	0.0
Rbp†	parasitic base resistance	ohms	0.0
Is†	transport saturation current	A	10^{-16}
Nf†	forward emission coefficient		1.0
Nr†	reverse emission coefficient		1.0
Fc	forward bias junction capacitance threshold		0.9
Cbeo	base-emitter small signal capacitance	F	0.0
† This parameter value varies with temperature based on model Tnom and device Temp.			

Name	**Definition**	**Unit**	**Default**
Cje†	base-emitter zero-bias junction capacitance	F	0.0
Pe†	base-emitter grading coefficient		0.75
Me	base-emitter junction exponent		0.33
Aje	base-emitter capacitance smoothing factor		-0.5
Cbco	extrinsic base-collector overlap capacitance	F	0.0
Cjc†	base-collector zero-bias capacitance	F	0.0
Qco	collector charge at zero bias	C	0.0
Cjep†	base-emitter extrinsic zero-bias capacitance	F	0.0
Pc†	base-collector grading coefficient		0.75
Mc	base-collector junction exponent		0.33
Ajc	base-collector capacitance smoothing factor		-0.5
Cjcp†	base-collector zero-bias extrinsic capacitance	F	0.0
Ps†	collector-substrate grading coefficient		0.75
Ms	collector-substrate junction exponent		0.33
Ajs	collector-substrate capacitance smoothing factor		-0.5
Ibei†	ideal base-emitter saturation current		10^{-18}
Wbe	portion of Ibei from Vbei, 1-Wbe from Vbex		1.0
Nei	ideal base-emitter emission coefficient		1.0
Iben†	non-ideal base-emitter saturation current		0.0
Nen	non-ideal base-emitter emission coefficient		2.0
Ibci†	ideal base-collector saturation current		10^{-16}
Nci	ideal base-collector emission coefficient		1.0
Ibcn†	non-ideal base-collector saturation current		0.0
Ncn	non-ideal base-collector emission coefficient		2.0
Isp†	parasitic transport saturation current		0.0
Wsp	portion of Iccp from Vbep, 1-Wsp from Vbci		1.0
Nfp	parasitic forward emission coefficient		1.0

† This parameter value varies with temperature based on model Tnom and device Temp.

Name	Definition	Unit	Default
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		1.0
Ibcnp†	non-ideal parasitic base-collector saturation current		0.0
Avc1	base-collector weak avalanche parameter 1		0.0
Avc2†	base-collector weak avalanche parameter 2		0.0
Ncnp	non-ideal parasitic base-collector emission coefficient		2.0
Vef	forward Early voltage (0=infinity)		0.0
Ver	reverse Early voltage (0=infinity)		0.0
Ikf	forward knee current. (0=infinity)	A	0.0
Ikr	reverse knee current (0=infinity)	A	0.0
Ikp	parasitic knee current (0=infinity)	A	0.0
Tf	forward transit time	sec	0.0
Qtf	variation of Tf with base-width modulation		0.0
Xtf	coefficient of Tf bias dependence		0.0
Vtf	coefficient of Tf dependence on Vbc		0.0
Itf	coefficient of Tf dependence on Icc		0.0
Tr	ideal reverse transit time	sec	0.0
Td	forward excess-phase delay time	sec	0.0
Kfn	flicker noise coefficient		0.0
Afn	flicker noise exponent		1.0
Bfn	flicker noise frequency exponent		1.0
Xre	temperature exponent of emitter resistance		0.0
Xrb	temperature exponent of base resistance		0.0
Xrc	temperature exponent of collector resistance		0.0
Xrs	temperature exponent of substrate resistance		0.0
Xvo	temperature exponent of Vo		0.0
Ea	activation energy for Is	eV	1.12

† This parameter value varies with temperature based on model Tnom and device Temp.

Name	Definition	Unit	Default
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		3.0
Xii	temperature exponent of Ibei/Ibci/Ibeip/Ibcip		3.0
Xin	temperature exponent of Iben/Ibcn/Ibenp/Ibcnp		3.0
Tnf	temperature coefficient of Nf		0.0
Tavc	temperature coefficient of Avc		0.0
Rth	thermal resistance	W	0.0
Cth	thermal capacitance	F	0.0
Imax	explosion current	A	1.0
Imelt	(similar to Imax; refer to Note 4)	A	1.0
Selft	flag denoting self-heating: yes, no		see Note 5
Dtmax	maximum expected device temperature	°C	500
wVsubfwd (Vsubfwd)	substrate junction forward bias (warning)	V	
wBvsub (Bvsub)	substrate junction reverse breakdown voltage (warning)	V	
wBvbe (Bvbe)	base-emitter reverse breakdown voltage (warning)	V	
wBvbc (Bvbc)	base-collector reverse breakdown voltage (warning)	V	
wVbcfwd (Vbcfwd)	base-collector forward bias (warning)	V	
wIbmax	maximum base current (warning)	A	
wIcmax	maximum collector current (warning)	A	
wPmax	maximum power dissipation (warning)	W	
AllParams	name of DataAccessComponent for file-based model parameter values		

† This parameter value varies with temperature based on model Tnom and device Temp.

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

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

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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*.

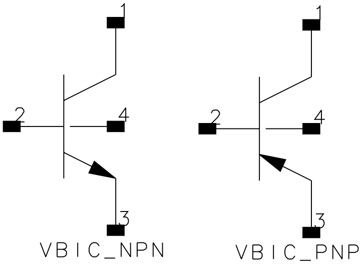
[2] W. J. Kloosterman and H. C. de Graaff. “Avalanche Multiplication in a Compact Bipolar Transistor Model for Circuit Simulation,” *IEEE 1988 BCTM*.

[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	Unit	Default
Model	name of a VBIC_Model		
Scale	scaling factor		1
Region	dc operating region: off=0, on=1, rev=2, sat=3		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Noise	noise generation option: yes=1, no=0		yes
Mode	simulation mode for this device: nonlinear, linear		nonlinear
_M	number of devices in parallel		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 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.
3. Table 2-9 lists the DC operating point parameters that can be sent to the dataset.

Table 2-9. DC Operating Point Information

Name	Description	Units
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Substrate current	A
Power	DC power dissipated	W
Gbe	Transconductance gbe	S
Cbe	Base-emitter capacitance cbe	F
Gbc	Transconductance gbc	S
Cbc	Base-collector capacitance cbc	F
Gbex	Transconductance gbex	S
Cbex	Base-emitter capacitance cbex	F
Gbep	Transconductance gbep	S
Cbep	Base-emitter capacitance cbep	F
Gbcp	Transconductance gbcp	S
Cbcp	Base-collector capacitance cbcp	F
dIcc_dVbei	(dIcc/dVbei)	S
dIcc_dVbci	(dIcc/dVbci)	S
dIccp_dVbep	(dIccp/dVbep)	S
dIccp_dVbcp	(dIccp/dVbcp)	S
dIccp_dVbci	(dIccp/dVbci)	S
dIbc_dVbei	(dIbc/dVbei)	S
Grbi	Base conductance grbi	S
dIrbi_dVbei	(dIrbi/dVbei)	S
dIrbi_dVbci	(dIrbi/dVbci)	S
Grbp	Base conductance grbp	S
dIrbp_dVbep	(dIrbp/dVbep)	S
dIrbp_dVbci	(dIrbp/dVbci)	S
Grci	Collector conductance grci	S
dIrci_dVbci	(dIrci/dVbci)	S

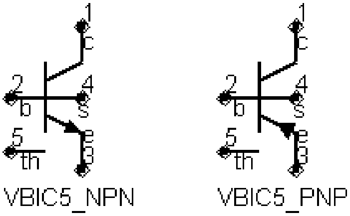
Table 2-9. DC Operating Point Information (continued)

Name	Description	Units
dQbe_dVbci	(dQbe/dVbci)	F
dQbep_dVbci	(dQbep/dVbci)	F
dQbcx_dVbci	(dQbcx/dVbci)	F
dQbcx_dVrci	(dQbcx/dVrci)	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

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

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

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a VBIC_Model		
Scale	scaling factor		1
Region	dc operating region: off=0, on=1, rev=2, sat=3		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: nonlinear, linear		nonlinear
Noise	noise generation option: yes=1, no=0		yes
_M	number of devices in parallel		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 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.
3. Table 2-10 lists the DC operating point parameters that can be sent to the dataset.

Table 2-10. DC Operating Point Information

Name	**Description**	**Units**
Ic	Collector current	A
Ib	Base current	A
Ie	Emitter current	A
Is	Source current	A
Power	DC power dissipated	W
Gbe	Transconductance gbe	S
Cbe	Base-emitter capacitance cbe	F
Gbc	Transconductance gbc	S
Cbc	Base-collector capacitance cbc	F
Gbex	Transconductance gbex	S
Cbex	Base-emitter capacitance cbex	F
Gbep	Transconductance gbep	S
Cbep	Base-emitter capacitance cbep	F
Gbcp	Transconductance gbcp	S
Cbcp	Base-collector capacitance cbcp	F
dIcc_dVbei	(dIcc/dVbei)	S
dIcc_dVbci	(dIcc/dVbci)	S
dIccp_dVbep	(dIccp/dVbep)	S
dIccp_dVbcp	(dIccp/dVbcp)	S
dIccp_dVbci	(dIccp/dVbci)	S
dIbc_dVbei	(dIbc/dVbei)	S
Grbi	Base conductance grbi	S
dIrbi_dVbei	(dIrbi/dVbei)	S
dIrbi_dVbci	(dIrbi/dVbci)	S
Grbp	Base conductance grbp	S
dIrbp_dVbep	(dIrbp/dVbep)	S
dIrbp_dVbci	(dIrbp/dVbci)	S
Grci	Collector conductance grci	S
dIrci_dVbci	(dIrci/dVbci)	S

Table 2-10. DC Operating Point Information (continued)

Name	**Description**	**Units**
dQbe_dVbci	(dQbe/dVbci)	F
dQbep_dVbci	(dQbep/dVbci)	F
dQbcx_dVbci	(dQbcx/dVbci)	F
dQbcx_dVrci	(dQbcx/dVrci)	F
Vbe	Base-emitter voltage	V
Vbc	Base-collector voltage	V
Vce	Collector-emitter voltage	V

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

Chapter 3: Devices and Models, GaAs

Bin Model

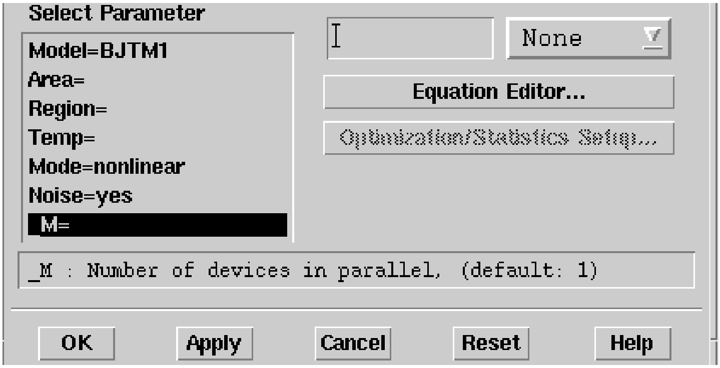
The BinModel in the GaAs library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn’t work for all sizes of a device.

For information on the use of the binning feature, refer to BinModel documentation in Chapter 1 of *Introduction and Simulation 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.

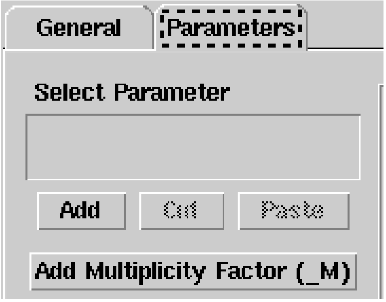
The _M parameter is available at the component level as shown here. (For components that don't explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

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 book 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 25ºC. 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

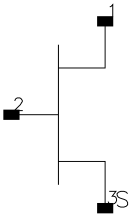
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp,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

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
```

Angelov_FET (Angelov Nonlinear GaAsFET)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of an Angelov_Model		
Temp	device operating temperature	°C	25
Trise	temperature rise over ambient		
_M	number of devices in parallel		1
Mode	nonlinear spectral model: nonlinear, linear		nonlinear
Noise	noise generation option: yes=1, no=0		yes

Notes/Equations

1. Table 3-2 lists the DC operating point parameters that can be sent to the dataset.

Table 3-1. DC Operating Point Information

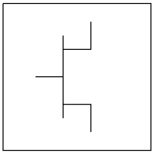
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
Ggs	Gate-source conductance	S
Ggd	Gate-drain conductance	S
Cgs	Gate-source capacitance	F

Table 3-1. DC Operating Point Information (continued)

Name	Description	Units
Cgd	Gate-drain capacitance	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V

Angelov_Model (Angelov (Chalmers) Nonlinear GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
Idsmod	Ids model flag		0
Igmod	Igs/Igd model flag		0
Capmod	Capacitance model selector		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		1.0
P2	Polynomial coefficient for channel current		0.0
P3	Polynomial coefficient for channel current		0.0
Alphar	Saturation parameter		0.1
Alphas	Saturation parameter		1.0
Vkn ††	Knee voltage	V	0.8
Lambda	Channel length modulation parameter		0.0
Lambda1 ††	Channel length modulation parameter		0.0
Lvg ††	Coefficient for Lambda parameter		0.0
B1	Unsaturated coefficient for P1		0.0
B2	Unsaturated coefficient for P2		3.0
Lsb0 †	Soft breakdown model parameter		0.0
Vtr	Threshold voltage for breakdown	V	20
Vsb2	Surface breakdown model parameter		0.0
Cds	Drain-source capacitance	F	0.0
Cgspi	Gate-source pinch-off capacitance	F	0.0

Name	Description	Unit	Default
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	F	0.0
P11	Polynomial coefficient for capacitance	F	1.0
P20	Polynomial coefficient for capacitance	F	0.0
P21	Polynomial coefficient for capacitance	F	0.2
P30	Polynomial coefficient for capacitance	F	0.0
P31	Polynomial coefficient for capacitance	F	0.2
P40	Polynomial coefficient for capacitance	F	0.0
P41	Polynomial coefficient for capacitance	F	1.0
P111	Polynomial coefficient for capacitance	F	0.0
Ij	Gate fwd saturation current	A	0.0005
Pg	Gate current parameter		15.0
Ne	Ideality factor		1.4
Vjg	Gate current parameter	V	0.7
Rg	Gate resistance	Ohms	1.0
Rd	Drain resistance	Ohms	1.0
Ri	Gate-source resistance	Ohms	1.0
Rs	Source resistance	Ohms	1.0
Rgd	Gate-drain resistance	Ohms	1.0
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	Ohms	1.0e3
Rc†	R for frequency dependent output conductance	Ohms	10.0e3
Crf†	C for frequency dependent output conductance	F	0.0
Rcin	R for frequency dependent input conductance	Ohms	100 KOhms
Crfin	C for frequency dependent input conductance	F	0.0

Name	Description	Unit	Default
Rth	Thermal resistance	Ohms	0.0
Cth	Thermal capacitance	F	0.0
Tcipk0	Temperature coefficient of Ipk0 parameter		0.0
Tcp1	Temperature coefficient of Ipk0 parameter		0.0
Tccgs0	Temperature coefficient of Cgs0 parameter		0.0
Tccgd0	Temperature coefficient of Cgd0 parameter		0.0
Tclsb0	Temperature coefficient of Lsb0 parameter		0.0
Tcrc	Temperature coefficient of Rc parameter		0.0
Tccrf	Temperature coefficient of Crf parameter		0.0
Tnom (Tamb)	Parameter measurement temperature	deg C	25
Selft	Flag denoting self-heating		no
Noimod	Noise model selector		0
NoiseR	Gate noise coefficient		0.5
NoiseP	Drain noise coefficient		1.0
NoiseC	Gate-drain noise correlation coefficient		0.9
Fnc	Flicker-noise corner frequency	Hz	0.0
Kf	Flicker noise coefficient		0.0
Af	Flicker noise exponent		1.0
Ffe	Flicker noise frequency exponent		1.0
Tg	Gate equivalent temperature	deg C	25
Td	Drain equivalent temperature coefficient	deg C	25
Tdl	Drain equivalent temperature coefficient		0.1
Tmn	Noise fitting coefficient		1.0
Klf	Flicker noise coefficient		1.0e14
Fgr	Generation-recombination frequency corner	Hz	60.0e3
Np	Flicker noise frequency exponent		0.3
Lw	effective gate noise width	mm	0.1
AllParams	DataAccessComponent for file-based model parameter values		

† 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:

   $$Rc = Rcmin + \frac{Rc}{(1 + \tanh(\tau))}$$

5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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)

$$ds = IPK0 \times (1 + \tanh(\psi)) \times \tanh(\alpha \times Vds)$$
$$\times (\ 1 + LAMBDA \times Vds + LSB0 \times \exp(Vdg - VTR))$$

For the symmetric model (Idsmod=1)

$$\psi_n = P1m \times ((Vgd - Vpkm) + P2 \times (Vgd - Vpkm)^2 + P3 \times (Vgd - Vpkm)^3)$$

$$\alpha_n = ALPHAR + ALPHAS \times (1 + \tanh(\psi_n))$$

$$\lambda_n = LAMBDA + LVG \times (1 + \tanh(\psi_n))$$

$$\lambda_p = LAMBDA + LVG \times (1 + \tanh(\psi))$$

$$\lambda_{n1} = LAMBDA1 + LVG \times (1 + \tanh(\psi_n))$$

$$\lambda_{p1} = LAMBDA1 + LVG \times (1 + \tanh(\psi))$$

$$dsp = IPK0 \times (1 + \tanh(\psi)) \times (1 + \tanh(\alpha \times Vds))$$
$$\times \left(1 + \lambda_p \text{Vds} \ \times \lambda_{p1} \times \exp\left(\frac{Vds}{Vkn} - 1\right)\right)$$

$$dsn = IPK0 \times (1 + \tanh(\psi_n)) \times (1 + \tanh(\alpha \times Vds))$$
$$\times \left(\ 1 - \lambda_n \left(Vds - \lambda_{n1} \times \exp\left(\frac{Vds}{Vkn} - 1\right)\right)\right)$$

$$Ids = 0.5 \times (Idsp - Idsn)$$

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 given, but NE is given then:

$$PG = 1/2/NE/Vt$$

where $Vt = K \times Temp / q$

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

$$Lc1 = 1n(\cosh(Phi1))$$
$$Lc10 = 1n(\cosh(P10 + P111 \times Vds))$$

$$Qgs = CGSP \times Vgsc + CGS0$$
$$\times ((Phi1 + Lc1 - Qgs0) \times (1 - P111 + \tanh(Phi2))/P11 + 2 \times P111 \times Vgsc)$$

$$Qgs0 = P10 + P111 \times Vds + Lc10$$

$$Lc4 = 1n(\cosh(Phi4))$$
$$Lc40 = 1n(\cosh(P40 + P111 \times Vds))$$

$$Qgd = CGDP \times Vgdc + CGD0$$
$$\times(\ (Phi4 + Lc4 - Qgd0) \times (1 - P111 + \tanh(Phi3)) / P411 + 2 \times P111 \times Vgdc)$$

$$Qgd0 = P40 - P111 \times Vds + Lc40$$

$$Phi1 = P10 + P11 \times Vgsc + P111 \times Vds$$
$$Phi2 = P20 + P21 \times Vds$$
$$Phi3 = P30 - P31 \times Vds$$
$$Phi4 = P40 + P41 \times Vgdc - P111 \times Vds$$

Temperature Equations

$$Ipk0 = IPK0 \times (1 + TCIPK0 \times (Temp - Tnom))$$

$$P1 = P1 \times (1 + TCP1 \times (Temp - Tnom))$$

$$Lsb0 = LSB0 \times (1 + TCLSB0 \times (Temp - Tnom))$$

$$Cgs0 = CGS0 \times (1 + TCGS0 \times (Temp - Tnom))$$

$$Cgd0 = CGD0 \times (1 + TCGD0 \times (Temp - Tnom))$$

$$Rc = RC \times (1 + TCRC \times (Temp - Tnom))$$

$$Crf = CRF \times (1 + TCCRF \times (Temp - Tnom))$$

Broadband Noise Equations

NoiseMod = 0 (default value)

$$Idtn = abs(Ids) + abs(Igd)$$

$$\langle i_d^2 \rangle / \Delta F = 4KT \times LW \times \sqrt{((TD)/(Temp) \times Idtn + TD1 \times Idtn^2)}$$

NoiseMod=1

Parameters P, R and C model drain and gate noise sources. If they are not given, they are calculated from:

$$R = gm \times Ri \times Tg / Temp$$
$$P = gd / gm \times Td / Temp$$
$$C = \sqrt{R/P}$$

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m \ P + 4kTg_m \ PFnc / f + Kf \ Ids^{Af} \ / f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT \ C_{gs}^2 \ \omega^2 \ R / g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj \ C_{gs} \ \omega \sqrt{PR} \ C$$

NoiseMod=2 (supported for linear noise only)

If TMN is given, 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)

Igs, Igd Shot Noise and Flicker Noise Equations

$$\frac{\langle igs^2 \rangle}{\Delta f} = 2 \times q \times Igs + Kf \times Igs^{Af} \ / freq^{Ffe}$$

$$\frac{\langle igd^2 \rangle}{\Delta f} = 2 \times q \times Igd + Kf \times Igd^{Af} \ / freq^{Ffe}$$

Ids Flicker Noise Equations

NoiMod=1 or NoiMod=2

$$\frac{\langle id^2 \rangle}{\Delta f} = Kf \times Ids^{Af} \ / freq^{Ffe}$$

NoiMod=0 (default value)

$$\frac{\langle idf^2 \rangle}{\Delta f} = Klfd \times \frac{id^2}{\Delta f}$$

where

$$Klfd = Klf \times \left(\frac{1}{freq^{NP}} + \frac{1}{1 + \frac{freq^2}{Fgr}} \right)$$

Thermal Noise Equations

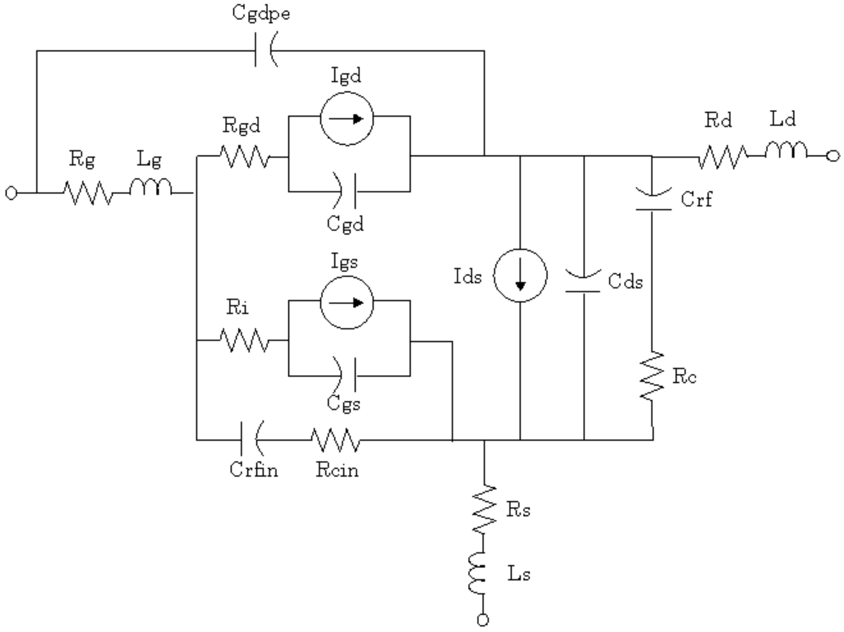
Thermal noise of resistances Rgd, Rd, Rg and Rs:

$$\frac{\langle i^2 \rangle}{\Delta f} = 4kT \times 1 / R$$

For Ri:

$$\frac{\langle i^2 \rangle}{\Delta f} = 4kTg \times 1 / Ri$$

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.

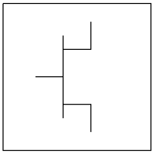
[4] B. Hughes, "A Temperature Noise Model for Extrinsic FETs," *IEEE Trans. MTT.*, Vol. 40, pp. 1821-1832, Sept. 1992.

[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	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		1
Vto[†],	threshold voltage	V	–2
Beta[†], [††]	transconductance	A/V^2	10^{-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	A/Temp°C	0
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	drain current exponential temperature coefficient	%/°C	0.0
Rin [†††]	channel resistance	ohms	0.0
Rf[†††]	gate-source effective forward- bias resistance	ohms	infinity[‡]
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgs[†], [††]	zero bias gate-source junction capacitance	F	0.0

[†] 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.

Name	**Description**	**Unit**	**Default**
Cgd †, ††	zero bias gate-drain junction capacitance	F	0.0
Rgd†††	gate drain resistance	ohms	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Rd†††	drain ohmic resistance	ohms	0.0
Rg	gate resistance	ohms	0.0
Rs†††	source ohmic resistance	ohms	0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0
Cds††	drain-source capacitance	F	0.0
Rc†††	used with Crf to model frequency dependent output conductance	ohms	infinity‡
Crf††	used with Rc to model frequency dependent output conductance	F	0.0
Gsfwd	0=none, 1=linear, 2=diode		linear
Gsrev	0=none, 1=linear, 2=diode		none
Gdfwd	0=none, 1=linear, 2=diode		none
Gdrev	0=none, 1=linear, 2=diode		linear
R1†††	approximate breakdown resistance	ohms	infinity‡
R2†††	resistance relating breakdown voltage to channel current	ohms	0.0
Vbi†	built-in gate potential	V	0.85
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with $V_{ds} < 0$)	V	10^{100}
Vjr	breakdown junction potential		0.025

† 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.

Name	Description	Unit	Default
Is[†], [††]	gate junction saturation current (diode model)	A	10^{-14}
Ir	gate reverse saturation current	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 2)	A	1.6
Xti	temperature exponent for saturation current		3.0
Eg	energy gap for temperature effect on Is	eV	1.11
N	gate junction emission coefficient (diode model)		1.0
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		0.9
Kf	flicker noise coefficient		0
Af	flicker noise exponent		1
Ffe	flicker noise frequency exponent		1
Taumdl	second order Bessel polynomial to model tau effect in transient simulation		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		

[†] 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). 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 $V_{gc} < Fc \times Vbi$

$$Q_{gs} = 2 \times V_{bi} \times Cgs \left[1 - \sqrt{1 - \frac{V_{gc}}{Vbi}} \right]$$

$$C_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{\sqrt{1 - \frac{V_{gc}}{Vbi}}}$$

For $V_{gc} \geq Fc \times Vbi$

$$Q_{gs} = 2 \times Vbi \times Cgs[1 - \sqrt{1 - Fc}] + \frac{Cgs}{(1 - Fc)^{3/2}} \times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times (V_{gc} - Fc \times Vbi) + \frac{V_{gc}^2 - (Fc \times Vbi)^2}{4 \times Vbi} \right]$$

$$C_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gc}}{2 \times Vbi} \right]$$

Gate-drain junction

For $V_{gd} < Fc \times Vbi$

$$Q_{gd} = 2 \times Vbi \times Cgd \times \left[1 - \sqrt{1 - \frac{V_{gd}}{Vbi}} \right]$$

$$C_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{\sqrt{1 - \frac{V_{gd}}{Vbi}}}$$

For $V_{gd} \geq Fc \times Vbi$

$$Q_{gd} = 2 \times Vbi \times Cgd[1 - \sqrt{1 - Fc}] + \frac{Cgd}{(1 - Fc)^{3/2}}$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2}\right) \times (V_{gd} - Fc \times Vbi) + \frac{V_{gd}^2 - (Fc \times Vbi)^2}{4 \times Vbi}\right]$$

$$C_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gd}}{2 \times Vbi}\right]$$

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 $V_{gs} \le Vbi$.

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 $V_{gd} \le Vbi$.

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):

$$I_{gd} = V_{dg} - V_b)/R1 \quad \text{when } V_{dg} \geq V_b \text{ and } V_b > 0$$
$$= 0 \quad \text{when } V_{dg} < V_b \text{ or } V_b \leq 0$$
$$V_b = Vbr + R2 \times I_{ds}$$

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:

$$I_{gs} = (V_{sg} - Vb)/R1 \quad \text{when } V_{sg} \geq Vbi \text{ and } Vb > 0$$

$$= 0 \quad \text{when } V_{sg} \text{ £ } Vbi \text{ or } Vb \leq 0$$

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 Figure 3-1 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 [2].

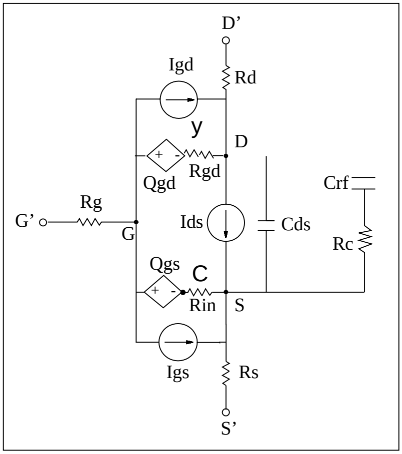


Figure 3-1. Curtice2_Model Schematic

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 $\neq$ 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.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kT g_m \; P + 4kT g_m \; PFnc / f + Kf \; Ids^{Af} \; / f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT \; C_{gs}^{2} \; \omega^2 \; R / g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj \; C_{gs} \; \omega \sqrt{PR} \; C$$

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.

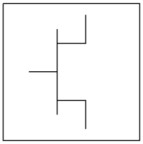
[2] C. Camacho-Penalosa and C.S. Aitchison, “Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies,” *Electron. Lett.*, Vol. 21, pp. 528-529, June 6, 1985.

[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.

Advanced_Curtice2_Model (Advanced Curtice-Quadratic GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		1
Vto†	threshold voltage	V	–2
Beta†, ††	transconductance	A/V^2	10^{-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
Taumdl	second order Bessel polynomial to model Tau effect in transient simulation		no
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Idstc	Ids temperature coefficient	A/Temp°C	0
Ucrit	critical field for mobility degradation		0
Vgexp	Vgs – Vto exponent		2
Gamds	effective pinch-off combined with Vds		-0.01
Vtotc	Vto temperature coefficient	V/°C	0.0

† 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.

Name	Description	Unit	Default
Betatce	drain current exponential temperature coefficient	%/°C	0.0
Rgs[†††]	gate-source resistance	ohms	0
Rf[†††]	gate-source effective forward- bias resistance	ohms	infinity[‡]
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		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		linear
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Rgd[†††]	gate drain resistance	ohms	0
Rd[†††]	drain ohmic resistance	ohms	0.0
Rg	gate resistance	ohms	0.0
Rs[†††]	source ohmic resistance	ohms	0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0
Cds[††]	drain-source capacitance	F	0.0
Rc[†††]	used with Crf to model frequency dependent output conductance	ohms	infinity[‡]
Crf[††]	used with Rc to model frequency dependent output conductance	F	0.0
Gsfwd	0=none, 1=linear, 2=diode		linear
Gsrev	0=none, 1=linear, 2=diode		none
Gdfwd	0=none, 1=linear, 2=diode		none
Gdrev	0=none, 1=linear, 2=diode		linear
R1[†††]	approximate breakdown resistance	ohms	infinity[‡]
R2[†††]	resistance relating breakdown voltage to channel current	ohms	0.0
Vbi[†]	built-in gate potential	V	0.85

[†] 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.

Name	**Description**	**Unit**	**Default**
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with V_{ds}<0)	V	10^{100}
Vjr	breakdown junction potential	V	1
Is[†, ††]	gate junction rev. saturation current (diode model)	A	10^{-14}
Ir	gate reverse saturation current	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 2)	A	1.6
Xti	temperature exponent for saturation current		3.0
Eg	energy gap for temperature effect on Is	eV	1.11
N	gate junction emission coefficient (diode model)		1.0
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		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	DataAccessComponent for file-based model parameter values		

[†] 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 $V_{ds} \geq 0.0V$.

   $$I_{ds} = \text{Beta}_{NEW} \times (V_{gs} - \text{Vto}_{NEW})^{\text{Vgexp}} \times (1+\text{Lambda} \times V_{ds}) \times \tanh(\text{Alpha} \times V_{ds})$$

   where

   $\text{Vto}_{NEW} = \text{Vto} + \text{Gainds} \times \text{Vds}$
   $\text{Beta}_{NEW} = \text{Beta}/(1 + (\text{Vgs} - \text{Vto}_{NEW} \times \text{Ucrit})$

Assuming symmetry, in the reverse region, the drain and source swap roles and the expression becomes:

$$I_{ds} = Beta_{NEW} \times (V_{gd} - Vto_{NEW})^{Vgexp} \times (1\text{-}Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds})$$

where

$$I_{ds} = Beta_{NEW} \times (V_{gd} - Vto_{NEW})^{Vgexp} \times (1+Lambda \times V_{ds}) \times \tanh(Alpha \times V_{ds}).$$

where

$$Vto_{NEW} = Vto + Gainds \times Vds$$

$$Beta_{NEW\,=}\, Beta/(1 + (Vgd\ \text{-}Vto_{NEW} \times Ucrit)$$

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.

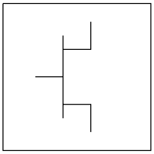
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

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.

Curtice3_Model (Curtice-Cubic GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		2
Beta2	coefficient for pinch-off change with respect to V_{ds}	1/V	10^{-4}
Rds0†††	dc drain-source resistance at Vgs=0	ohms	0
Vout0	output voltage (Vds) at which A0, A1, A2, A3 were evaluated	V	0.0
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	A/Temp°C	0
A0†, ††	cubic polynomial I_{ds} equation coefficient 1	A	0.0
A1†, ††	cubic polynomial I_{ds} equation coefficient 2	A/V	0.0
A2†, ††	cubic polynomial I_{ds}equation coefficient 3	A/V^2	0.0
A3†, ††	cubic polynomial I_{ds} equation coefficient 4	A/V^3	0.0
Vtotc	A0, A1, A2, A3 temperature coefficient	V/°C	0.0

† 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.

Name	**Description**	**Unit**	**Default**
Betatce	drain current exponential temperature coefficient	%/°C	0.0
Rin†††	channel resistance	ohms	0.0
Rf†††	gate-source effective forward-bias resistance	ohms	infinity‡
Fc	forward-bias depletion capacitance coefficient (diode model)		0.5
Gscap	0=none,1=linear,2=junction,3=Statz charge,5=Statz cap		linear
Cgs††	zero-bias gate-source capacitance	F	0.0
Cgd††	zero-bias gate-drain capacitance	F	0.0
Rgd†††	gate drain resistance	ohms	0.0
Gdcap	0=none,1=linear,2=junction,3=Statz charge,5=Statz cap		linear
Rd††	drain ohmic resistance	ohms	0.0
Rg	gate resistance	ohms	0.0
Rs†††	source ohmic resistance	ohms	0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	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	ohms	infinity‡
Gsfwd	0=none, 1=linear, 2=diode		linear
Gsrev	0=none, 1=linear, 2=diode		none
Gdfwd	0=none, 1=linear, 2=diode		none
Gdrev	0=none, 1=linear, 2=diode		linear
R1†††	approximate breakdown resistance	ohms	infinity‡
R2†††	resistance relating breakdown voltage to channel current	ohms	0.0

† 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.

Name	**Description**	**Unit**	**Default**
Vbi[†]	built-in gate potential	V	0.85
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with $V_{ds} < 0$)	V	10^{100}
Vjr	breakdown junction potential		0.025
Is[†] [††]	gate junction saturation current (diode model)	A	10^{-14}
Ir	gate reverse saturation current	A	10^{-14}
Xti	temperature exponent for saturation current		3.0
Eg	energy gap for temperature effect on Is	eV	1.11
N	gate junction emission coefficient (diode model)		1.0
A5	time delay proportionality constant for Vds		0.0
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 3)	A	1.6
Taumdl	second order Bessel polynomial to model tau effect in transient simulation		no
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		0.9
Vto	(not used in this model)		
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	
Kf	flicker noise coefficient		0
Af	flicker noise exponent		1

[†] 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.

Name	Description	Unit	Default
Ffe	flicker noise frequency exponent		1
AllParams	DataAccessComponent for file-based model parameter values		

† 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). 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:

$$I_{ds} = I_{dso} \times \mathrm{tanh}(\mathrm{Gamma} \times V_{ds}),\ \mathrm{Tau}_{NEW} = \mathrm{Tau} + \mathrm{A5} \times \mathrm{Vds}$$

where

$$I_{dso} = [\mathrm{A0} + \mathrm{A1} \times V_1 + \mathrm{A2} \times V_1^2 + \mathrm{A3} \times V_1^3] + (\mathrm{Vds} - \mathrm{Vdsdc})/\mathrm{Rds0}$$
$$V_1 = V_{gs}(t - \mathrm{Tau}_{NEW}) \times (1 + \mathrm{Beta2} \geq (\mathrm{Vout0} - V_{ds})),\ \text{when } V_{ds} \geq 0.0\ \mathrm{V}$$
$$V_1 = V_{gd}(t - \mathrm{Tau}_{NEW}) \times (1 + \mathrm{Beta2} \geq (\mathrm{Vout0} + V_{ds})),\ \text{when } V_{ds} < 0.0\ \mathrm{V}$$

The latter results in a symmetrical drain-source current that is continuous at V_{ds}=0.0 V. For values of V_1 below the internal calculated maximum pinchoff voltage Vpmax, which is the voltage at the local minimum of the function

$$\mathrm{A0} + \mathrm{A1} \times \nu + \mathrm{A2} \times \nu^2 + \mathrm{A3} \times \nu^3$$

I_{dso} is replaced with the following expression:

$$I_{dso} = [\mathrm{A0} + \mathrm{A1} \times \mathrm{Vpmax} + \mathrm{A2} \times \mathrm{Vpmax}^2 + \mathrm{A3} \times \mathrm{Vpmax}^3] + (\mathrm{Vds} - \mathrm{Vdsdc})/\mathrm{Rds0}$$

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 $V_{gc} < Fc \times Vbi$

$$Q_{gs} = 2 \times V_{bi} \times Cgs \times \left[1 - \sqrt{1 - \frac{V_{gc}}{Vbi}} \right]$$

$$C_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{\sqrt{1 - \frac{V_{gc}}{Vbi}}}$$

For $V_{gc} \geq Fc \times Vbi$

$$Q_{gs} = 2 \times V_{bi} \times Cgs \times [1 - \sqrt{1 - Fc}] + \frac{Cgs}{(1 - Fc)^{3/2}}$$

$$\times \left[\left(1 - \frac{3 \times Fc}{2} \right) \times (V_{gc} - Fc \times Vbi) \left(\frac{V_{gc}^{2} - (Fc \times Vbi)^{2}}{4 \times Vbi} \right) \right]$$

$$C_{gs} = \frac{\partial Q_{gs}}{\partial V_{gc}} = \frac{Cgs}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gc}}{2 \times Vbi} \right]$$

Gate-Drain Junction

For $V_{gd} < Fc \times Vbi$

$$Q_{gd} = 2 \times V_{bi} \times Cgd \times \left[1 - \sqrt{1 - \frac{V_{gd}}{Vbi}} \right]$$

$$C_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{\sqrt{1 - \frac{V_{gd}}{Vbi}}}$$

For $V_{gd} \geq Fc \times Vbi$

$$Q_{gd} = 2 \times V_{bi} \times Cgd \times \left([1 - \sqrt{1 - Fc}] + \frac{Cgd}{(1 - Fc)^{3/2}} \right)$$

$$\times \left(1 - \frac{3 \times Fc}{2} \right) \times \left(V_{gd} - F(c \times Vbi) + \frac{V_{gd}^2 - (Fbi)^2}{4 \times Vbi} \right)$$

$$C_{gd} = \frac{\partial Q_{gd}}{\partial V_{gd}} = \frac{Cgd}{(1 - Fc)^{3/2}} \times \left[1 - \frac{3 \times Fc}{2} + \frac{V_{gd}}{2 \times Vbi} \right]$$

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):

$$I_{gd} = V_{dg} - V_b)/R1 \quad \text{when } V_{dg} \geq V_b \text{ and } V_b > 0$$
$$= 0 \quad \text{when } V_{dg} < V_b \text{ or } V_b \leq 0$$
$$V_b = Vbr + R2 \times I_{ds}$$

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:

$$I_{gs} = (V_{sg} - Vb)/R1 \quad \text{when } V_{sg} \geq Vbi \text{ and } Vb > 0$$
$$= 0 \quad \text{when } V_{sg} \leq Vbi \text{ or } Vb \leq 0$$

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 (Figure 3-2) 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]).

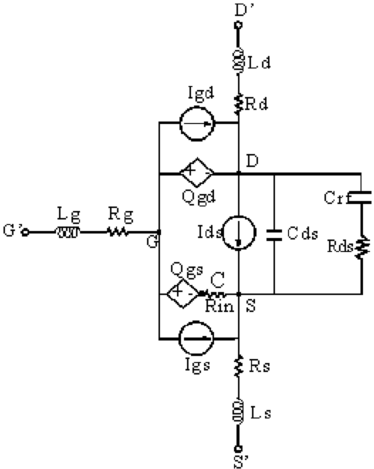


Figure 3-2. Curtice Cubic Model

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:

$$\Delta = Vtotc(Temp - Tnom)$$

$$A0^{NEW} = (A0 - \Delta \times A1 + \Delta^2 \times A2 - \Delta^3 \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A1^{NEW} = (A1 - 2\Delta \times A2 + 3\Delta^2 \times A3 - \Delta^3 \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A2^{NEW} = (A2 - 3\Delta \times A3) \times 1.01^{Betatce(Temp - Tnom)}$$

$$A3^{NEW} = (A3) \times 1.01^{Betatce(Temp - Tnom)}$$

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 A's, 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 can't be found, a warning message is given *cubic model does not pinch off*.

During analysis, the following are calculated:

$vc = vgs \times (1 + Beta \times (Vout0 - vds))$
$ids = ((A0 + A1 \times vc + A2 \times vc \times\times 2 + A3 \times vc \times\times 3) + (vds - Vdsdc) / Rds0)$
$\times \tanh(Gamma \times vds)$

If ids < 0 then sets ids = 0.

If ids > 0 and $Vc \leq Vpmax$ 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 A's 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.

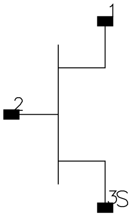
[2] C. Camacho-Penalosa and C.S. Aitchison, “Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies,” *Electron. Lett.*, Vol. 21, pp. 528-529, June 6, 1985.

[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	Unit	Default
Model	name of an EE_FET3_Model		
Ugw	unit gate width, in length units		0
N	number of gate fingers		1
Temp	device operating temperature	°C	25
Noise	noise generation option: yes=1, no=0		yes
_M	number of devices in parallel		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. Table 3-2 lists the DC operating point parameters that can be sent to the dataset.

Table 3-2. DC Operating Point Information

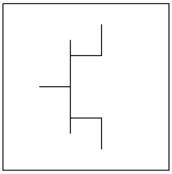
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A

Table 3-2. DC Operating Point Information (continued)

Name	Description	Units
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	S
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	S
Ggs	Gate-source conductance	S
Ggd	Gate-drain conductance	S
dIgd_dVgs	(dIgd/dVgs)	S
Cgc	Gate-source capacitance (dQgc/dVgc)	F
dQgc_dVgy	(dQgc/dVgy)	F
Cgy	Gate-drain capacitance (dQgy/dVgy)	F
dQgy_dVgc	(dQgy/dVgc)	F
Vgs	Gate-source voltage	V
Vds	Gate-drain voltage	V

EE_FET3_Model (EEsof Scalable Nonlinear GaAsFet Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
Vto	zero bias threshold	V	-1.5
Gamma	Vds dependent threshold	1/V	0.05
Vgo	gate-source voltage where transconductance is a maximum	V	–0.5
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	70×10^{-3}
Vdso	output voltage where Vds dependence disappears from equations	V	2.0
Vsat	drain-source current saturation	V	1.0
Kapa	output conductance	1/V	0.0
Peff	channel to backside self-heating	W	2.0
Vtso	subthreshold onset voltage	V	–10.0
Is	gate junction reverse saturation current	A	10^{-20}
N	gate junction ideality factor		1.0
Ris	source end channel resistance	ohms	2.0
Rid	drain end channel resistance	ohms	0.0
Tau	gate transit time delay	sec	10^{-12}
Cdso	drain-source inter-electrode capacitance	F	80×10^{-15}
Rdb	dispersion source output impedance	ohms	10^{9}

Name	Description	Unit	Default
Cbs	trapping-state capacitance	F	1.6×10^{-13}
Vtoac	zero bias threshold (ac)	V	–1.5
Vtoactc	linear temperature coefficient for Vtoac		0.0
Gammaac	Vds dependent threshold (ac)	1/V	0.05
Vdeltac	controls linearization point for transconductance characteristic (ac)	V/°C	0.0
Gmmaxac	peak transconductance (ac)	S	600×10^{-3}
Gmmaxtc	linear temperature coefficient for Gmmax		0.0
Gammatc	linear temperature coefficient for Gamma		0.0
Gmmaxactc	linear temperature coefficient for Gmmaxac		0.0
Gammaactc	linear temperature coefficient for Gammaac		0.0
Kapaac	output conductance (ac)	1/V	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	S	0.0
Kdb	controls Vds dependence of additional d-b branch conductance.		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	0.3×10^{-12}
C11th	minimum (threshold) input capacitance for Vds=Vdso	F	0.03×10^{-12}
Vinfl	inflection point in C11-Vgs characteristic	V	–1.0
Vinfltc	linear temperature coefficient for Vinfl		0.0
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	1.5
C12sat	input transcapacitance for Vgs=Vinfl and Vds>Deltds	F	0.03×10^{-12}
Cgdsat	gate drain capacitance for Vds>Deltds	F	0.05×10^{-12}
Kbk	breakdown current coefficient at threshold		0.0
Vbr	drain-gate voltage where breakdown source begins conducting	V	15.0

Name	Description	Unit	Default
Nbr	breakdown current exponent		2.0
Idsoc	open channel (maximum) value of Ids	A	100×10^{-3}
Rd	drain contact resistance	ohms	1.0
Rs	source contact resistance	ohms	1.0
Rg	gate metallization resistance	ohms	1.0
Ugw	unit gate width of device		0.0
Ngf	number of device gate fingers		1.0
Tnom	parameter measurement temperature		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	linear temperature coefficient for pinchoff voltage		0.0
Gmmaxtc	linear temperature coefficient for Gmmax		0.0
Xti	saturation current temperature exponent		3.0
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		

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:

   $Rd = 10^{-4}$
   $Rs = 10^{-4}$
   $Rg = 10^{-4}$
   $Ris = 10^{-4}$

$\text{Rid} = 10^{-4}$
Vsat = 0.1
$\text{Peff} = 10^{-6}$
$\text{Peffac} = 10^{-6}$
Deltds = 0.1
Deltgs = 0.1
Idsoc = 0.1
$\text{Is} = 10^{-50}$

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 $V_{ds} > 0.0$ V although the model is equally valid for $V_{ds} < 0.0$ V. 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 ($V_{ds} < 0.0$ V) 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

$$g_{mm}(V) = \frac{Gmmax}{2}[1 + Gamma(Vdso - V_{ds})]$$

$$\times\left\{\cos\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right] + 1\right\}$$

$$I_{dsm}(V) = \frac{Gmmax}{2}\left(((Vto - Vgo)/\pi)\sin\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right]\right.$$

$$\left. + V_x(V) - (Vto - Vch)\right)$$

$$V_x(V) = (V - Vch)[1 + Gamma(Vdso - V_{ds})]$$

$$V_g = \frac{Vgo - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch$$

$$V_t = \frac{Vto - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch$$

$$V_{gb} = \frac{(Vgo - Vdelt) - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch$$

$$m_{g_{mm}} = \left.\frac{\partial g_{mm}}{\partial V}\right|_{V = V_{gb}}$$

$$= -\frac{Gmmax\pi}{2(Vto - Vgo)}[1 + Gamma(Vdso - V_{ds})]^2$$

$$\times \sin\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right]$$

$$g_{mm}(V_{gb}) = \frac{Gmmax}{2}[1 + Gamma(Vdso - V_{ds})]$$

$$\times \left\{\cos\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right] + 1\right\}$$

$$I_{dsm}(V_{gb}) = \frac{Gmmax}{2}\Bigg(((Vto - Vgo)/\pi)\sin\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right]$$

$$+ (Vgo - Vdelt - Vto))$$

$$\frac{\partial(g_{mm}(V_{gb}))}{\partial V_{ds}} = -\frac{Gmmax}{2}Gamma\left\{\cos\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right] + 1\right\}$$

$$\frac{\partial m_{g_{mm}}}{\partial V_{ds}} = \frac{Gmmax\pi}{(Vto - Vgo)}(Gamma)[1 + Ganna(Vdso - V_{ds})]$$

$$\times \sin\left[-\pi \times \frac{Vdelt}{Vto - Vgo}\right]$$

$$\frac{\partial V_{gb}}{\partial V_{ds}} = \frac{(Vgo - Vdelt) - Vch}{[1 + Gamma(Vdso - V_{ds})]^2} \times Gamma$$

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:

$$I_{ds} = \frac{I'_{ds}}{1 + \dfrac{P_{diss}}{Peff}}$$

$$g_m = \frac{g'_m}{\left[1 + \dfrac{P_{diss}}{Peff}\right]^2}$$

$$g_{ds} = \frac{g'_{ds} - \dfrac{I'^2_{ds}}{Peff}}{\left[1 + \dfrac{P_{diss}}{Peff}\right]^2}$$

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 illustrated in Figure 3-3.

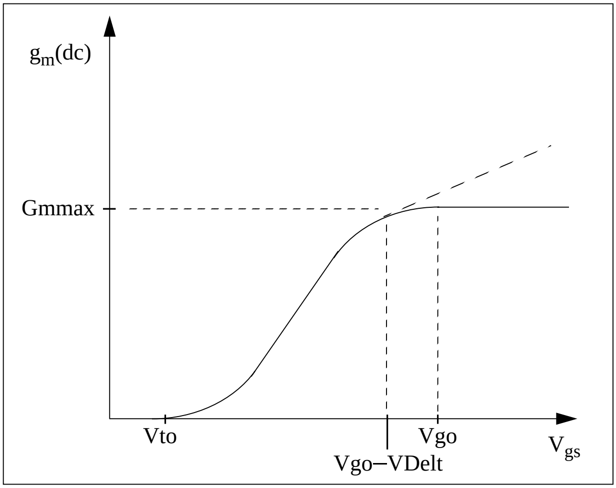


Figure 3-3. EEFET3 g_m-V_{gs} Parameters

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:

$$\begin{aligned} I_{ds}^{dc}(Voltages, Parameters) = {} & I_{ds}(Voltages, Gmmax, Vdelt, Vto, \text{Gamma}, \\ & Kapa, Peff, Vtso, Vgo, Vch, Vdso, Vsat) \end{aligned}$$

$$\begin{aligned} I_{ds}^{ac}(Voltages, Parameters) = {} & I_{ds}(Voltages, Gmmaxac, Vdeltac, Vtoac, \\ & Gammaac, Kappaac, Peffac, Vtsoac, \\ & Vgo, Vch, Vdso, Vsat) \end{aligned}$$

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:

$$q_{gc}(V_{gc}) = Cgdsat(V_{gc} + q_{gco})$$

The following continuous charge equations satisfy these constraints and are specified in terms of the gate charge:

$$q_{gy}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times f_2 \\ + Cgdsa \times V_{gy} \times f_1$$

$$q_{gc}(V_{gc}, V_{gy}) = \{q_g(V_{gc}, V_{gc} - V_{gy}) - C(gdsat \times V_{gy})\} \times f_1 \\ + Cgdsat \times V_{gc} \times f_2$$

where f_1 and f_2 are smoothing functions defined by

$$f_1 = \frac{1}{2}\left[1 + \tanh\left(\frac{3}{Deltds}(V_{gc} - V_{gy})\right)\right]$$

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 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 illustrated in Figure 3-4. 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.

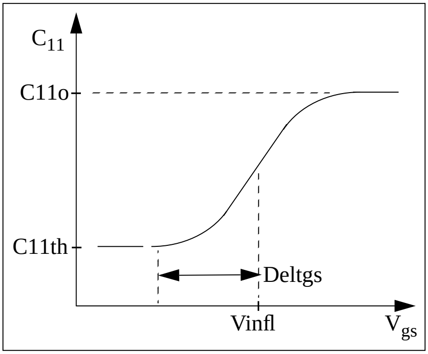


Figure 3-4. EE_FET3 C_{11}-V_{gs} Parameters

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 $-V_{gd} \le Vbr$

$$I_{gd}(V_{gd}, V_{gs}) = 0$$

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:

$$RG^{NEW} = Rg[1 + Rgtc(Temp - Tnom)]$$

$$RD^{NEW} = Rd[1 + Rdtc(Temp - Tnom)]$$

$$RS^{NEW} = Rs[1 + Rstc(Temp - Tnom)]$$

$$VTOAC^{NEW} = Vtoac + Vtoactc(Temp - Tnom)$$

$$VTSO^{NEW} = Vtso + Vtotc(Temp - Tnom)$$

$$VTSOAC^{NEW} = Vtsoac + Vtoactc(Temp - Tnom)$$

$$GAMMA^{NEW} = GAMMA\left(\left\lceil \frac{Temp}{Tnom} \right\rceil^{GAMMATC}\right)$$

$$GAMMAAC^{NEW} = GAMMAAC\left(\left\lceil \frac{Temp}{Tnom} \right\rceil^{GAMMAACTC}\right)$$

$$GMMAX^{NEW} = GMMAX + GMMAXTC(Temp - Tnom)$$

$$GMMAXAC^{NEW} = GMMAXAC + GMMAXACTC(Temp - Tnom)$$

$$VINFL^{NEW} = Vinfl + Vinfltc(Temp - Tnom)$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd, Ris, Rid, and Rdb is characterized by the following spectral density.

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

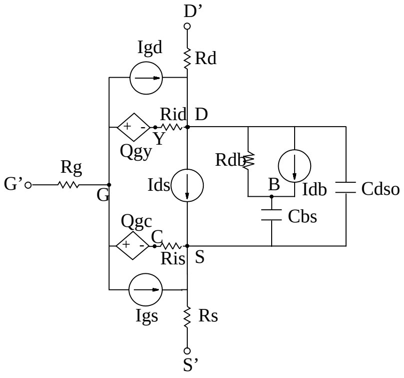
Channel noise generated by the DC transconductance g_m is characterized by the following spectral density:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3}$$

In these expressions, k is Boltzmann's constant, T is the operating temperature in Kelvin, q is the electron charge, and Δf 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 the *Circuit Simulation* manual. Data displayed for EE_FET3_Model (and EE_HEMT1_model) is:

EE_FET3	X1.A1
Id	0.167708
Ig	-9.99941e-015
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.

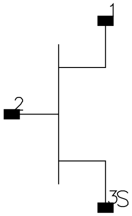
[2] P. C. Canfield, “Modeling of frequency and temperature effects in GaAs MESFETs” *IEEE Journal of Solid-State Circuits,* Vol. 25, pp. 299-306,Feb. 1990.

[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	Default
Model	name of an EE_HEMT1_Model	
Ugw	new unit gate width, in length units	
N	new number of gate fingers	
Noise	noise generation option: yes=1, no=0	yes
_M	number of devices in parallel	1

Range of Usage

Ugw > 0
N > 0

Notes/Equations

1. Ugw and N are used for scaling device instance; refer to the EE_HEMT1_Model information.
2. Table 3-3 lists the DC operating point parameters that can be sent to the dataset.

Table 3-3. DC Operating Point Information

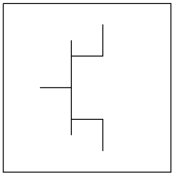
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W

Table 3-3. DC Operating Point Information (continued)

Name	**Description**	**Units**
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	S
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	S
Ggs	Gate-source conductance	S
Ggd	Gate-drain conductance	S
dIgd_dVgs	(dIgd/dVgs)	S
Cgc	Gate-source capacitance (dQgc/dVgc)	F
dQgc_dVgy	(dQgc/dVgy)	F
Cgy	Gate-drain capacitance (dQgy/dVgy)	F
dQgy_dVgc	(dQgy/dVgc)	F
Vgs	Gate-source voltage	V
Vds	Gate-drain voltage	V

EE_HEMT1_Model (EEsof Scalable Nonlinear HEMT Model)

Symbol



Parameters

Model Data parameters must be specified in SI units.

Name	Description	Unit	Default
Vto	zero bias threshold	V	–1.5
Gamma	Vds dependent threshold	1/V	0.05
Vgo	gate-source voltage where transconductance is a maximum	V	–0.5
Vdelt	not used	V	0.0
Vch	gate-source voltage where Gamma no longer affects I-V curves	V	1.0
Gmmax	peak transconductance	S	70×10^{-3}
Vdso	output voltage where Vo dependence disappears from equations	V	2.0
Vsat	drain-source current saturation	V	1.0
Kapa	output conductance	1/V	0.0
Peff	channel to backside self-heating	W	2.0
Vtso	subthreshold onset voltage	V	–10.0
Is	gate junction reverse saturation current	A	10^{-20}
N	gate junction ideality factor		1.0
Ris	source end channel resistance	ohms	2.0
Rid	drain end channel resistance	ohms	0.0
Tau	gate transit time delay	sec	10^{-12}
Cdso	drain-source inter-electrode capacitance	F	80×10^{-15}
Rdb	dispersion source output impedance	ohms	10^{9}

Name	Description	Unit	Default
Cbs	trapping-state capacitance	F	1.6×10^{-13}
Vtoac	zero bias threshold (ac)	V	–1.5
Gammaac	Vo dependent threshold (ac)	s	0.05
Vdeltac	not used	V	0.0
Gmmaxac	peak transconductance (ac)	S	600×10^{-3}
Kapaac	output conductance (ac)	1/V	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 Vo = VDSM	S	0.0
Kdb	controls Vds dependence of additional d-b branch conductance.		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	0.3×10^{-12}
C11th	minimum (threshold) input capacitance for Vds=Vdso	F	0.03×10^{-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	0.03×10^{-12}
Cgdsat	gate drain capacitance for Vds>Deltds	F	0.05×10^{-12}
Kbk	breakdown current coefficient at threshold		0.0
Vbr	drain-gate voltage where breakdown source begins conducting	V	15.0
Nbr	breakdown current exponent	-	2.0
Idsoc	open channel (maximum) value of Ids	A	10010^{-3}
Rd	drain contact resistance	ohms	1.0
Rs	source contact resistance	ohms	1.0
Rg	gate metallization resistance	ohms	1.0
Ugw	unit gate width of device	M	0.0

Name	Description	Unit	Default
Ngf	number of device gate fingers		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	adds Vds dependence to transconductance compression onset		1
Deltgm	slope of transconductance compression characteristic	S/V	0.0
Deltgmac	slope of transconductance compression characteristic (ac)	S/V	0.0
Alpha	transconductance saturation to compression transition	V	10^{-3}
Kmod	library model number		1
Kver	version number		1
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	
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	linear temperature coefficient for pinchoff voltage	V/°C	0.0
Gmmaxtc	linear temperature coefficient for Gmmax		0.0
Xti	saturation current temperature exponent		3.0
Vinfltc	linear temperature coefficient for Vinfl		0.0
Gammatc	linear temperature coefficient for Gamma		0.0
Vtoactc	linear temperature coefficient for Vtoac		0.0
Gmmaxactc	linear temperature coefficient for Gmmaxac		0.0
Gammaactc	linear temperature co-officiate for Gammaac		0.0

Name	Description	Unit	Default
Tnom	parameter measurement temperature		25.0
AllParams	DataAccessComponent for file-based model parameter values		

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. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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 $V_{gs} \geq V_g$

$$g_{mo} = Gmmax\{1 + Gamma(Vdso - V_{ds})\}$$

$$I_{dso} = Gmmax\left\{V_x(V_{gs}) - \frac{(V(go) + Vto)}{2} + Vch\right\}$$

$$g_{dso} = -Gmmax \times Gamma(V_{gs} - Vch)$$

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

$$g_{mm}(V) = \frac{Gmmax}{2}[1 + Gamma(Vdso - V_{ds})]$$

$$\times \left\{ \cos\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right] + 1 \right\}$$

$$I_{dsm}(V) = \frac{Gmmax}{2}\Bigg(((Vto - Vgo)/\pi) \sin\left[\pi \times \frac{V_x(V) - (Vgo - Vch)}{Vto - Vgo}\right]$$

$$+ V_x(V) - (Vto - Vch))$$

$$V_x(V) = (V - Vch)[1 + Gamma(Vdso - V_{ds})]$$

$$V_g = \frac{Vgo - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch$$

$$V_t = \frac{Vto - Vch}{1 + Gamma(Vdso - V_{ds})} + Vch\,.$$

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

$$a = \frac{g_{mv}(V_b, V_{ds}) - g_{moff}}{Vba^b}$$
$$b = \frac{s_{vb} \times Vba}{g_{mv}(V_b, V_{ds}) - g_{moff}}$$

$$s_{vb} = Deltgm \times \frac{Vbc}{\sqrt{Alpha^2 + Vbc^2}}$$

$$g_{mv}(V, V_{ds}) = Deltgm \times \left[\sqrt{Alpha^2 + (V - V_c)^2} - Alpha \right]$$

$$I_{dsv}(V, V_{ds}) =$$

$$Deltgm\left(\frac{1}{2}\left((V - V_c)\sqrt{Alpha^2 + (V - V_c)^2} - Alpha^2 \times \log\left[\frac{(V - V_c) + \sqrt{Alpha^2 + (V - V_c)^2}}{Alpha}\right]\right) - Alpha \times (V - V_c)\right)$$

$$g_{dsv}(V, V_{ds}) =$$

$$Deltgm \times Mu\left(\frac{1}{2}\left(\frac{2(V - V_c)^2 + Alpha^2}{\sqrt{Alpha^2 + (V - V_c)^2}} + \frac{Alpha^2}{(V - V_c) + \sqrt{Alpha^2 + (V - V_c)^2}} \times \left[1 + \frac{(V - V_c)}{\sqrt{Alpha^2 + (V - V_c)^2}}\right]\right) - Alpha\right)$$

where $g_{moff} = g_{mo}(Vco, Vdso)$ means replace Vgs by Vco, Vds by $Vdso$; i.e.,

if $Vco > Vgo$

$g_{moff} = \mathrm{Gmmax}$

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 $Idso \neq 0$ and $Vgs < Vts$ and $Vtso > Vto$

and $gmo/Idso > 0$

$$\arg = -\left(\frac{gmo}{Idso}\right) \times (Vts - Vgs)$$

$$Idso = Idso \times \exp(\arg)$$

$$gmo = gmo \times \exp(\arg)$$

$$dso = gdso \times \exp(\arg)$$

where

$Idso$, gmo are $Idso^{comp}$, gmo^{comp} if $Vgs > Vc$

To prevent g_m from becoming negative at high gate-source biases, the following restriction is placed on the parameter Deltgm:

$$Deltgm < \frac{g_{moff}}{\sqrt{Alpha^2 + Vbc^2} - Alpha}$$

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 Figure 3-5.

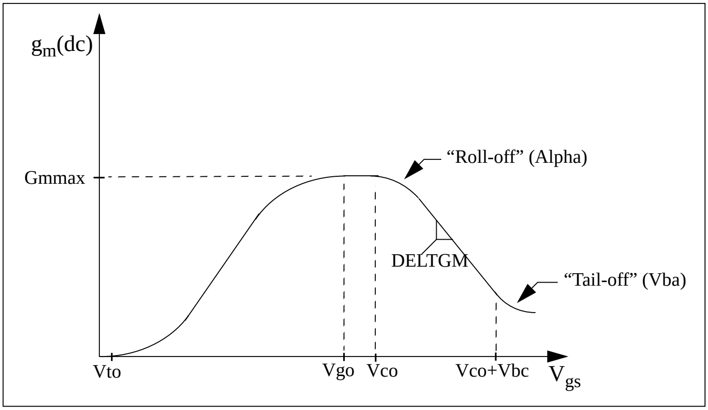


Figure 3-5. EE_HEMT1 g_m–V_{gs} Parameters

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 $\omega = 0$,

$$Re[y_{21}] = g_m = g_{dsgs}$$
$$Re[y_{22}] = g_{ds} = g_{dsds}$$

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 $\tau_{disp} = Rdb \times Cbs$. 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_{ds} equations. The DC and AC drain-source currents can be 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 $-Vdsm \le V_{ds} \le Vdsm$ 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

$$\begin{array}{l} AC \\ ds \end{array}$$

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

$$\begin{array}{l} AC \\ ds \end{array}$$

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 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:

$$\begin{aligned} C_{gygy} = \frac{\partial q_{gy}}{\partial V_{gy}} &= \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gy}} \\ &\quad + f_2 \times C_{ggy} + Cgdsat \times \left[V_{gy} \times \frac{\partial f_1}{\partial V_{gy}} + f_1 \right] \end{aligned}$$

$$\begin{aligned} C_{gygc} = \frac{\partial q_{gy}}{\partial V_{gc}} &= \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gc}\} \times \frac{\partial f_2}{\partial V_{gc}} \\ &\quad + f_2 \times [C_{ggc} - Cgdsat] + Cgdsat \times V_{gy} \times \frac{\partial f_1}{\partial V_{gc}} \end{aligned}$$

$$\begin{aligned} C_{gcgc} = \frac{\partial q_{gc}}{\partial V_{gc}} &= \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times \frac{\partial f_1}{\partial V_{gc}} \\ &\quad + f_1 \times C_{ggc} + Cdsat \times \left[V_{gc} \times \frac{\partial f_2}{\partial V_{gc}} + f_2 \right] \end{aligned}$$

$$\begin{aligned} C_{gcgy} = \frac{\partial q_{gc}}{\partial V_{gy}} &= \{q_g(V_{gc}, V_{gc} - V_{gy}) - Cgdsat \times V_{gy}\} \times \frac{\partial f_1}{\partial V_{gy}} \\ &\quad + f_1 \times [C_{ggy} - Cgdsat] + Cgdsat \times V_{gc} \times \frac{\partial f_2}{\partial V_{gy}} \end{aligned}$$

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 illustrated in Figure 3-6.

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.

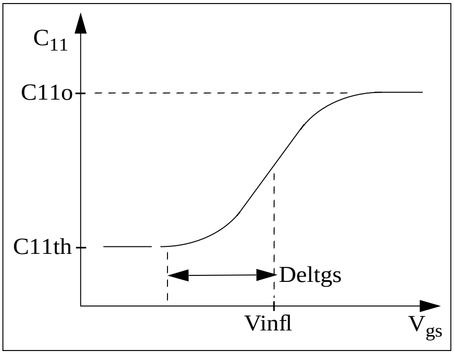


Figure 3-6. EE_HEMT1 C_{11}-V_{gs} Parameters

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 $-V_{gd} \leq Vbr$

$$I_{gd}(V_{gd}, V_{gs}) = 0$$

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 Δf 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:

$$RG^{NEW} = Rg[1 + Rgtc(Temp - Tnom)]$$

$$RD^{NEW} = Rd[1 + Rdtc(Temp - Tnom)]$$

$$RS^{NEW} = Rs[1 + Rstc(Temp - Tnom)]$$

$$VTOAC^{NEW} = Vtoac + Vtoactc(Temp - Tnom)$$

$$VTSO^{NEW} = Vtso + Vtotc(Temp - Tnom)$$

$$VTSOAC^{NEW} = Vtsoac + Vtoactc(Temp - Tnom)$$

$$GAMMA^{NEW} = GAMMA\left(\left\lceil \frac{Temp}{Tnom} \right\rceil^{GAMMATC}\right)$$

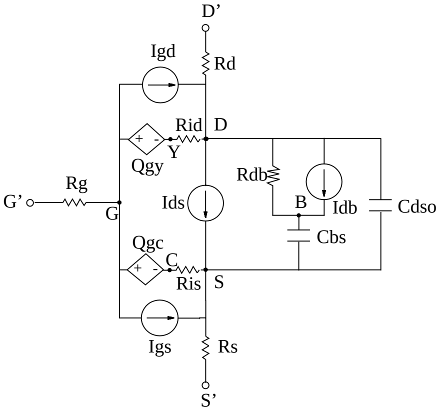
$$GAMMAAC^{NEW} = GAMMAAC\left(\left\lceil \frac{Temp}{Tnom} \right\rceil^{GAMMAACTC}\right)$$

$$GMMAX^{NEW} = GMMAX + GMMAXTC(Temp - Tnom)$$

$$GMMAXAC^{NEW} = GMMAXAC + GMMAXACTC(Temp - Tnom)$$

$$VINFL^{NEW} = Vinfl + Vinfltc(Temp - Tnom)$$

Equivalent Circuit



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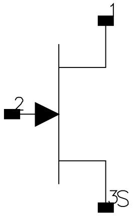
GaAsFET (Nonlinear Gallium Arsenide FET)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a GaAsFET model		
Area	scaling factor that scales certain parameter values of the associated model item		1.0
Temp	device operating temperature	°C	25
Mode	simulation mode for this device: linear, nonlinear		nonlinear
Noise	noise generation option: yes=1, no=0		yes
_M	number of devices in parallel		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 Mode parameter is used during harmonic balance, oscillator, or large-signal S-parameter analysis only. 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.
5. Table 3-4 lists the DC operating point parameters that can be sent to the dataset.

Table 3-4. DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
Ggs	Gate to source conductance	S
Ggd	Gate to drain conductance	S
dIgs_dVgd	(dIgs/dVgd)	S
dIgd_dVgs	(dIgd/dVgs)	S
dIds_dVgb	Backgate transconductance (dIds/dVgb)	S
Cgs	Gate-source capacitance	F
Cgd	Gate-drain capacitance	F

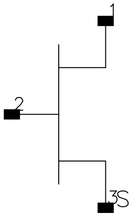
Table 3-4. DC Operating Point Information (continued)

Name	**Description**	**Units**
Cds	Drain-source capacitance	F
dQgs_dVgd	(dQgs/dVgd)	F
dQgd_dVgs	(dQgd/dVgs)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V

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

HP_FET (HP_Root FET)

Symbol



Parameters

Name	Description	Unit	Default
Mode	name of an HP_FET model		
Wtot	total device gate width	um, mm, cm, meter, mil, in	10^{-4}
N	number of device gate fingers		1
_M	number of devices in parallel		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 HP_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. HP_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 HP_FET cannot be temperature scaled and is noiseless.
7. Table 3-5 lists the DC operating point parameters that can be sent to the dataset.

Table 3-5. DC Operating Point Information

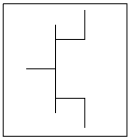
Name	**Description**	**Units**
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
Ggs	Gate conductance (dIg/dVgs)	S
dIg_dVds	(dIg/dVds)	S
dQd_dVds	(dQd/dVds)	F

Table 3-5. DC Operating Point Information (continued)

Name	**Description**	**Units**
dQd_dVgs	(dQd/dVgs)	F
dQg_dVds	(dQg/dVds)	F
dQg_dVgs	(dQg/dVgs)	F
Vgs	Gate-source voltage	V
Vds	Gate-drain voltage	V

HP_FET_Model (HP Root Model GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
File	name of file containing measured data		
Rs	source resistance (overrides extracted value)	ohms	rawfile value
Rg	gate resistance (overrides extracted value)	ohms	rawfile value
Rd	drain resistance (overrides extracted value)	ohms	rawfile value
Ls	source inductance (overrides extracted value)	H	rawfile value
Lg	gate inductance (overrides extracted value)	H	rawfile value
Ld	drain inductance (overrides extracted value)	H	rawfile value
AllParams	DataAccessComponent for file-based model parameter values		

Notes/Equations

1. This model supplies values for an HP_FET device.
2. The default extension for the model file is*.raw*. This file should be in the same format as HP 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). 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. 15th 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.

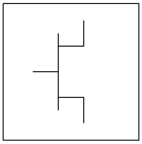
[4] D. E. Root and B. Hughes, “Principles of nonlinear active device modeling for circuit simulation,” in *32nd ARFTG Conf. Dig.*, Tempe, AZ, 1988, pp. 3-26.

[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.

Materka_Model (Materka GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		4
Idss	saturation drain current	A	0
Vto†	threshold voltage	V	–2
Alpha	hyperbolic tangent function	V	2
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
Rin	channel resistance	ohms	0
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgs	zero bias gate-source junction capacitance	F	0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgd	zero bias gate-drain junction capacitance	F	0.0
Rd	drain ohmic resistance	ohms	0.0
Rg	gate resistance		0.0
Rs	source resistance		0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0

† Parameter value varies with temperature based on model Tnom and device Temp.

Name	Description	Unit	Default
Gsfwd	0-none, 1=linear, 2=diode		linear
Gsrev	0-none, 1=linear, 2=diode		none
Gdfwd	0-none, 1=linear, 2=diode		none
Gdrev	0-none, 1=linear, 2=diode		linear
Vbi†	built-in gate potential	V	0.85
Vjr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with $V_{ds} < 0$)	V	0.025
Is	gate junction reverse saturation current (diode model)	A	10^{-14}
Ir	gate reverse saturation current	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 2)	A	1.6
N	gate junction ideality factor (diode model)		
Vbr	gate junction reverse bias breakdown voltage	V	
Fnc	flicker noise corner frequency	Hz	10^{100}
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		0.9
Taumdl	second order Bessel polynomial to model tau effect in transient simulation		no
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
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		

† 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 × Vds

   if (Vfc - Vp ≤ 0 or Vp ≥ 0)

   else

   TI = ABS (Alpha × Vds)

   TanhF = tanh (TI/(Vgc – Vp))

   $$Ids - Idss \times \left(\frac{Vgc}{Vp} - 1\right)^2 \times TanhF \times (1 + Lambda \times Vds)$$
4. The P, R, and C parameters model drain and gate noise sources.

   $$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m \; P(1 + f_{NC}/f)$$

   $$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT \; C_{gs}^2 \; \omega^2 \; R/g_m$$

   $$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj \; C_{gs} \; \omega \sqrt{PR} \; C$$

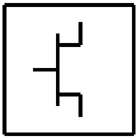
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

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	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		6
Ids	user-defined equation for drain-source current		see Note 1
Qgs	user-defined equation for gate-source charge	V	see Note 1
Qgd	user-defined equation for gate-drain charge	1/V	see Note1
Igd	user-defined equation for gate-drain current	1/V	see Note 1
Igs	user-defined equation for gate-source current	1/V	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		0.3
Tnom	nominal ambient temperature	ohms	25
Idstc	IDS temperature coefficient	ohms	0
Vbi	built-in gate potential	V	0.85
Tau	transit time under gate	S	0.0
Rds0	dc drain-source resistance at Vgs = 0	ohms	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		linear
Gdcap	0=none, 1=linear, 2 = junction, 3 = Statz Charge, 4 = Symbolic, 5 = Statz Cap		linear

Name	Description	Unit	Default
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 (0 = infinity)	Ohm	0.0
Tqm	temperature coefficient for triquint junction capacitance		0.2
Vmax	maximum junction voltage before capacitance limiting		0.5
Fc	coefficient for forward-bias depletion cap		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
Lg	gate inductance	H	fixed at 0
Ls	source inductance	H	fixed at 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 (0 = infinity)	Ohm	0.5
Gsfwd	0 = none, 1 = linear, 2 = diode		linear
Gdfwd	0 = none, 1 = linear, 2 = diode		none
Gsrev	0 = none, 1 = linear, 2 = diode, 3 = custom		none
Gdrev	gate junction forward bias warning		none
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
Imelt	(similar to Imax; refer to Note 2)	A	1.6
Xti	saturation current temperature exponent		3.0
N	gate junction emission coefficient		1
Eg	energy tap for temperature effect on IS		1.1.1

Name	Description	Unit	Default
Vbr	gate junction reverse bias breakdown voltage (0 = infinity)	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		no
Fnc	flicker noise corner frequency	Hertz	0.0
R	gate noise coefficient		0.5
C	gate-drain noise correlation coefficient		0.9
P	drain noise coefficient		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	W	
AllParams	DataAccessComponent for file-based model parameter values		

Notes/Equations

1. Equations for default settings:

   $$\mathrm{Ids} = (100\mathrm{ma}) \times ((1+\_v2))^{2}) \times \mathrm{tanh}(\_v1)$$

   $$\mathrm{Qgs} = (1\mathrm{pf}) \times (\_v1) - (1\mathrm{pf}) \times ((\_v2) -(\_v1)) \times (\_v1)$$

   $$\mathrm{Qgd} = (1\mathrm{prf}) \times (\_v1) - ((v2) -(v1)) \times (\_v1)$$

   $$\mathrm{Igd} = \mathrm{ramp}\ ((10 + (\_v1)) / 10)$$

   $$\mathrm{Igs} = \mathrm{ramp}\ ((10 + (\_v1)) / 10)$$

2. Imax and Imelt Parameters

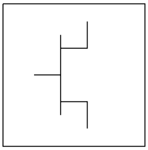
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.

   If the Imelt value is less than the 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).

Modified_Materka_Model (Modified Materka GaAsFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		8
Idss	saturation drain current	A	0
Vto	threshold voltage	V	–2
Beta2	coefficient for pinch-off change with respect to Vds	1/V	2
Ee	exponent defining dependence of saturation current	1/V	2
Ke	description of dependence on gate voltage	1/V	0
Kg	dependence on Vgs of drain slope in linear region	1/V	0
Sl	linear region slope of Vgs-0 drain characteristic	S	1
Ss	saturation region drain slope characteristic at vgs=0	S	0
Tau	transit time under gate	sec	0
Rgs	channel resistance	ohms	0
Rgd	gate drain resistance	ohms	0
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		
Cgs	zero bias gate-source junction capacitance	F	
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		
Cgd	zero bias gate-drain junction capacitance	F	
Rd	drain ohmic resistance	ohms	0.0
Rg	gate resistance	ohms	0.0
Rs	source ohmic resistance	ohms	0.0

Name	**Description**	**Unit**	**Default**
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0
Cds	drain-source capacitance	F	0.0
Gsfwd	0-none, 1=linear, 2=diode		
Gsrev	0-none, 1=linear, 2=diode		
Gdfwd	0-none, 1=linear, 2=diode		
Gdrev	0-none, 1=linear, 2=diode		
Vbi†	built-in gate potential	V	
Vjr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with $V_{ds} < 0$)	V	0.025
Is	gate junction saturation current (diode model)	A	10^{-14}
Ir	gate reverse saturation current	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 3)	A	1.6
N	gate junction emission coefficient (diode model)		1
Fnc	flicker noise corner frequency	Hz	0
Lambda	channel length modulation	1/V	0
Vbr	reverse bias breakdown voltage	V	10^{100}
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		0.9
Taumdl	2nd order Bessel polynomial to model tau effect in transient simulation		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	

Name	Description	Unit	Default
wPmax	maximum power dissipation warning	W	
AllParams	DataAccessComponent for file-based model parameter values		

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 ($Vfc - Vp \leq 0$ or $Vp \geq 0$)

   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.

$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P(1 + f_{NC}/f)$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^2\ \omega^2\ R/g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega\sqrt{PR}\ C$$

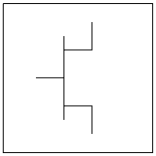
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

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	Unit	Default
NFET	N-channel type		yes
PFET	P-channel type		no
Idsmod	Statz model		3
Vto[††]	threshold voltage	V	–2
Beta[†, ††]	transconductance	A/V^2	10^{-4}
Lambda	output conductance	1/V	0.0
Alpha	current saturation	1/V	2.0
B	controls I_{ds}-V_{gs} characteristic transition from quadratic to linear behavior (b in Statz's paper)	1/V	0.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Idstc	Ids temperature coefficient	A/Temp°C	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

[†] 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.

Name	**Description**	**Unit**	**Default**
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgs[†, ††]	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgd[†, ††]	zero bias gate-drain junction capacitance	F	0.0
Rgd[‡]	gate drain resistance	ohms	0
Tqm	junction capacitance temperature coefficient		0.2
Vmax	maximum junction voltage before capacitance limiting	V	0.5
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Rd ‡	drain ohmic resistance	ohms	0.0
Rg	gate resistance	ohms	0.0
Rs‡	source ohmic resistance	ohms	0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0
Cds[†]	drain-source capacitance	F	0
Crf[†]	used with Rc to model frequency dependent output conductance	F	0.0
Rc‡	used with Crf to model frequency dependent output conductance	ohms	infinity[†††]
Gsfwd	0-none, 1=linear, 2=diode		linear
Gsrev	0-none, 1=linear, 2=diode		none
Gdfwd	0-none, 1=linear, 2=diode		none
Gdrev	0-none, 1=linear, 2=diode		linear
Vjr	breakdown junction potential	V	0.025
Is[†]	gate junction saturation current (diode model)	A	10^{-14}

[†] 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.

Name	Description	Unit	Default
Ir†	gate reverse saturation current	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 3)	A	1.6
Xti	temperature exponent for saturation current		3.0
N	gate junction emission coefficient		1
Eg	energy gap for temperature effect on Is	eV	1.11
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with V_{ds}<0)	V	10^{100}
Vtotc	Vto temperature coefficient	V/°C	0.0
Rin ‡	channel resistance	ohms	0.0
Taumdl	second order Bessel polynomial to model tau effect in transient		no
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
C	gate-drain noise correlation coefficient		0.9
P	drain noise coefficient		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	
Kf	flicker noise coefficient		0
Af	flicker noise exponent		1
Ffe	flicker noise frequency exponent		1
AllParams	DataAccessComponent for file-based model parameter values		

† 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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  gf1  GaAs Idsmod=3 \
  Vto=-2.5 Beta=1e-3 NFET=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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). 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 $0 < V_{ds} < 3 / \alpha$

$$I_{ds} = \frac{\beta(V_{gs} - Vto)^2}{1 + \beta(V_{gs} - Vto)}\left[1 - \left[1 - \frac{\alpha V_{ds}}{3}\right]^3\right](1 + \lambda V_{ds})$$

where α is Alpha, β is Beta, Θ is B.

For $V_{ds} \geq 3/\alpha$

$$I_{ds} = \frac{\beta(V_{gs} - Vto)^2}{1 + \beta(V_{gs} - Vto)}(1 + \lambda V_{ds})$$

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 $V_{new} \leq V_{max}$

$$Q_g = Cgs \times 2 \times Vbi\left(1 - \sqrt{1 - \frac{V_{new}}{Vbi}}\right) + Cgd \times V_{eff2}$$

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, Figure 3-7, 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. (Also see [3].)

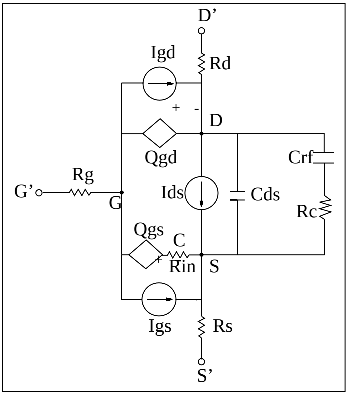


Figure 3-7. Statz_Model Schematic

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:

$$Cgs^{NEW} = Cgs\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

$$Cgd^{NEW} = Cgd\left[\frac{1 + 0.5[4 \times 10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + 0.5[4 \times 10^{-4}(Tnom - T_{REF}) - \gamma^{Tnom}]}\right]$$

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 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.

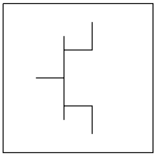
[3] C. Camacho-Penalosa and C.S. Aitchison. “Modelling frequency dependence of output impedance of a microwave MESFET at low frequencies,” *Electron. Lett.*, Vol. 21, pp. 528-529, June 6, 1985.

[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	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Idsmod	Ids model		5
Vdss	drain current saturation voltage of this model	V	1
Vto	value of V1 below which Ids = Ids(V1=VT0,Vds)	V	–2
Beta2	coefficient for pinch-off change with respect to Vds	1/V	0
Ta	model 5: ‘a’ coefficient		–0.2
Tb	model 5: ‘b’ coefficient		0.6
Tm	model 5: ‘m’ coefficient		3.0
Idss	saturation drain current	A	0
Rin††	channel resistance	ohms	0
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Gscap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgs††	zero bias gate-source junction capacitance	F	0.0
Gdcap	0=none, 1=linear, 2=junction, 3=Statz charge, 5=Statz cap		linear
Cgd††	zero bias gate-drain junction capacitance	F	0.0
Rd	drain ohmic resistance	ohms	0.0

† 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.

Name	**Description**	**Unit**	**Default**
Rg	gate resistance	ohms	0.0
Rs	source ohmic resistance	ohms	0.0
Ld	drain inductance	henry	0.0
Lg	gate inductance	henry	0.0
Ls	source inductance	henry	0.0
Cds††	drain-source capacitance	F	0.0
Crf††	used to model frequency-dependent output conductance	F	0.0
Rc†††	output resistance for RF operation	ohms	infinity‡
Gsfwd	0=none, 1=linear, 2=diode		linear
Gsrev	0=none, 1=linear, 2=diode		none
Gdfwd	0=none, 1=linear, 2=diode		none
Gdrev	0=none, 1=linear, 2=diode		linear
Vbi†	built-in gate potential	V	0.85
Is	gate junction reverse saturation current (diode model)	A	10^{-14}
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 4)	A	1.6
N	gate junction emission coefficient (diode model)		1
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate-drain noise correlation coefficient		0.9
Tnom	nominal ambient temperature	^{o}C	25
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	

† 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.

Name	**Description**	**Unit**	**Default**
wIdsmax	maximum drain-source current warning	A	
wPmax	maximum power dissipation warning	W	
AllParams	DataAccessComponent for file-based model parameter values		

† 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:

$$\upsilon_p = \mathrm{Vto} - \mathrm{Beta}^2 \times \mathrm{Vds} - \mathrm{Vbi}$$

$$\upsilon c = (\upsilon gs - \mathrm{Vbi} - \upsilon p)/\upsilon p$$

If υ_p 0 or $\upsilon_c \geq 0$, then ids = 0

else

$$id_1 = \left[\frac{(\exp(Tm \bullet \upsilon c)^{-1})}{Tm} - \upsilon c\right] \Big/ \left[1 - \frac{(1 - \exp(-Tm))}{Tm}\right]$$

$$id_2 = Idss \bullet \left[1 - \exp\left(\left(\frac{\upsilon ds}{Vdss}\right) - Ta\left(\frac{\upsilon ds}{Vdss}\right)^2 - Tb\left(\frac{\upsilon ds}{Vdss}\right)^3\right)\right]$$

$$\mathrm{ids} = \mathrm{id}_1 \times \mathrm{id}_2$$

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).

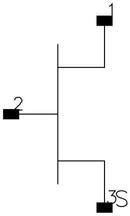
5. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). A nonlinear device model parameter value that is explicitly specified will override the value set by an AllParams association.

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.

TOM (TriQuint Scalable Nonlinear GaAsFET)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a TOM_Model		
W	new unit gate width, in length units		1.0
N	new number of gate fingers		1
Temp	device operating temperature	°C	25
Mode	simulation mode for this device: linear or nonlinear		nonlinear
_M	number of devices in parallel		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 Mode parameter is used during harmonic balance, oscillator, or large-signal S-parameter analysis only. 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.
3. Table 3-6 lists the DC operating point parameters that can be sent to the dataset.

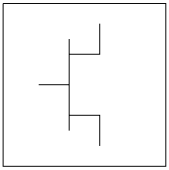
Table 3-6. DC Operating Point Information

Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
Ggs	Gate to source conductance	S
Ggd	Gate to drain conductance	S
dIgs_dVgd	(dIgs/dVgd)	S
dIgd_dVgs	(dIgd/dVgs)	S
dIds_dVgb	Backgate transconductance (dIds/dVgb)	S
Cgs	Gate-source capacitance	F
Cgd	Gate-drain capacitance	F
Cds	Drain-source capacitance	F
dQgs_dVgd	(dQgs/dVgd)	F
dQgd_dVgs	(dQgd/dVgs)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V

4. 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	Unit	Default
Idsmod	Ids model		7
Vto†	nonscalable portion of threshold voltage	V	–2
Vtosc††	scalable portion of threshold voltage	V	0.0
Alpha	saturation voltage coefficient	1/V	2.0
Beta†, †††	transconductance coefficient	A/V^2	10^{-4}
Tqdelta††	output feedback coefficient	1/W	0
Tqgamma	dc drain pull coefficient		0.0
TggammaAc	AC pinchoff change with vds		0.0
Tnom	nominal ambient temperature at which these model parameters were derived	°C	25
Q	power law exponent		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

† 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.

Name	**Description**	**Unit**	**Default**
Tqm	temperature coefficient for TriQuint junction capacitance		0.2
Vmax	maximum junction voltage before capacitance limiting	V	
Fc	coefficient for forward bias depletion capacitance (diode model)		0.5
Delta1	capacitance saturation transition voltage	V	0.3
Delta2	capacitance threshold transition voltage	V	0.2
M	grading coefficient		0.5
Is†, †††	gate diode saturation current (diode model)	A	10^{-14}
N	gate diode emission coefficient (diode model)		1.0
Eg	energy gap for temperature effect on Is	eV	1.11
Xti	temperature exponent for saturation current		3.0
Vbr	gate-drain junction reverse bias breakdown voltage (gate-source junction reverse bias breakdown voltage with $V_{ds} = 0$)	V	infinity‡
Rg‡‡	gate resistance	ohms	0.0
Rd††	drain contact resistance	ohms	0.0
Rs††	source contact resistance	ohms	0.0
Trg1	linear temperature coefficient for Rg	1/°C	0
Trd1	linear temperature coefficient for Rd	1/°C	0
Trs1	linear temperature coefficient for Rs	1/°C	0
Cds†††	drain source capacitance	F	0.0
Rdb	R for frequency-dependent output conductance	Ohms	0.0
Cbs	C for frequency-dependent output capacitance	F	0.0
Rgmet‡‡	gate metal resistance	ohms	0.0
Ris††	source end channel resistance	ohms	0.0
Rid††	drain end channel resistance	ohms	0.0

† 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.

Name	Description	Unit	Default
Vgr	Vg (s,d) c includes voltage across Rg (s,d)		No
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 4)	A	1.6
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1
C	gate drain noise correlation coefficient		0.9
Kf	flicker noise coefficient		0
Af	flicker noise exponent		1
Ffe	flicker noise frequency exponent		1
Taumdl	second order Bessel polynomial to model tau effect in transient simulation		no
Ugw	unit gate width of device	meter	1e-6
Ngf	number of device gate fingers		1
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	
Gscap	0=none,1=linear,2=junction,3=Statz charge, 5=Statz cap		Statz
Gsfwd	0=none,1=linear,2=diode		diode

[†] 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

$$Idso = \beta(V_{gs} - V_t)^Q \times \left[1 - \left[1 - \frac{\alpha Vds}{3}\right]^3\right] \text{ for } 0 < \text{Vds} < 3/\alpha$$

$$Idso = \beta(V_{gs} - V_t)^Q \text{ for Vds} \geq 3/\alpha$$

The threshold voltage V_t is given by:

$$\text{Vt} = (\text{Vto} + \text{Vtosc}) - \text{Tqgamma} \times \text{Vds}$$

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 γ 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.

$$Vbi(Temp) = Vbi \times \left(\frac{Temp}{Tnom}\right) - 3V_t \log\left(\frac{Temp}{Tnom}\right) - E_g(Tnom) \times \left(\frac{Temp}{Tnom}\right) + E_g(Temp)$$

$$Beta(Temp) = Beta \times 1.01^{Betatce \times (Temp - Tnom}$$

$$Vto(Temp) = Vto + Vtotc \times (Temp - Tnom)$$

$$Is(Temp) = exp\left[\left(\frac{Temp}{Tnom} - 1\right) \times \frac{Eg}{V_t}\right] \times Is\left(\frac{Temp}{Tnom}\right)^{\frac{Xti}{N}}$$

$$Rd(Temp) = Rd \times (1 + Trd1 \times (Temp - Tnom))$$

$$Rs(Temp) = Rs \times (1 + Trs1 \times (Temp - Tnom))$$

$$Cgs(Temp) = Cgs\left[1 + Tqm \times \left[4.0 \times 10^{-4}(Temp - Tnom) + 1 - \frac{Vbi(Temp)}{Vbi}\right]\right]$$

$$Cgd(Temp) = Cgd\left[1 + Tqm \times \left[4.0 \times 10^{-4} \times \left((Temp - Tnom) + 1 - \frac{Vbi(Temp)}{Vbi}\right)\right]\right]$$

where

$$V_t = \frac{V \times Temp}{q}$$

$$E_g(T) = \frac{1.519 - 5.405 \times 10^{-4} T^2}{T + 204}$$

where

$$K = \text{Boltzmann's constant} = 8.62 \times 10^{-5} eV\ K^{-1}$$

$$q = \text{electron charge} = 1.602 \times 10^{-19} C.$$

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.

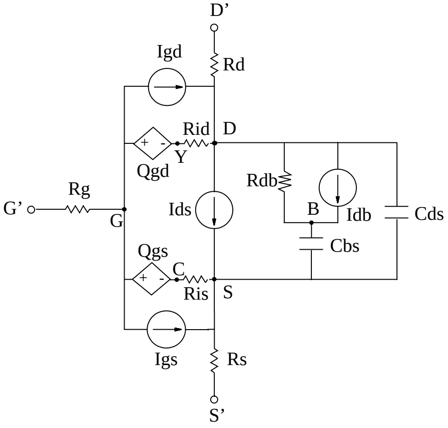
$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m\ P + 4kTg_m\ PFnc / f + Kf\ Ids^{Af}\ / f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^2\ \omega^2\ R / g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega \sqrt{PR}\ C$$

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

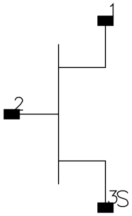
[1] A. McCaman, G. McCormack and D. Smith. "An Improved GaAs MESFET Model for SPICE", *IEEE Trans. on Microwave Theory Tech.*, vol. MTT-38, pp. 822-824, June 1990.

[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.

TOM3 (TriQuint TOM3 Scalable Nonlinear FET)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a TOM3_Model		TOM3M1
W	gate width	m	0 (no scaling)
Ng	number of gate fingers		0 (no scaling)
Temp	device instance temperature	°C	25
Trise	device temperature relative to circuit ambient (if Temp not specified)	°C	0
Mode	simulation mode for this device: linear or nonlinear		nonlinear
Noise	noise generation option: yes, no		yes
_M	number of devices in parallel		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 Mode parameter is used during harmonic balance, oscillator, or large-signal S-parameter analysis only. 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.
3. Table 3-7 lists the DC operating point parameters that can be sent to the dataset.

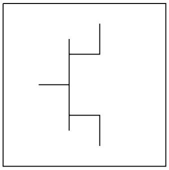
Table 3-7. DC Operating Point Information

Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgsi)	S
Gds	Output conductance (dIds/dVds)	S
Cgs	Gate-source capacitance (dQg/dVgsi)	F
Cgd	Gate-drain capacitance (dQg/dVgdi)	F
Ggse	Gate-source diode conductance	S
Ggde	Gate-drain diode conductance	S
Ggsi	Gate-source leakage conductance	S
Ggdi	Gate-drain leakage conductance	S
Vgse	Gate-source voltage	V
Vgde	Gate-drain voltage	V
Vcvs	Gate voltage offset	V
dVcvs_dVc	Controlling coefficient for VCVS	
Vgs	External gate-source voltage	V
Vds	External drain-source voltage	V

4. This device has no default artwork associated with it.
5. For this release, the TOM3 device is not explicitly available in RFDE.

TOM3_Model (TriQuint TOM3 Scalable Nonlinear FET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NFET	N-channel type		YES
PFET	P-channel type		NO
Tnom	model temperature at which all parameters were derived	deg C	25
Ugw	gate width to which model parameters are normalized	m	1.0e-6
Ngf	number of gate fingers to which model parameters are normalized		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		0.1
Q	power generalizing the square-law for Ids current		2.0
K	knee function power law coefficient		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		0.33
Taugd	series Ctau-Rtau time constant (implicit definition of Rtau)	sec	1.0e-9
Ctau	dispersion model capacitance	F	1.0e-15
Qggl[†††]	low-power gate charge nonlinear term coefficient	C	0.2e-12

Name	Description	Unit	Default
Qgqh[†††]	high-power gate charge nonlinear term coefficient	C	0.1e-12
Qgi0[†††]	reference current in high-power gate charge nonlinear Ids term	A	0.1e-3
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		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/deg 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/deg C	0
Is[†, †††]	saturation current in forward gate current diode models	A	1.0e-12
Eta	emission coefficient for gate diode models		1.25
Alphatce	temperature exponential coefficient for Alpha	1/deg C	0
Gammatc	temperature linear coefficient for Gamma	1/deg C	0
Msttc	temperature linear coefficient for Mst	1/(V deg C)	0
Vsttc	temperature linear coefficient for Vst	V/deg C	0
Vtotc	temperature linear coefficient for Vto	V/deg C	0
Betatce	temperature exponential coefficient for Beta	1/deg C	0
Xti	temperature exponent for saturation current		2.5
Eg	energy gap for temperature effect on Is	eV	1.11

Name	Description	Unit	Default
Imax	explosion current	A	1.6
Fnc	flicker noise corner frequency	Hz	0
R	gate noise coefficient		0.5
P	drain noise coefficient		1.0
C	gate-drain noise correlation coefficient		0.9
Kf	flicker noise coefficient		0
Af	flicker noise exponent		1
Ffe	flicker noise frequency exponent		1
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		

† 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" on page 3-149). 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" on page 3-150). 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, 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 M_{ST0} (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

$$C_{gs} = \left.\frac{\partial Q_{GG}}{\partial V_{gsi}}\right|_{V_{gdi} = \text{const}}$$

$$C_{gd} = \left.\frac{\partial Q_{GG}}{\partial V_{gdi}}\right|_{V_{gsi} = \text{const}}$$

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 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 V_T 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].

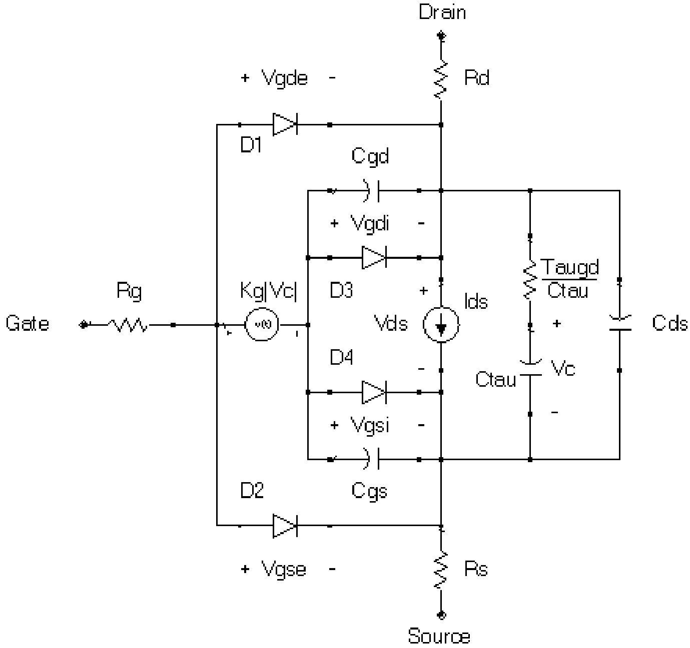
$$\frac{\langle i_d^2 \rangle}{\Delta f} = 4kTg_m P + 4kTg_m PFnc / f + Kf\ Ids^{Af} / f^{Ffe}$$

$$\frac{\langle i_g^2 \rangle}{\Delta f} = 4kT\ C_{gs}^2\ \omega^2\ R / g_m$$

$$\frac{\langle i_g, i_d^* \rangle}{\Delta f} = 4kTj\ C_{gs}\ \omega \sqrt{PR}\ C$$

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.

Chapter 4: Devices and Models, JFET

Bin Model

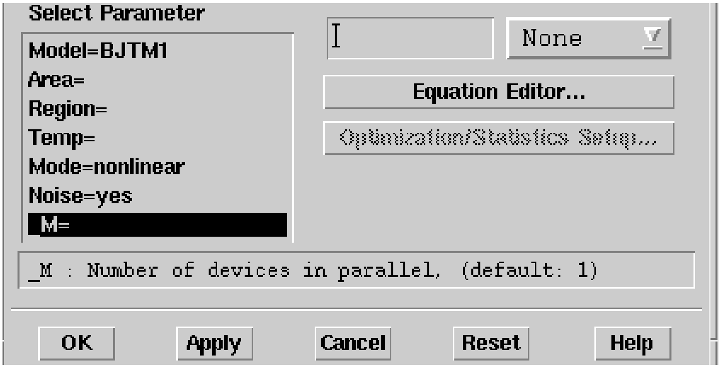
The BinModel in the JFET library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn’t work for all sizes of a device.

For information on the use of the binning feature, refer to BinModel documentation in Chapter 1 of *Introduction and Simulation 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.

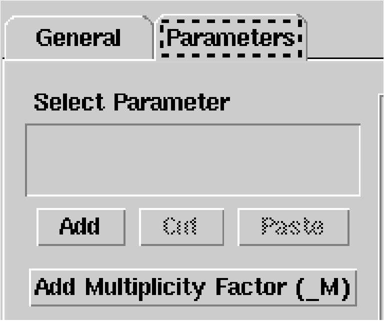
The _M parameter is available at the component level as shown here. (For components that don't explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



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 Parameter**s 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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

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 book 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 25ºC. 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

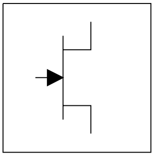
The ADS circuit simulation allows the user to directly specify the temperature of each individual device instance. This is done with the device instance parameter Temp which is the device temperature in degrees Celsius. If it is not specified, it defaults to the ambient temperature set with Options.Temp,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

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	Unit	Default
NFET	N-channel model		yes
PFET	P-channel model		no
Vto†	zero-bias threshold voltage	V	–2.0
Beta†, ††	transconductance parameter	A/V^2	10^{-4}
Lambda	channel-length modulation parameter	1/V	0.0
Rd††	drain ohmic resistance	ohms	0.0
Rs††	source ohmic resistance	ohms	0.0
Is†, ††	gate-junction saturation current	A	10^{-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		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		0.0
Af	flicker-noise exponent		1.0
Imax	explosion current	A	1.6
Imelt	(similar to Imax; refer to Note 5)	A	1.6

† Parameter value varies with temperature based on model Tnom and device Temp.

†† Parameter value is scaled with Area specified with the JFET device.

Name	Description	Unit	Default
N	gate P-N emission coefficient		1.0
Isr[†]	gate P-N recombination current parameter	A	0.0
Nr	Isr emission coefficient		2.0
Alpha	ionization coefficient	1/V	0.0
Vk	ionization knee voltage	V	0.0
M	gate P-N grading coefficient		0.5
Vtotc	Vto temperature coefficient	V/°C	0.0
Betatce	Beta exponential temperature coefficient	%/°C	0.0
Xti	temperature coefficient		3.0
Ffe	flicker noise frequency exponent		1.0
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-based parameters		

[†] 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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  U310  JFET \
  Vto=-3 Beta=3e-4 NFET=yes
```

Notes

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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). 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:

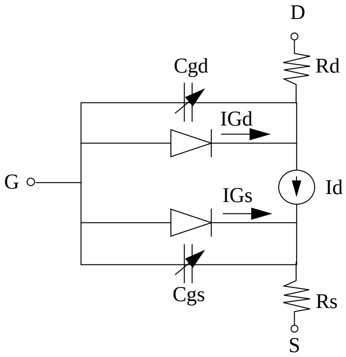
$$\frac{< i^2 >}{\Delta f} = \frac{4kT}{R}$$

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:

$$\frac{< i_{ds}^2 >}{\Delta f} = \frac{8kTg_m}{3} + Kf\frac{I_{Ds}^{Af}}{f^{Ffe}}$$

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

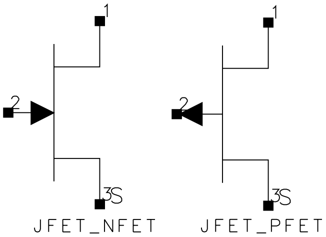


References

[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	Unit	Default
Model	name of a JFET_Model		
Area	scaling factor that scales certain parameter values of the JFET_Model		1
Region	dc operating region: off, on, rev, ohmic		on
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Noise	noise generation option: yes, no		yes
Mode	simulation mode for this device: linear, nonlinear		nonlinear
_M	number of devices in parallel		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 to see which parameter values are scaled.
2. The Mode parameter is used during harmonic balance, oscillator, or large-signal S-parameter analysis only. 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.

3. Table 4-1 lists the DC operating point parameters that can be sent to the dataset.

Table 4-1. DC Operating Point Information

Name	**Description**	**Units**
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
Cgs	Gate-source capacitance	F
Cgd	Gate-drain capacitance	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V

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.

Chapter 5: Devices and Models, MOS

Bin Model

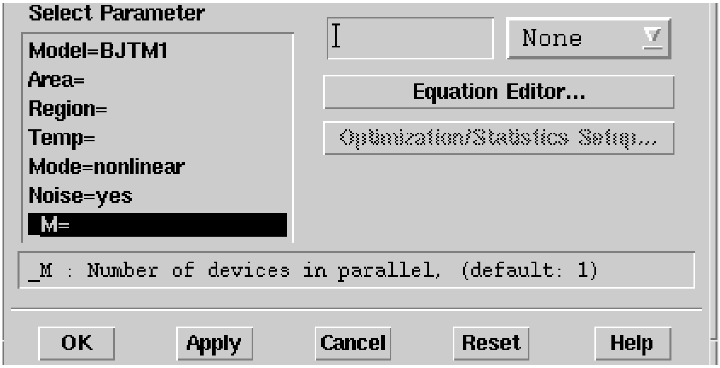
The BinModel in the MOS library allows you to sweep a parameter (usually a geometry, such as gate length), then enable the simulator to automatically select between different model cards. This alleviates the problem that one scalable model typically doesn't work for all sizes of a device.

For information on the use of the binning feature, refer to BinModel documentation in Chapter 1 of *Introduction and Simulation 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.

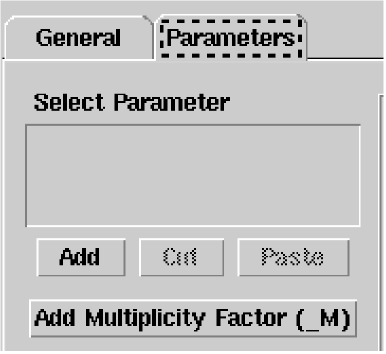
The _M parameter is available at the component level as shown here. (For components that don't explicitly have a Multiplicity parameter, the same functionality can be achieved by placing the component in a sub-circuit and using the sub-circuit's Multiplicity parameter, as described next.)



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 Parameter**s 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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

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 book 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^{o}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^{o}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

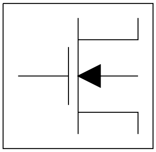
The MOSFET noise model is controlled by the model parameter Nlev. Table 5-1 shows which noise equations are used for each value of Nlev. These equations are always used for the BSIM1, BSIM2, LEVEL1, LEVEL2, LEVEL3 and LEVEL3_MOD models. For a BSIM3, these equations can be used to override the standard BSIM3v3 noise equations only when Nlev $\geq$ 1.

Table 5-1. Equations Used for Nlev parameter

Nlev Value	Channel Noise	Flicker Noise	Default
-1	8/3k T g_m	$\frac{Kf\lvert I_{DS}\rvert^{Af}}{f^{Ffe}}$	ADS default (not usable with BSIM3v3)
0	8/3k T g_m	$\frac{Kf\lvert I_{DS}\rvert^{Af}}{f^{Ffe}C_{OX}L^2Eff}$	Spice2G6 Hspice Nlev=0 (not usable with BSIM3v3)
1	8/3k T g_m	$\frac{Kf\lvert I_{DS}\rvert^{Af}}{f^{Ffe}C_{OX}W_{Eff\ LEff}}$	Hspice Nlev=1
2	8/3k T g_m	$\frac{Kf\,{g_m}^2}{f^{Ffe}C_{OX}W_{Eff\ L_{Eff}}}$	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)	$\frac{Kf\,{g_m}^2}{f^{Ffe}C_{OX}W_{Eff\ L_{Eff}}}$	Hspice Nlev=3

BSIM1_Model (BSIM1 MOSFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NMOS	N-channel type model		yes
PMOS	P-channel type model		no
Idsmod	Ids model		4
Rsh	drain and source diffusion sheet resistance	ohms/sq	0.0
Js	bulk junction area saturation current	A/m^2	0.0
Temp	parameter measurement temperature	°C	25
Muz	zero-bias surface mobility	$cm^2/Vsec$	600
Dl	shortening of channel		0.0
Dw	narrowing of channel		0.0
Vdd	measurement drain bias range	V	5.0
Vfb	flat-band voltage	V	–0.3
Phi	surface potential at strong inversion	V	0.6
K1	body effect coefficient	$\sqrt{V}$	0.5
K2	drain/source depletion charge sharing coefficient		0.0
Eta	drain-induced barrier lowering coefficient		0.0
U0	transverse field mobility degradation coefficient	1/V	670.0
U1	zero-bias velocity saturation coefficient	µm/V	0.0
X2mz	sensitivity of mobility to substrate bias	cm^2/V^2	0.0
X2e	sensitivity of barrier lowering cf to substrate bias	1/V	-0.07
X3e	sensitivity of barrier lowering cf to drain bias	1/V	0.0
X2u0	sensitivity of transverse field cf to substrate bias	$1/V^2$	0.0

Name	Description	Unit	Default
X2u1	sensitivity of velocity saturation to substrate bias	$\mu m/V^2$	0.0
X3u1	sensitivity of velocity saturation to drain bias	$\mu m/V^2$	0.0
Mus	mobility at zero substrate bias at Vds=Vdd	cm^2/Vs	1082
X2ms	sensitivity of mobility to substrate bias	cm^2/V^2s	0.0
X3ms	sensitivity of mobility to drain bias at Vds=Vdd	cm^2/V^2s	0.0
N0	zero-bias subthreshold slope coefficient		0.5
Nb	sensitivity of subthreshold slope to substrate bias	1/V	0.0
Nd	sensitivity of subthreshold slope to drain bias	1/V	0.0
Tox	oxide thickness	μm	10^{-7}
Cj	zero-bias bulk junction bottom capacitance	F/m^2	0.0
Mj	bulk junction bottom grading coefficient		0.5
Cjsw	zero-bias bulk junction sidewall capacitance	F/m	0.0
Mjsw	bulk junction sidewall grading coefficient		0.33
Pb	bulk junction potential	V	0.8
Pbsw	built-in potential of source drain junction sidewall	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		1.0
Nlev	Noise model level		-1
Gdwnoi	Drain noise parameters for Nlev=3		1
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Ffe	flicker noise frequency exponent		1.0
Rg	gate resistance	ohms	0
N	bulk P-N emission coefficient		1.0
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 3)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite

Name	Description	Unit	Default
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
AllParams	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch4  MOSFET Idsmod=4 \
  Vfb=-0.9 Muz=500 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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

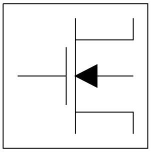
   Imax and Imelt specify the P-N junction explosion current. Imax and Imelt can be specified in the device model or in the Options component; the device model value takes precedence over the Options value.

   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). 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

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NMOS	N-channel type model		yes
PMOS	P-channel type model		no
Idsmod	Ids model		5
Rsh	drain and source diffusion sheet resistance		0.0
Js	bulk junction saturation current, per junction area	A/m^2	0.0
Mu0	zero-bias surface mobility	cm^2/V-s	600
Dl	shortening of channel, in	µm	0.0
Dw	Narrowing of channel, in	µm	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	measurement temperature	^{o}C	25
Tox	oxide thickness	µm	10^{-7}
Cj	zero-bias bulk junction bottom capacitance	F/m^2	5.0
Mj	bulk junction bottom grading coefficient		0.5
Cjsw	zero-bias bulk junction sidewall capacitance	F/m	0.0
Mjsw	bulk junction sidewall grading coefficient		0.33
Pb	bulk junction potential	V	0.8
Pbsw	built-in potential of source drain junction sidewall	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

Name	Description	Unit	Default
Cgbo	gate-bulk overlap capacitance, per channel width		0.0
Xpart	coefficient of channel charge share		1.0
Vfb	flat-band voltage	V	-0.1
Phi	surface potential at strong inversion	V	0.6
K1	body effect coefficient	$\sqrt{V}$	0.5
K2	drain/source depletion charge sharing coefficient		0.0
Eta0	zero-bias drain-induced barrier lowering coefficient		0.08
Ua0	transverse field mobility degradation coefficient	1/V	670.0
U10	zero-bias velocity saturation coefficient	µm/V	0.0
Mu0b	sensitivity of mobility to substrate bias	cm^2/V^2s	0.0
Etab	sensitivity of barrier lowering cf to substrate bias	1/V	-0.07
Uab	sensitivity of transverse field cf to substrate bias	$1/V^2$	0.0
U1b	sensitivity of velocity saturation to substrate bias	$\mu m/V^2$	0.0
U1d	sensitivity of velocity saturation to drain bias	$\mu m/V^2$	0.0
Mus0	mobility at zero substrate bias at Vds=Vdd	cm^2/Vs	600.0
Musb	sensitivity of mobility to substrate bias	cm^2/V^2s	0.0
N0	zero-bias subthreshold slope coefficient		0.5
Nb	sensitivity of subthreshold slope to substrate bias	1/V	1.0
Nd	sensitivity of subthreshold slope to drain bias	1/V	0.0
Mu20	empirical parameter in beta 0 expression		0.0
Mu2b	sensitivity of Mu2 to Vbs	1/V	0.0
Mu2g	sensitivity of Mu2 to Vgs	1/V	0.0
Mu30	linear empirical parameter in beta 0 exp	cm^2/V^2s	0.0
Mu3b	sensitivity of Mu3 to Vbs	cm^2/V^3s	0.0
Mu3g	sensitivity of Mu3 to Vgs	cm^2/V^3s	0.0
Mu40	quadratic empirical parameter in beta0 exp	cm^2/v^3s	0.0
Mu4b	sensitivity of Mu4 to Vbs	cm^2/v^4s	0.0
Ub0	mobility reduction to vertical field at Vbs=0	$1/V^2$	0.0

Name	Description	Unit	Default
Ubb	sensitivity of mobility reduction to Vbs	$1/V^3$	0.0
Vof0	threshold voltage offset in the subthreshold region	V	0.0
Vofb	sensitivity of Vof to Vbs		0.0
Vofd	sensitivity of Vof to Vds		0.0
Ai0	pre-factor of hot-electron effect		0.0
Aib	sensitivity of Ai to Vbs	1/V	0.0
Bi0	exponential factor of hot-electron effect	V	0.0
Bib	sensitivity of Bi to Vbs		0.0
Vghigh	upper bound for the transition region	V	0.0
Vglow	lower bound for the transition region	V	-0.15
Lvglow	length dependence of Vglow	um*V	0.0
Wvglow	length dependence of Vglow	um*V	0.0
Nlev	Noise model level		-1
Gdwnoi	Drain noise parameters for Nlev=3		1
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Ffe	flicker noise frequency exponent		1.0
Rg	gate resistance		0
N	bulk P-N emission coefficient		1.0
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 3)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
AllParams	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8*, ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch5 MOSFET Idsmod=5 \
  Vfb=-0.9 Mu0=500 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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.

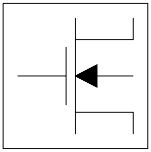
   If the Imelt value is less than the Imax value, the Imelt value is increased to the Imax value.

   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). 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	N-channel type model		yes
PMOS	P-channel type model		no
Idsmod	Ids model		8
Version	model version		3.22
Mobmod	mobility model selector		1
Capmod	capacitance model selector		1
Noimod	noise model selector		1
Paramchk	model parameter checking selector		0
Binunit	bin unit selector		1
Rg	gate resistance	ohms	0
Rsh	drain and source diffusion sheet resistance	ohms/sq	0.0
Nj	bulk P-N emission coefficient		1.0
Xti	junction current temp. exponent		3.0
Js	gate saturation current	A/m^2	10^{-4}
Jsw	sidewall junction reverse saturation current	A/m^2	0.0
Lint	length offset fitting parameter (binning parameter; see Note 3)	m	0.0
Ll	coefficient of length dependence for length offset	m^{Lln}	0.0
Lln	power of length dependence of length offset		1.0
Lw	coefficient of width dependence for length offset	m^{Lwn}	0.0
Lwn	power of width dependence of length offset		1.0

Name	Description	Units	Default
Lwl	coefficient of length and width cross term for length offset	$m^{(Lwn+Lln)}$	0.0
Wint	width offset fitting parameter (binning parameter; see Note 3)	m	0.0
Wl	coefficient of length dependence for width offset	m^{Wln}	0.0
Wln	power of length dependence of width offset		1.0
Ww	coefficient of width dependence for width offset	m^{Wwn}	0.0
Wwn	power of width dependence of width offset		1.0
Wwl	coefficient of length and width cross term for width offset	$m^{(Wwn+Wln)}$	0.0
Tnom	parameter measurement temp.	°C	25
Trise	temperature rise above ambient	°C	0
Tox	oxide thickness	m	1.5×10^{-8}
Cj	zero-bias bulk junction bottom capacitance	F/m^2	5.0×10^{-4}
Mj	bulk junction bottom grading coefficient		0.5
Cjsw	zero-bias bulk junction sidewall capacitance	F/m	5.0×10^{-10}
Mjsw	bulk junction sidewall grading coefficient		0.33
Pb	bulk junction potential	V	1.0
Pbsw	sidewall junction potential	V	1.0
Xt	doping depth	m	1.55×10^{-7}
Vbm	maximum applied body bias	V	–5.0
Vbx	Vth transition body voltage	V	calculated parameter
Xj	metallurgical junction depth	m	1.5×10^{-7}
Dwg	coefficient of Weff's gate dependence (binning parameter; see Note 3)	m/V	0.0
Dwb	coefficient of Weff's body dependence (binning parameter; see Note 3)	$m/V^{(1/2)}$	0.0
Nch	channel doping concentration	$1/cm^3$	1.7×10^{17}
Nsub	substrate doping concentration	$1/cm^3$	6.0×10^{16}

Name	Description	Units	Default
Ngate	poly-gate doping concentration	$1/cm^3$	†
Gamma1	body effect coefficient near interface	$V^{(1/2)}$	†
Gamma2	body effect coefficient in the bulk	$V^{(1/2)}$	†
Alpha0	1st parameter of impact ionization current (binning parameter; see Note 3)	m/V	0.0
Beta0	2nd parameter of impact ionization current (binning parameter; see Note 3)	V	30.0
Vth0	zero-bias threshold voltage (binning parameter; see Note 3)	V	†
K1	first order body effect coefficient (binning parameter; see Note 3)	$V^{(1/2)}$	†
K2	second order body effect coefficient (binning parameter; see Note 3)		†
K3	narrow width effect coefficient (binning parameter; see Note 3)		80.0
K3b	body effect coefficient of K3 (binning parameter; see Note 3)	1/V	0.0
W0	narrow width effect W offset (binning parameter; see Note 3)	m	2.5×10^{-6}
Nlx	lateral non-uniform doping effect (binning parameter; see Note 3)	m	1.74×10^{-7}
Dvt0	short channel effect coefficient 0 (binning parameter; see Note 3)		2.2
Dvt1	short channel effect coefficient 1 (binning parameter; see Note 3)		0.53
Dvt2	short channel effect coefficient 2 (binning parameter; see Note 3)	1/V	–0.032
Dvt0w	narrow width effect coefficient 0 (binning parameter; see Note 3)	1/m	0.0
Dvt1w	narrow width effect coefficient 1 (binning parameter; see Note 3)	1/m	5.3×10^6
Dvt2w	narrow width effect coefficient 2 (binning parameter; see Note 3)	1/V	–0.032
Cgso	gate-source overlap capacitance, per channel width	F/m	†

Name	**Description**	**Units**	**Default**
Cgdo	gate-drain overlap capacitance, per channel width	F/m	†
Cgbo	gate-bulk overlap capacitance, per channel length	F/m	0.0
Xpart	flag for channel charge partition		0.0
Drout	DIBL effect on Rout coefficient binning parameter; see Note 3)		0.56
Dsub	DIBL effect coefficient in subthreshold region binning parameter; see Note 3)		(fixed by Drout)
Ua	linear Vgs dependence of mobility (binning parameter; see Note 3)	m/V	2.25×10^{-9}
Ua1	temperature coefficient of Ua	m/V	4.31×10^{-9}
Ub	quadratic Vgs dependence of mobility (binning parameter; see Note 3)	$(m/V)^2$	5.87×10^{-19}
Ub1	temperature coefficient of Ub	$(m/V)^2$	-7.61×10^{-18}
Uc	body-bias dependence of mobility (binning parameter; see Note 3)	m/V^2 1/V	-4.65×10^{-11} Mobmod=1, 2 –0.0465 Mobmod=3
Uc1	temperature coefficient of Uc	m/V^2 1/V	-5.6×10^{-11} Mobmod=1,2 –0.056 Mobmod=3
U0	low-field mobility at T=Tnom (binning parameter; see Note 3)	$cm^{2/Vs}$	670.0 NMOS 250.0 PMOS
Ute	temperature coefficient of mobility		–1.5
Rdsw	source drain resistance per width (binning parameter; see Note 3)	ohms $\times$ μm^{Wr}	0.0
Prwg	gate bias effect coefficient of Rdsw (binning parameter; see Note 3)	1/V	0.0
Prwb	body effect coefficient of Rdsw (binning parameter; see Note 3)	1/V	0.0
Wr	width dependence of Rds (binning parameter; see Note 3)		1.0
Prt	temperature coefficient of Rdsw	ohms $\times$ μm	0.0
Vsat	saturation velocity at T=Tnom (binning parameter; see Note 3)	m/s	8.0×10^{4}
At	temperature coefficient of Vsat	m/s	3.3×10^{4}

Name	Description	Units	Default
A0	bulk charge effect coefficient for channel length (binning parameter; see Note 3)		1.0
Keta	body-bias coefficient of bulk charge (binning parameter; see Note 3)	1/V	–0.047
Ags	gate bias coefficient of Abulk (binning parameter; see Note 3)	1/V	0.0
A1	first non-saturation factor for PMOS (binning parameter; see Note 3)	1/V	0.0
A2	second non-saturation factor for PMOS (binning parameter; see Note 3)		1.0
B0	bulk charge effect coefficient for channel width (binning parameter; see Note 3)	m	0.0
B1	bulk charge effect width offset (binning parameter; see Note 3)	m	0.0
Voff	threshold voltage offset (binning parameter; see Note 3)	V	-0.08
Nfactor	subthreshold swing factor (binning parameter; see Note 3)		1.0
Cdsc	D/S and channel coupling capacitance (binning parameter; see Note 3)	F/m^2	2.4×10^{-4}
Cdscb	body-bias dependence of Cdsc (binning parameter; see Note 3)	$F/V/m^2$	0.0
Cdscd	drain-bias dependence of Cdsc (binning parameter; see Note 3)	$F/V/m^2$	0.0
Cit	interface state capacitance (binning parameter; see Note 3)	F/m^2	0.0
Eta0	subthreshold region DIBL coefficient (binning parameter; see Note 3)		0.08
Etab	body-bias coefficient for DIBL effect (binning parameter; see Note 3)	1/V	–0.07
Pclm	channel-length modulation coefficient (binning parameter; see Note 3)		1.3
Pdiblc1	first Rout DIBL effect coefficient		0.39
Pdiblc2	second Rout DIBL effect coefficient		0.0086
Pdiblcb	body effect coefficient of DIBL correction parameters	1/V	0

Name	Description	Units	Default
Pscbe1	first substrate current body effect	V/m	4.24×10^8
Pscbe2	second substrate current body effect	m/V	10^{-5}
Pvag	Vg dependence of Rout coefficient (binning parameter; see Note 3)		0.0
Delta	effective Vds parameter (binning parameter; see Note 3)	V	0.01
Kt1	temperature coefficient of Vth	V	–0.11
Kt1l	channel length sensitivity of Kt1	V×m	0.0
Kt2	body bias coefficient of Kt1		0.022
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 lightly doped region overlap capacitance	F/m	0.6
Cf	fringing field capacitance	F/m	
Clc	constant term for short channel model	m	0.1×10^{-6}
Cle	exponential term for short channel		0.6
Dlc	length offset fitting parameter from C-V	m	Lint
Dwc	width offset fitting parameter from C-V	m	Wint
Nlev	Noise model level		-1
Gdwnoi	Drain noise parameters for Nlev=3		1
Kf	flicker (1/f) noise coefficient		0.0
Af	flicker (1/f) noise exponent		1.0
Ef	flicker (1/f) noise frequency exponent		1.0
Em	flicker (1/f) noise parameter	V/m	4.1×10^7
Noia	noise parameter A		1.0×10^{20} NMOS 9.9×10^{18} PMOS
Noib	noise parameter B		5.0×10^4 NMOS 2.4×10^3 PMOS

Name	Description	Units	Default
Noic	noise parameter C		-1.4×10^{-12} NMOS 1.4×10^{12} PMOS
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 7 on Ijth)	A	Ijth
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
Toxm	gate oxide thickness tox value at which parameters are extracted	m	
Vfb	DC flat-band voltage	V	†
Noff	CV parameter in VgsteffCV for weak-to-strong inversion region		1.0
Voffcv	CV parameter in VgsteffCV for weak-to-strong inversion region		1.0
Ijth	diode limiting current	A	†
Alpha1	substrate current parameter	1/V	0.0
Acde	exponential coefficient for charge thickness in the accumulation and depletion regions (binning parameter; see Note 3)	m/V	1.0
Moin	coefficient for the gate-bias dependent surface potential (binning parameter; see Note 3)	$V^{(1/2)}$	15.0
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	coefficient of length dependence for CV channel length offset	m^{Lln}	DC Ll

Name	Description	Units	Default
Lwc	coefficient of width dependence for CV channel length offset	m^{Lwn}	DC Lw
Lwlc	coefficient of length and width cross-term for CV channel length offset	$m^{Lwn + LLn}$	DC Lwl
Wlc	coefficient of length dependence for CV channel width offset	m^{Wln}	DC Wl
Wwc	coefficient of width dependence for CV channel width offset	m^{Wwn}	DC Ww
Wwlc	coefficient of length and width cross-term for CV channel width offset	$m^{Wln + Wwn}$	DC Wwl
wPmax	maximum power dissipation (warning)	W	infinite
Acm	area calculation method		-1
Calcacm	flag to use Acm when Acm=12		0
Hdif	length of heavily doped diffusion (ACM=2,3 only)	m	0
Ldif	length of lightly doped diffusion adjacent to gate (ACM=1,2)	m	0
Wmlt	width diffusion layer shrink reduction factor		1
Xw	accounts for masking and etching effects	m	0
Xl	accounts for masking and etching effects	m	0
Rdc	additional drain resistance due to contact resistance	ohms	0
Rsc	additional source resistance due to contact resistance	ohms	0
Vfbcv	flat-band voltage parameter for capmod=0 only	F/m	-1.0
B3qmod	BSIM3 charge model (0 for Berkeley, 1 for Hspice Capmod = 0)		0
Cjswg	S/D (gate side) sidewall junction capacitance	F/m	Cjsw
Pbswg	S/D (gate side) sidewall junction built in potential	V	Mjsw
Mjswg	S/D (gate side) sidewall junction grading coefficient		Pbsw
Is	bulk junction saturation current	A	1e-14
Nqsmod	non-quasi-static model selector		0

Name	Description	Units	Default
Elm	non-quasi-static Elmore constant parameter		5.0
Rd	drain resistance	ohms	0
Rs	source resistance	ohms	0
Flkmod	flicker noise model selector		0
Tlev	temperature equation selector (0/1/2/3)		0
Tlevc	temperature equation selector for capacitance (0/1/2/3)		0
Eg	band gap	eV	1.16
Gap1	energy gap temperature coefficient alpha	V/^{o}C	7.02e-4
Gap2	energy gap temperature coefficient beta	K	1108
Cta	Cj linear temperature coefficient	1/^{o}C	0
Ctp	Cjsw linear temperature coefficient	1/^{o}C	0
Pta	Vj linear temperature coefficnet	1/^{o}C	0
Ptp	Vjsw linear temperature coefficient	1/^{o}C	0
Trd	Rd linear temperature coefficient	1/^{o}C	0
Trs	Rs linear temperature coefficient	1/^{o}C	0
Wmin	binning minimum width (not used for binning; use BinModel)	m	0
Wmax	binning maximum width (not used for binning; use BinModel)	m	1
Lmin	binning minimum length (not used for binning; use BinModel)	m	0
Lmax	binning maximum length (not used for binning; use BinModel)	m	1
AllParams	DataAccessComponent-based parameters		
Dtoxcv	delta oxide thickness (used in Capmod=3)	m	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 the *Design Kit Development book*.

```
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 is used to tell 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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch6  MOSFET Idsmod=8 \
  Vtho=0.7 Cj=3e-4 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

1. This model supplies values for a MOSFET device. The default Version is 3.22. The previous version can be used by setting the Version parameter to 3.0, 3.1, 3.2, or 3.21.
2. More information about this model is available at

   http://www-device.eecs.berkeley.edu/%7ebsim3/

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. 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=lkl, P_W=wkl, P_P=pkl. 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}=0.5µm and W_{eff}=10µm, 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:

$$\text{Vsat} = 1\text{e}5 + 1\text{e}4/0.5 + 2\text{e}4/10 + 3\text{e}4/(0.5 \times 10) = 1.28\text{e}5$$

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:

$$\text{Vsat} = 1\text{e}5 + 1\text{e-}2/0.5\text{e}6 + 2\text{e}{-}2/10\text{e}{-}6 + 3\text{e}\,{-}8/(0.5\text{e-}6 \times 10\text{e}{-}6) = 1.28\text{e}5$$

5. The nonquasi-static (NQS) charge model is supported in versions 3.2 and later.
6. Model parameter U0 can be entered in meters or centimeters. U0 is converted to m^2/V sec as follows: if U0 > 1, it is multiplied by 10^{-4}.
7. 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.
8. 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).

9. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.
10. 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 doing this is described in the *Circuit Simulation* manual. 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

11. 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:

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

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

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

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

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

$$Cj^{NEW} = Cj\left(1 + Mj\left[1 + 4\times10^{-4}(Temp - Tnom) - \frac{Pb^{NEW}}{Pb}\right]\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 + Mjsw\left[1 + 4\times10^{-4}(Temp - Tnom) - \frac{Pbsw^{NEW}}{Pbsw}\right]\right)$$

$$Cjswg^{NEW} = Cjswg\left(1 + Mjswg\left[1 + 4\times10^{-4}(Temp - Tnom) - \frac{Pbswg^{NEW}}{Pbswg}\right]\right)$$

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

$$dPbdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pb\right)\frac{1}{Tnom}$$

$$dPbswdT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pbsw\right)\frac{1}{Tnom}$$

$$dPbswdgT = -\left(E_G(Tnom) + \frac{3kTnom}{q} + (Eg - E_G(Tnom))\frac{Tnom + 2Gap2}{Tnom + Gap2} - Pbswg\right)\frac{1}{Tnom}$$

$$Pb^{NEW} = Pb + dPbdT(Temp - Tnom)$$

$$Pbsw^{NEW} = Pbsw + dPbswdT(Temp - Tnom)$$

$$Pbswg^{NEW} = Pbswg + dPbswgT(Temp - Tnom)$$

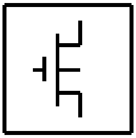
$$Cj^{NEW} = Ce\left(1 - \frac{dPbdT(Temp - Tnom)}{2Pb}\right)$$

$$Cjsw^{NEW} = Cjsw\left(1 - \frac{dPbswdT(Temp - Tnom)}{2Pbsw}\right)$$

$$Cjswg^{NEW} = Cjswg\left(1 - \frac{dPbswgdT(Temp - Tnom)}{2Pbswg}\right)$$

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	N-channel type model		yes
PMOS	P-channel type model		no
Capmod	short-channel capacitance model selector		2
Mobmod	mobility model selector		1
Noimod	noise model selector		1
Shmod	self-heating mode selector; 0 = no self-heating, 1 = self-heating		0
Ddmod	dynamic depletion mode selector		0
Igmod	gate current model selector		0
Paramchk	model parameter checking selector		0
Binunit	Bin unit selector		1
Version	model version		2.0
Tox	gate oxide thickness	m	1.0e-8
Cdsc	drain, source, and channel coupling capacitance	F/m^2	2.4e-4
Cdsccb	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/(V*m^2	1.0
Nfactor	subthreshold swing factor (binning parameter; see Note 3)		0.0
Vsat	saturation velocity at temp, m/s (binning parameter; see Note 3)	m/s	8.0e4

† Calculated parameter

Parameter	**Description**	**Units**	**Default**
At	temperature coefficient for saturation velocity (binning parameter; see Note 3)	m/s	3.3e4
A0	bulk change effect coefficient (binning parameter; see Note 3)		1.0
Ags	gate bulk coefficient of Abulk (binning parameter; see Note 3)	V^{-1}	0.0
A1	first saturation factor (binning parameter; see Note 3)	V^{-1}	0.0
A2	second non-saturation factor (binning parameter; see Note 3)		1.0
Keta	body-bias coefficient of the bulk charge effect (binning parameter; see Note 3)	V^{-1}	-0.6
Nsub	substrate doping concentration with polarity	cm	6.0e16
Nch	Channel doping concentration	cm^{-3}	17e17
Ngate	poly-gate doping concentration	cm^{-3}	0
Gamma1	body-effect coefficient near the interface	$V^{1/2}$	†
Gamma2	body-effect coefficient in the bulk	$V^{1/2}$	†
Vbx	Vth transition body voltage	V	†
Vbm	maximum body voltage	V	-3.0
Xt	doping depth	m	1.55e-7
K1	body-effect coefficient (binning parameter; see Note 3)	$V^{1/2}$	0.5
Kt1	temperature coefficient for threshold voltage,	V	-0.11
Kt11	channel length sensitivity of ktl	V+m	0.0
Kt2	body-bias coefficient		0.022
K2	bulk effect coefficient 2 (binning parameter; see Note 3)		0.0
K3	narrow width coefficient (binning parameter; see Note 3)		0.0
K3b	body effect coefficient of K3 (binning parameter; see Note 3)	V^{-1}	0.0
WO	narrow width (binning parameter; see Note 3)		0.0
Nlx	lateral non-uniform doping coefficient (binning parameter; see Note 3)	m	1.74e-7

† Calculated parameter

Parameter	Description	Units	Default
Dvt0	first coefficient of short-channel effect on Vth (binning parameter; see Note 3)		2.2
Dvt1	first coefficient of short-channel effect on Vth (binning parameter; see Note 3)		0.53
Dvt2	body-bias coefficient of short-channel effect on Vth (binning parameter; see Note 3)	V^{-1}	-0.032
Dvt0w	first coefficient of narrow-width effect on Vth (binning parameter; see Note 3)		0.0
Dvt1w	first coefficient of narrow-width effect on Vth (binning parameter; see Note 3)	m^{1}	5.3e6
Dvt2w	second coefficient of narrow-width effect on Vth (binning parameter; see Note 3)	m^{1}	5.3e6
Drout	L depend (binning parameter; see Note 3)		0.56
Dsub	BL coefficient in sub-threshold region (binning parameter; see Note 3)		Drout
Vth0	zero-bias threshold voltage (binning parameter; see Note 3)		0.7 (NMOS) -0.7 (PMOS)
Ua	first-order mobility degradation coefficient (binning parameter; see Note 3)	m/V	2.25e-9
Ua1	temperature coefficient of Ua	m/V	4.31e-9
Ub	second-order mobility degradation coefficient (binning parameter; see Note 3)	$(m/V)^2$	5.87e-19
Ub1	temperature coefficient of Ub	$(m/V)^2$	–7.61e-18
Uc	body-bias mobility degradation coefficient (binning parameter; see Note 3)	V^{-1}	-0.0465
Uc1	temperature coefficient of Uc	V^{-1}	-0.056
U0	low-field mobility at T=Tnom (binning parameter; see Note 3)	$m^2/(V*s)$	0.067 NMOS 0.025 PMOS
Ute	temperature coefficient of mobility		–1.5
Voff	Offset voltage in sub-threshold region (binning parameter; see Note 3)	V	0.08
Tnom	measurement temperature	C	25
Trise	temperature rise above ambient	°C	0

† Calculated parameter

Parameter	Description	Units	Default
Cgdo	G-D overlap capacitance per meter channel width	F/m	†
Xpart	coefficient of channel charge share		0.0
Delta	effective Vds (binning parameter; see Note 3)	V	0.01
Rsh	drain and source diffusion sheet resistance	ohm/sq	0.0 (set to >0 or leave it blank)
Rdsw	parasitic resistance per unit width (binning parameter; see Note 3)	ohms*um^{Wr}	0.0
Prwg	gate bias effect on parasitic resistance (binning parameter; see Note 3)	V^{-1}	0.0
Prwb	body effect on parasitic resistance (binning parameter; see Note 3)	$V^{-1/2}$	–0.047
Prt	temperature coefficient of parasitic resistance	ohms*um	0.0
Eta0	sub-threshold region DIBL coefficient		0.08
Etab	second non-saturation factor for PMOS	V^{-1}	-0.07
Pclm	channel-length modulation effect coefficient		1.3
Pdiblc1	drain induced barrier lowering effect coefficient 1		0.39
Pdiblc2	drain induced barrier lowering effect coefficient 1	V	-0.086
Pdiblc2b	body effect on drain induced barrier lowering	V^{-1}	0.0
Pvag	gate voltage dependence of Rout coefficient (binning parameter; see Note 3)		0.0
Tbox	back gate oxide thickness	m	3.0e-7
Tsi	silicon-on-insulator thickness	m	1.0e-7
Xj	metallurgical junction depth	m	Tsi
Rth0	self-heating thermal resistance	ohms	0.0
Ctho	self-heating thermal capacitance	F	0.0
Ngidi	GIDL first parameter	V	1.2
Agidi	GIDL second parameter	ohm^{-1}	0.0
Bgidi	GIDL third parameter	V/m	0.0
Ndiode	diode non-ideality factor (binning parameter; see Note 3)		1.0
Xbjt	temperature coefficient for Isbjt		1.0

† Calculated parameter

Parameter	Description	Units	Default
Xdif	temperature coefficient for Isdif		1.0
Xrec	temperature coefficient for Isrec		1.0
Xtun	temperature coefficient for Istun		0.0
Pbswg	S/D (gate side) sidewall junction built-in potential	V	0.07
Mjswg	S/D (gate side) sidewall junction grading coefficient		0.5
Cjswg	S/D (gate side) sidewall junction capacitance	m	1.0e–10
Lint	length reduction parameter (binning parameter; see Note 3)	m	0.0
L1	coefficient of length dependence for length offset	m	0.0
Lln	power of length dependence of length offset	m	1.0
Lw	coefficient of width dependence for length offset	m	0.0
Lwn	power of width dependence for length offset	m	1.0
Lwl	coefficient of lenth and width cross term length offset	m	0.0
Wr	width dependence of Rds (binning parameter; see Note 3)		1.0
Wint	width reduction parameter (binning parameter; see Note 3)	m	0.0
Dwg	coefficient of Weff's gate dependence (binning parameter; see Note 3)	m/V	0.0
Dwb	coefficient of Weff's substrate body bias dependence (binning parameter; see Note 3)	$m/V^{-1/2}$	0.0
W1	coefficient of length dependence for width offset	m	0.0
Win	power of length dependence for width offset		1.0
Ww	coefficient of width dependence for width offset	m	0.0
Wwn	power of width dependence for width offset		1.0
Wwl	coefficient of length and width cross term width of offset	m	0.0
BO	bulk charge coefficient for channel width (binning parameter; see Note 3)	m	0.0
B1	bulk charge effect width offset (binning parameter; see Note 3)	m	0.0
Cgsl	light doped source-gate region overlap capacitance	F/m	0.0
Ckappa	coefficient for light doped source-gate region overlap capacitance	F/m	0.0

† Calculated parameter

Parameter	Description	Units	Default
Cf	fringing field capacitance	F/m	†
Clc	constant term for the short channel model	m	0.1e-7
Cle	exponential term for the short channel model		0.0
Dwc	width offset fitting parameter from C-V	m	Wint
Dlc	length offset fitting parameter from C-V	m	Lint
Alpha0	first parameter of impact ionization current (binning parameter; see Note 3)	m/V	0.0
Noia	noise parameter A		1.0e20 (NMOS) 9.9e18 (PMOS)
Noib	noise parameter B		5.0e4(NMOS), 2.4e3 (PMOS)
Noic	noise parameter C		-1,4e-12 (NMOS) -1,4e-12 (PMOS)
Em	flicker (l/f) noise parameter	V/m	4.1e-7
Ef	flicker (l/f) noise frequency exponent	V	1.0
Af	flicker (l/f) noise exponent		1.0
Kf	flicker (l/f) noise coefficient		0.0
Noif	floating body noise ideality factor		1.0
K1w1	first body effect with dependent parameter (binning parameter; see Note 3)	m	0.0
K1w2	second body effect with dependent parameter (binning parameter; see Note 3)	m	0.0
Ketas	surface potential adjustment for bulk charge effect (binning parameter; see Note 3)	V	0.0
Dwbc	width offset for body contact isolation edge	m	0.0
Beta0	first Vds parameter of impact isolation current (binning parameter; see Note 3)	V^{-1}	0.0
Beta1	second Vds parameter of impact isolation current (binning parameter; see Note 3)		0.0
Beta2	third Vds parameter of impact isolation current (binning parameter; see Note 3)	V	0.0
VdsatiiO	nominal drain saturation voltage at threshold for impact ionization current	V	0.9

† Calculated parameter

Parameter	Description	Units	Default
Tii	temperature dependent parameter for impact ionization (binning parameter; see Note 3)		0.0
Lii	channel length dependent parameter threshold for impact ionization (binning parameter; see Note 3)		0.0
Sii0	first Vgs dependent parameter for impact ionization current (binning parameter; see Note 3)	V^{-1}	0.5
Sii1	second Vgs dependent parameter for impact ionization current (binning parameter; see Note 3)	V^{-1}	0.1
Sii2	third Vgs dependent parameter for impact ionization current (binning parameter; see Note 3)	V^{-1}	0.1
Siid	Vgs dependent parameter for impact ionization current (binning parameter; see Note 3)	V^{-1}	0.1
Fbjtii	fraction of bipolar current affecting the impact ionization		0.0
Esatii	saturation electric field for impact ionization (binning parameter; see Note 3)	V /m	1.0e7
Ntun	reverse tunneling new-ideality factor (binning parameter; see Note 3)		10.0
Nrecf0	recombination non-ideality factor at forward bias (binning parameter; see Note 3)		2.0
Nrecro	recombination non-ideality factor at reversed bias (binning parameter; see Note 3)		10.0
Isbjt	BJT injection saturation current (binning parameter; see Note 3)	A/m^2	1.0e-6
Isdif	Body to source/drain injection saturation current (binning parameter; see Note 3)	A/m^2	0.0
Isrec	recombination in depletion saturation current (binning parameter; see Note 3)	A/m^2	1.0e-6
Istun	reverse tunneling saturation current (binning parameter; see Note 3)	A/m^2	0.0
Ln	electron/hole diffusion length	m	2.0e-6
Vrec0	voltage dependent parameter for recombination current (binning parameter; see Note 3)	V	0.0
Vtun0	voltage dependent parameter for tunneling current (binning parameter; see Note 3)	V	0.0

† Calculated parameter

Parameter	Description	Units	Default
Nbjt	power coefficient of channel length dependency for bipolar current (binning parameter; see Note 3)		1.0
Lbjt0	channel length for bipolar current (binning parameter; see Note 3)	m	0.2e-6
Ldif0	channel length dependency coefficient of diffusion cap		1.0
Vabjt	early voltage for bipolar current (binning parameter; see Note 3)	V	10.0
Aely	channel length dependency of early voltage for bipolar current (binning parameter; see Note 3)	V/m	10.0
Ahli	high level injection parameter for bipolar current (binning parameter; see Note 3)		0.0
Rbody	intrinsic body sheet resistance	ohm/m^2	0.0
Rbsh	extrinsic body sheet resistance	ohm/m^2	0.0
Cgeo	capacitance per unit channel length	F/m	0/0
Tt	diffusion capacitance transit time coefficient	s	1.0e-12
Ndif	power coefficient of channel length dependency for diffusion capacitance		-1.0
Vsdfb	capacitance flatband voltage (binning parameter; see Note 3)	V	†
Vsdth	capacitance threshold voltage (binning parameter; see Note 3)	V	†
Csdmin	source/drain bottom diffusion minimum capacitance	F	†
Asd	source/drain bottom diffusion smoothing parameter		0.3
Cdesw	source/drain sidewall fringing capacitance per unit channel length	F/m	0/0
Ntrecf	temperature coefficient for Ncref		0.0
Ntrecr	temperature coefficient for Ncrer		0.0
Dlcb	length offset fitting parameter for body charge	m	Lint
Fbody	scaling factor for body charge		1.0
Tcjswg	temperature coefficient of Cjswg	K^{-1}	0.0
Tpbswg	temperature coefficient of Pbswg	V/K	0.0

† Calculated parameter

Parameter	Description	Units	Default
Acde	exponential coefficient for finite charge thickness (binning parameter; see Note 3)	m/V	1.0
Moin	coefficient for gate-bias dependent surface potential (binning parameter; see Note 3)	$V^{1/2}$	15.0
Delvt	threshold voltage adjust for CV, V (binning parameter; see Note 3)		0.0
Kb1	coefficient of Vbs0 dependency on Ves (binning parameter; see Note 3)		1.0
Dlbg	length offset fitting parameter for backgate charge	m	0.0
Toxqm	effective oxide thickness considering quantum effect	m	Tox
Wth0	minimum width for thermal resistance calculation	m	0.0
Rhalo	Body halo sheet resistance	ohms	1.0e15
Ntox	power term of gate current		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		0.35
Betagb2	second Vox dependent parameter for gate current in inversion		0.03
Vgb1	third Vox dependent parameter for gate current in inversion		300.0
Necb	condition-band electron non-ideality factor		1.0
Alphagb2	first Vox dependent parameter for gate current in accumulation		0.43
Betagb2	second Vox dependent parameter for gate current in accumulation		0.05
Vgb2	third Vox dependent parameter for gate current in accumulation		17.0
Voxh	limit of Vox in gate current calculation	V	5.0
Deltavox	Smoothing parameter in the Vox smoothing function	V	0.005
Gmin	minimum conductance added in parallel to the P-N junction	Siemens	1.0e-20

† Calculated parameter

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch8 B3SOI \
  Vtho=0.7 Cj=3e-4 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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 = lkl, P_W = wkl, P_P=pkl. 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}=0.5μm and W_{eff}=10μm, 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:

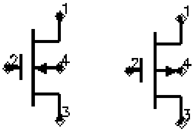
   Vsat = 1e5 + 1e4/0.5 + 2e4/10 + 3e4/(0.5 × 10) = 1.28e5

   To get the same effective value of Vsat for Binunit=0, values of Vsat, Lvsat, Wvsat, and Pvsat would be 1e5, le–2, 2e–2, 3e–8, respectively. Thus:

   Vsat = 1e5 + 1e-2/0.5e6 + 2e–2/10e–6 + 3e –8/(0.5e-6 × 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	Unit	Default
Model	model instance name		
Length	channel length	um, mm, cm, meter, mil, in	5.0e-6
Width	channel width	um, mm, cm, meter, mil, in	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		0.0
Nrd	number of squares of drain diffusion		1.0
Nrs	number of squares of source diffusion		1.0
Nrb	number of squares in body		1.0
Bjtoff	BJT on/off flag: yes = 1, no = 0		no
Rth0	instance thermal resistance	ohms	model Rth0
Cth0	instance thermal capacitance	farads	model Cth0
Nbc	number of body contact insulation edge		0.0
Nseg	number of segments for width partitioning		1.0
Pdbcp	perimter length for bc parasitics at drain side		0.0
Psbcp	perimter length for bc parasitics at source side		0.0
Agbcp	gate to body overlap area for bc parasitics	m^2	0.0

Name	Description	Unit	Default
Aebcp	substrate to body overlap area for bc parasitics	m^2	
Vbsusr	Vbs specified by the user, in V (default: Vbs)	volts	
Temp	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: linear, nonlinear		nonlinear
Noise	noise generation option (yes = 1, no = 0)		yes
_M	number of devices in parallel		1

Notes/Equations

1. Table 5-2 lists the DC operating point parameters that can be sent to the dataset.

Table 5-2. DC Operating Point Information

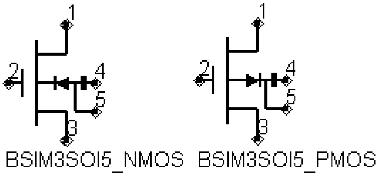
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gmb	Backgate transconductance (dIds/dVbs)	S
Gds	Output conductance (dIds/dVds)	S
Vth	Threshold voltage	V
Vdsat	Drain-source saturation voltage	V
DqgDvgb	(dQg/dVgb)	F
DqgDvdb	(dQg/dVdb)	F
DqgDvsb	(dQg/dVsb)	F
DqgDveb	(dQg/dVeb)	F
DqbDvgb	(dQb/dVgb)	F
DqbDvdb	(dQb/dVdb)	F
DqbDvsb	(dQb/dVsb)	F

Table 5-2. DC Operating Point Information (continued)

Name	**Description**	**Units**
DqbDveb	(dQb/dVeb)	F
DqdDvgb	(dQd/dVgb)	F
DqdDvdb	(dQd/dVdb)	F
DqdDvsb	(dQd/dVsb)	F
DqdDveb	(dQd/dVeb)	F
DqeDvgb	(dQe/dVgb)	F
DqeDvdb	(dQe/dVdb)	F
DqeDvsb	(dQe/dVsb)	F
DqeDveb	(dQe/dVeb)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V
Ves	Substrate-source voltage	V
Vps	Body-source voltage	V

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	Unit	Default
Model	model instance name		
Length	channel length	um, mm, cm, meter, mil, in	5.0e-6 m
Width	channel width	um, mm, cm, meter, mil, in	5.0e-6 m
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		1.0
Nrs	number of squares of the source diffusion		1.0
Nrb	number of squares in body		1.0
Bjtoff	BJT on/off flag: yes = 1, no = 0		no
Rth0	instance thermal resistance	ohms	model Rth0
Cth0	instance thermal capacitance	farads	model Cth0
Nbc	number of body contact insulation edge		0.0
Nseg	number segments for width partitioning		1.0

Name	Description	Unit	Default
Pdbcp	perimter length for bc parasitics at drain side		0.0
Psbcp	perimter length for bc parasitics at source side		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	0.0
Vbsusr	Vbs specified by the user	fV, pV, nV, uV, mV, V	Vbs
Temp	device operating temperature	^oC	25
Trise	temperature rise above ambient	°C	0
Mode	simulation mode for this device: linear, nonlinear		nonlinear
Noise	noise generation option (yes = 1, no = 0)		yes
_M	number of devices in parallel		1

Notes/Equations

1. Table 5-3 lists the DC operating point parameters that can be sent to the dataset.

Table 5-3. DC Operating Point Information

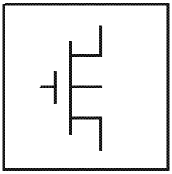
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gmb	Backgate transconductance (dIds/dVbs)	S
Gds	Output conductance (dIds/dVds)	S
Vth	Threshold voltage	V
Vdsat	Drain-source saturation voltage	V
DqgDvgb	(dQg/dVgb)	F
DqgDvdb	(dQg/dVdb)	F

Table 5-3. DC Operating Point Information (continued)

Name	Description	Units
DqgDvsb	(dQg/dVsb)	F
DqgDveb	(dQg/dVeb)	F
DqbDvgb	(dQb/dVgb)	F
DqbDvdb	(dQb/dVdb)	F
DqbDvsb	(dQb/dVsb)	F
DqbDveb	(dQb/dVeb)	F
DqdDvgb	(dQd/dVgb)	F
DqdDvdb	(dQd/dVdb)	F
DqdDvsb	(dQd/dVsb)	F
DqdDveb	(dQd/dVeb)	F
DqeDvgb	(dQe/dVgb)	F
DqeDvdb	(dQe/dVdb)	F
DqeDvsb	(dQe/dVsb)	F
DqeDveb	(dQe/dVeb)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V
Ves	Substrate-source voltage	V
Vps	Body-source voltage	V

BSIM4_Model (BSIM4 MOSFET Model)

Symbol



Parameters

Name	Description	Unit	Default
NMOS	model type: yes, no		yes
PMOS	model type: yes, no		no
Capmod	Capacitance model selector		2
Diomod	Diode IV model selector		1
Rdsmod	Bias-dependent S/D resistance model selector		0
Trnqsmod	Transient NQS model selector		0
Acnqsmod	AC NQS model selector		0
Mobmod	Mobility model selector		0
Rbodymod	Distributed body R model selector		0
Rgatemod	Gate R model selector		0
Permod	Pd and Ps model selector		1
Geomod	Geometry dependent parasitics model selector		0
Fnoimod	Flicker noise model selector		1
Tnoimod	Thermal noise model selector		0
Igcmod	Gate-to-channel Ig model selector		0
Igbmod	Gate-to-body Ig model selector		0
Paramchk	Model parameter checking selector		1
Binunit	Bin unit selector		1
Version	Parameter for model version		4.2
Toxe	Electrical gate oxide thickness in meters		30.0e-10
Toxp	Physical gate oxide thickness in meters		Toxe
Toxm	Gate oxide thickness at which parameters are extracted		Toxe

Name	Description	Unit	Default
Toxref	Target tox value		30.0e-10
Dtox	Defined as (toxe - toxp)		0.0
Epsrox	Dielectric constant of the gate oxide relative to vacuum		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		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		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		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

Name	**Description**	**Unit**	**Default**
K1	Bulk effect coefficient 1	$V^{1/2}$	0.5
Kt1	Temperature coefficient of Vth	V	-0.11
Kt1l	Temperature coefficient of Vth	V*m	0.0
Kt2	Body-coefficient of kt1		
K2	Bulk effect coefficient 2		0.0
K3	Narrow width effect coefficient		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		2.2
Dvt1	Short channel effect coefficient 1		0.53
Dvt2	Short channel effect coefficient 2	V^{-1}	-0.032
Dvt0w	Narrow Width coefficient 0		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		0.56
Dsub	DIBL coefficient in the subthreshold region		fixed by Drout
Vth0 (Vtho)	Threshold voltage	V	0.7 (NMOS) -0.7 (PMOS)
Ua	Linear gate dependence of mobility		1.0e-15 (Mobmod 2) 1.0e-9 (Mobmod 0, 1)
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)

Name	**Description**	**Unit**	**Default**
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*s)	0.0677 (NMOS) -0.025 (PMOS)
Eu	Mobility exponent		1.67 (NMOS) 1.0 (PMOS)
Ute	Temperature coefficient of mobility		-1.5
Voff	Threshold voltage offset	V	-0.08
Minv	Fitting parameter for moderate inversion in Vgsteff		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		0.0
Delta	Effective Vds parameter	V	0.01
Rsh	Source-drain sheet resistance	ohms/sq	0.0
Rdsw	Source-drain resistance per width	ohms*um	200.0
Rdswmin	Source-drain resistance per width at high Vg	ohms*um	0.0
Rsw	Source resistance per width	ohms*um	100.0
Rdw	Drain resistance per width	ohms*um	100.0
Rdwmin	Drain resistance per width at high Vg	ohms*um	0.0
Rswmin	Source resistance per width at high Vg	ohms*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	ohms*um	0.0
Eta0	Subthreshold region DIBL coefficient		0.08
Etab	Subthreshold region DIBL coefficient	V^{-1}	-0.07
Pclm	Channel length modulation Coefficient		1.3

Name	Description	Unit	Default
Pdiblc1	Drain-induced barrier lowering coefficient		0.39
Pdiblc2	Drain-induced barrier lowering coefficient		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		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		1.0
Xtis	Source junction current temperature exponent		3.0
Mjs	Source bottom junction capacitance grading coefficient		0.5
Pbsws	Source sidewall junction capacitance built in potential	V	1.0
Mjsws	Source sidewall junction capacitance grading coefficient		0.33
Pbswgs	Source gate side sidewall junction capacitance built in potential	V	Pbsws
Mjswgs	Source gate side sidewall junction capacitance grading coefficient		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

Name	Description	Unit	Default
Cjswgs	Source gate side sidewall junction capacitance per unit width	F/m	Cjsws
Jsd	Bottom drain junction reverse saturation current density	A/m^2	Jss
Jswd	Isolation edge sidewall drain junction reverse saturation current density	A/m	Jsws
Jswgd	Gate edge drain junction reverse saturation current density		Jswgs
Pbd	Drain junction built-in potential	V	Pbs
Njd	Drain junction emission coefficient		Njs
Xtid	Drain junction current temperature exponent		Xtis
Mjd	Drain bottom junction capacitance grading coefficient		Mjs
Pbswd	Drain sidewall junction capacitance built in potential	V	Pbsws
Mjswd	Drain sidewall junction capacitance grading coefficient		Mjsws
Pbswgd	Drain gate side sidewall junction capacitance built in potential	V	Pbswgs
Mjswgd	Drain gate side sidewall junction capacitance grading coefficient		Mjswgs
Cjd	Drain bottom junction capacitance per unit area	F/m^2	Cjs
Cjswd	Drain sidewall junction capacitance per unit periphery	F/m	Cjsws
Cjswgd	Drain gate side sidewall junction capacitance per unit width	F/m	Cjswg
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

Name	**Description**	**Unit**	**Default**
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		15.0
Noff	C-V turn-on/off parameter		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	m	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	ohms/sq	0.1
Ngcon	Number of gate contacts		1.0
Xrcrg1	First fitting parameter the bias-dependent Rg		12.0
Xrcrg2	Second fitting parameter the bias-dependent Rg		1.0
Xw	W offset for channel width due to mask/etch effect	m	
Xl	L offset for channel width due to mask/etch effect	m	
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		0.0
Lw	Length reduction parameter	m	0.0
Lwc	Length reduction parameter for CV	m	Lw
Lwn	Length reduction parameter		1.0
Lwl	Length reduction parameter	m	0.0
Lwlc	Length reduction parameter for CV	m	Lwl
Lmin	Minimum length for the model	m	0.0
Lmax	Maximum length for the model	m	1.0

Name	**Description**	**Unit**	**Default**
Wr	Width dependence of rds		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	m	Wl
Wln	Width reduction parameter		1.0
Ww	Width reduction parameter	m	0.0
Wwc	Width reduction parameter for CV	m	Ww
Wwn	Width reduction parameter		1.0
Wwl	Width reduction parameter	m	0.0
Wwlc	Width reduction parameter for CV	m	Wwl
Wmin	Minimum width for the model	m	0.0
Wmax	Maximum width for the model	m	1.0
B0	Abulk narrow width parameter	m	0.0
B1	Abulk 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	V	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		0.6
Dwc	Delta W for C-V model	m	Wint
Dlc	Delta L for C-V model	m	Lint
Dlcig	Delta L for Ig model	m	Lint
Dwj	Delta W for S/D junctions		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	30.0

Name	**Description**	**Unit**	**Default**
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		0.43 (NMOS) 0.31 (PMOS)
Bigc	Parameter for Igc		0.054 (NMOS) 0.024 (PMOS)
Cigc	Parameter for Igc	V^{-1}	0.075 (NMOS) 0.03 (PMOS)
Aigsd	Parameter for Igs,d		0.043 (NMOS) 0.31 (PMOS)
Bigsd	Parameter for Igs,d		0.054 (NMOS) 0.024 (PMOS)
Cigsd	Parameter for Igs,d	V^{-1}	0.075 (NMOS) 0.03 (PMOS)
Aigbacc	Parameter for Igb		0.43
Bigbacc	Parameter for Igb		0.054
Cigbacc	Parameter for Igb	V^{-1}	0.075
Aigbinv	Parameter for Igb		0.35
Bigbinv	Parameter for Igb		0.03
Cigbinv	Parameter for Igb	V^{-1}	0.006
Nigc	Parameter for Igc slope		1.0
Nigbinv	Parameter for Igbinv slope		3.0
Nigbacc	Parameter for Igbacc slope		1.0
Ntox	Exponent for Tox ratio		1.0
Eigbinv	Parameter for the Si bandgap for Igbinv	V	1.1
Pigcd	Parameter for Igc partition		1.0
Poxedge	Factor for the gate edge Tox		1.0
Ijthdfwd	Forward drain diode forward limiting current	A	Ijthsfwd
Ijthsfwd	Forward source diode forward limiting current	A	0.1
Ijthdrev	Reverse drain diode forward limiting current	A	Ijthsrev

Name	Description	Unit	Default
Ijthsrev	Reverse source diode forward limiting current	A	0.1
Imelt	(similar to Ijth*; refer to Note 12 on Imelt, Ijth, Ijthdfwd, Ijthsfwd, Ijthdrev, Ijthsrev)	A	Ijthsfwd
Xjbvd	Fitting parameter for drain diode breakdown current		Xjbvs
Xjbvs	Fitting parameter for source diode breakdown current		1.0
Bvd	Drain diode breakdown voltage	V	Bvs
Bvs	Source diode breakdown voltage	V	10.0
Gbmin	Minimum body conductance	ohm^{-1}	1.0e-12
Rbdb	Resistance between bNode and dbNode	ohms	50.0
Rbpb	Resistance between bNodePrime and bNode	ohms	50.0
Rbsb	Resistance between bNode and sbNode	ohms	50.0
Rbps	Resistance between bNodePrime and sbNode	ohms	50.0
Rbpd	Resistance between bNodePrime and bNode	ohms	50.0
Lcdsc	Length dependence of cdsc		0.0
Lcdscb	Length dependence of cdscb		0.0
Lcdscd	Length dependence of cdscd		0.0
Lcit	Length dependence of cit		0.0
Lnfactor	Length dependence of nfactor		0.0
Lxj	Length dependence of xj		0.0
Lvsat	Length dependence of vsat		0.0
Lat	Length dependence of at		0.0
La0	Length dependence of a0		0.0
Lags	Length dependence of ags		0.0
La1	Length dependence of a1		0.0
La2	Length dependence of a2		0.0
Lketa	Length dependence of keta		0.0
Lnsub	Length dependence of nsub		0.0
Lndep	Length dependence of ndep		0.0
Lnsd	Length dependence of nsd		0.0

Name	Description	Unit	Default
Lphin	Length dependence of phin		0.0
Lngate	Length dependence of ngate		0.0
Lgamma1	Length dependence of gamma1		0.0
Lgamma2	Length dependence of gamma2		0.0
Lvbx	Length dependence of vbx		0.0
Lvbm	Length dependence of vbm		0.0
Lxt	Length dependence of xt		0.0
Lk1	Length dependence of k1		0.0
Lkt1	Length dependence of kt1		0.0
Lkt1l	Length dependence of kt1l		0.0
Lkt2	Length dependence of kt2		0.0
Lk2	Length dependence of k2		0.0
Lk3	Length dependence of k3		0.0
Lk3b	Length dependence of k3b		0.0
Lw0	Length dependence of w0		0.0
Ldvtp0	Length dependence of dvtp0		0.0
Ldvtp1	Length dependence of dvtp1		0.0
Llpe0	Length dependence of lpe0		0.0
Llpeb	Length dependence of lpeb		0.0
Ldvt0	Length dependence of dvt0		0.0
Ldvt1	Length dependence of dvt1		0.0
Ldvt2	Length dependence of dvt2		0.0
Ldvt0w	Length dependence of dvt0w		0.0
Ldvt1w	Length dependence of dvt1w		0.0
Ldvt2w	Length dependence of dvt2w		0.0
Ldrout	Length dependence of drout		0.0
Ldsub	Length dependence of dsub		0.0
Lvth0 (Lvtho)	Length dependence of vto		0.0
Lua	Length dependence of ua		0.0
Lua1	Length dependence of ua1		0.0

Name	Description	Unit	Default
Lub	Length dependence of ub		0.0
Lub1	Length dependence of ub1		0.0
Luc	Length dependence of uc		0.0
Luc1	Length dependence of uc1		0.0
Lu0	Length dependence of u0		0.0
Lute	Length dependence of ute		0.0
Lvoff	Length dependence of voff		0.0
Lminv	Length dependence of minv		0.0
Ldelta	Length dependence of delta		0.0
Lrdsw	Length dependence of rdsw		0.0
Lrsw	Length dependence of rsw		0.0
Lrdw	Length dependence of rdw		0.0
Lprwg	Length dependence of prwg		0.0
Lprwb	Length dependence of prwb		0.0
Lprt	Length dependence of prt		0.0
Leta0	Length dependence of eta0		0.0
Letab	Length dependence of etab		0.0
Lpclm	Length dependence of pclm		0.0
Lpdiblc1	Length dependence of pdiblc1		0.0
Lpdiblc2	Length dependence of pdiblc2		0.0
Lpdiblcb	Length dependence of pdiblcb		0.0
Lfprout	Length dependence of pdiblcb		0.0
Lpdits	Length dependence of pdits		0.0
Lpditsd	Length dependence of pditsd		0.0
Lpscbe1	Length dependence of pscbe1		0.0
Lpscbe2	Length dependence of pscbe2		0.0
Lpvag	Length dependence of pvag		0.0
Lwr	Length dependence of wr		0.0
Ldwg	Length dependence of dwg		0.0
Ldwb	Length dependence of dwb		0.0
Lb0	Length dependence of b0		0.0

Name	**Description**	**Unit**	**Default**
Lb1	Length dependence of b1		0.0
Lcgsl	Length dependence of cgsl		0.0
Lcgdl	Length dependence of cgdl		0.0
Lckappas	Length dependence of ckappas		0.0
Lckappad	Length dependence of ckappad		0.0
Lcf	Length dependence of cf		0.0
Lclc	Length dependence of clc		0.0
Lcle	Length dependence of cle		0.0
Lalpha0	Length dependence of alpha0		0.0
Lalpha1	Length dependence of alpha1		0.0
Lbeta0	Length dependence of beta0		0.0
Lagidl	Length dependence of agidl		0.0
Lbgidl	Length dependence of bgidl		0.0
Lcgidl	Length dependence of cgidl		0.0
Legidl	Length dependence of egidl		0.0
Laigc	Length dependence of aigc		0.0
Lbigc	Length dependence of bigc		0.0
Lcigc	Length dependence of cigc		0.0
Laigsd	Length dependence of aigsd		0.0
Lbigsd	Length dependence of bigsd		0.0
Lcigsd	Length dependence of cigsd		0.0
Laigbacc	Length dependence of aigbacc		0.0
Lbigbacc	Length dependence of bigbacc		0.0
Lcigbacc	Length dependence of cigbacc		0.0
Laigbinv	Length dependence of aigbinv		0.0
Lbigbinv	Length dependence of bigbinv		0.0
Lcigbinv	Length dependence of cigbinv		0.0
Lnigc	Length dependence of nigc		0.0
Lnigbinv	Length dependence of nigbinv		0.0
Lnigbacc	Length dependence of nigbacc		0.0
Lntox	Length dependence of ntox		0.0

Name	Description	Unit	Default
Leigbinv	Length dependence for eigbinv		0.0
Lpigcd	Length dependence for pigcd		0.0
Lpoxedge	Length dependence for poxedge		0.0
Lvfbcv	Length dependence of vfbcv		0.0
Lvfb	Length dependence of vfb		0.0
Lacde	Length dependence of acde		0.0
Lmoin	Length dependence of moin		0.0
Lnoff	Length dependence of noff		0.0
Lvoffcv	Length dependence of voffcv		0.0
Lxrcrg1	Length dependence of xrcrg1		0.0
Lxrcrg2	Length dependence of xrcrg2		0.0
Leu	Length dependence of eu		0.0
Wcdsc	Width dependence of cdsc		0.0
Wcdscb	Width dependence of cdscb		0.0
Wcdscd	Width dependence of cdscd		0.0
Wcit	Width dependence of cit		0.0
Wnfactor	Width dependence of nfactor		0.0
Wxj	Width dependence of xj		0.0
Wvsat	Width dependence of vsat		0.0
Wat	Width dependence of at		0.0
Wa0	Width dependence of a0		0.0
Wags	Width dependence of ags		0.0
Wa1	Width dependence of a1		0.0
Wa2	Width dependence of a2		0.0
Wketa	Width dependence of keta		0.0
Wnsub	Width dependence of nsub		0.0
Wndep	Width dependence of ndep		0.0
Wnsd	Width dependence of nsd		0.0
Wphin	Width dependence of phin		0.0
Wngate	Width dependence of ngate		0.0
Wgamma1	Width dependence of gamma1		0.0

Name	Description	Unit	Default
Wgamma2	Width dependence of gamma2		0.0
Wvbx	Width dependence of vbx		0.0
Wvbm	Width dependence of vbm		0.0
Wxt	Width dependence of xt		0.0
Wk1	Width dependence of k1		0.0
Wkt1	Width dependence of kt1		0.0
Wkt1l	Width dependence of kt1l		0.0
Wkt2	Width dependence of kt2		0.0
Wk2	Width dependence of k2		0.0
Wk3	Width dependence of k3		0.0
Wk3b	Width dependence of k3b		0.0
Ww0	Width dependence of w0		0.0
Wdvtp0	Width dependence of dvtp0		0.0
Wdvtp1	Width dependence of dvtp1		0.0
Wlpe0	Width dependence of lpe0		0.0
Wlpeb	Width dependence of lpeb		0.0
Wdvt0	Width dependence of dvt0		0.0
Wdvt1	Width dependence of dvt1		0.0
Wdvt2	Width dependence of dvt2		0.0
Wdvt0w	Width dependence of dvt0w		0.0
Wdvt1w	Width dependence of dvt1w		0.0
Wdvt2w	Width dependence of dvt2w		0.0
Wdrout	Width dependence of drout		0.0
Wdsub	Width dependence of dsub		0.0
Wvth0 (Wvtho)	Width dependence of vto		0.0
Wua	Width dependence of ua		0.0
Wua1	Width dependence of ua1		0.0
Wub	Width dependence of ub		0.0
Wub1	Width dependence of ub1		0.0
Wuc	Width dependence of uc		0.0

Name	Description	Unit	Default
Wuc1	Width dependence of uc1		0.0
Wu0	Width dependence of u0		0.0
Wute	Width dependence of ute		0.0
Wvoff	Width dependence of voff		0.0
Wminv	Width dependence of minv		0.0
Wdelta	Width dependence of delta		0.0
Wrdsw	Width dependence of rdsw		0.0
Wrsw	Width dependence of rsw		0.0
Wrdw	Width dependence of rdw		0.0
Wprwg	Width dependence of prwg		0.0
Wprwb	Width dependence of prwb		0.0
Wprt	Width dependence of prt		0.0
Weta0	Width dependence of eta0		0.0
Wetab	Width dependence of etab		0.0
Wpclm	Width dependence of pclm		0.0
Wpdiblc1	Width dependence of pdiblc1		0.0
Wpdiblc2	Width dependence of pdiblc2		0.0
Wpdiblcb	Width dependence of pdiblcb		0.0
Wfprout	Width dependence of pdiblcb		0.0
Wpdits	Width dependence of pdits		0.0
Wpditsd	Width dependence of pditsd		0.0
Wpscbe1	Width dependence of pscbe1		0.0
Wpscbe2	Width dependence of pscbe2		0.0
Wpvag	Width dependence of pvag		0.0
Wwr	Width dependence of wr		0.0
Wdwg	Width dependence of dwg		0.0
Wdwb	Width dependence of dwb		0.0
Wb0	Width dependence of b0		0.0
Wb1	Width dependence of b1		0.0
Wcgsl	Width dependence of cgsl		0.0
Wcgdl	Width dependence of cgdl		0.0

Name	Description	Unit	Default
Wckappas	Width dependence of ckappas		0.0
Wckappad	Width dependence of ckappad		0.0
Wcf	Width dependence of cf		0.0
Wclc	Width dependence of clc		0.0
Wcle	Width dependence of cle		0.0
Walpha0	Width dependence of alpha0		0.0
Walpha1	Width dependence of alpha1		0.0
Wbeta0	Width dependence of beta0		0.0
Wagidl	Width dependence of agidl		0.0
Wbgidl	Width dependence of bgidl		0.0
Wcgidl	Width dependence of cgidl		0.0
Wegidl	Width dependence of egidl		0.0
Waigc	Width dependence of aigc		0.0
Wbigc	Width dependence of bigc		0.0
Wcigc	Width dependence of cigc		0.0
Waigsd	Width dependence of aigsd		0.0
Wbigsd	Width dependence of bigsd		0.0
Wcigsd	Width dependence of cigsd		0.0
Waigbacc	Width dependence of aigbacc		0.0
Wbigbacc	Width dependence of bigbacc		0.0
Wcigbacc	Width dependence of cigbacc		0.0
Waigbinv	Width dependence of aigbinv		0.0
Wbigbinv	Width dependence of bigbinv		0.0
Wcigbinv	Width dependence of cigbinv		0.0
Wnigc	Width dependence of nigc		0.0
Wnigbinv	Width dependence of nigbinv		0.0
Wnigbacc	Width dependence of nigbacc		0.0
Wntox	Width dependence of ntox		0.0
Weigbinv	Width dependence for eigbinv		0.0
Wpigcd	Width dependence for pigcd		0.0
Wpoxedge	Width dependence for poxedge		0.0

Name	Description	Unit	Default
Wvfbcv	Width dependence of vfbcv		0.0
Wvfb	Width dependence of vfb		0.0
Wacde	Width dependence of acde		0.0
Wmoin	Width dependence of moin		0.0
Wnoff	Width dependence of noff		0.0
Wvoffcv	Width dependence of voffcv		0.0
Wxrcrg1	Width dependence of xrcrg1		0.0
Wxrcrg2	Width dependence of xrcrg2		0.0
Weu	Width dependence of eu		0.0
Pcdsc	Cross-term dependence of cdsc		0.0
Pcdscb	Cross-term dependence of cdscb		0.0
Pcdscd	Cross-term dependence of cdscd		0.0
Pcit	Cross-term dependence of cit		0.0
Pnfactor	Cross-term dependence of nfactor		0.0
Pxj	Cross-term dependence of xj		0.0
Pvsat	Cross-term dependence of vsat		0.0
Pat	Cross-term dependence of at		0.0
Pa0	Cross-term dependence of a0		0.0
Pags	Cross-term dependence of ags		0.0
Pa1	Cross-term dependence of a1		0.0
Pa2	Cross-term dependence of a2		0.0
Pketa	Cross-term dependence of keta		0.0
Pnsub	Cross-term dependence of nsub		0.0
Pndep	Cross-term dependence of ndep		0.0
Pnsd	Cross-term dependence of nsd		0.0
Pphin	Cross-term dependence of phin		0.0
Pngate	Cross-term dependence of ngate		0.0
Pgamma1	Cross-term dependence of gamma1		0.0
Pgamma2	Cross-term dependence of gamma2		0.0
Pvbx	Cross-term dependence of vbx		0.0
Pvbm	Cross-term dependence of vbm		0.0

Name	Description	Unit	Default
Pxt	Cross-term dependence of xt		0.0
Pk1	Cross-term dependence of k1		0.0
Pkt1	Cross-term dependence of kt1		0.0
Pkt1l	Cross-term dependence of kt1l		0.0
Pkt2	Cross-term dependence of kt2		0.0
Pk2	Cross-term dependence of k2		0.0
Pk3	Cross-term dependence of k3		0.0
Pk3b	Cross-term dependence of k3b		0.0
Pw0	Cross-term dependence of w0		0.0
Pdvtp0	Cross-term dependence of dvtp0		0.0
Pdvtp1	Cross-term dependence of dvtp1		0.0
Plpe0	Cross-term dependence of lpe0		0.0
Plpeb	Cross-term dependence of lpeb		0.0
Pdvt0	Cross-term dependence of dvt0		0.0
Pdvt1	Cross-term dependence of dvt1		0.0
Pdvt2	Cross-term dependence of dvt2		0.0
Pdvt0w	Cross-term dependence of dvt0w		0.0
Pdvt1w	Cross-term dependence of dvt1w		0.0
Pdvt2w	Cross-term dependence of dvt2w		0.0
Pdrout	Cross-term dependence of drout		0.0
Pdsub	Cross-term dependence of dsub		0.0
Pvth0 (Pvtho)	Cross-term dependence of vto		0.0
Pua	Cross-term dependence of ua		0.0
Pua1	Cross-term dependence of ua1		0.0
Pub	Cross-term dependence of ub		0.0
Pub1	Cross-term dependence of ub1		0.0
Puc	Cross-term dependence of uc		0.0
Puc1	Cross-term dependence of uc1		0.0
Pu0	Cross-term dependence of u0		0.0
Pute	Cross-term dependence of ute		0.0

Name	Description	Unit	Default
Pvoff	Cross-term dependence of voff		0.0
Pminv	Cross-term dependence of minv		0.0
Pdelta	Cross-term dependence of delta		0.0
Prdsw	Cross-term dependence of rdsw		0.0
Prsw	Cross-term dependence of rsw		0.0
Prdw	Cross-term dependence of rdw		0.0
Pprwg	Cross-term dependence of prwg		0.0
Pprwb	Cross-term dependence of prwb		0.0
Pprt	Cross-term dependence of prt		0.0
Peta0	Cross-term dependence of eta0		0.0
Petab	Cross-term dependence of etab		0.0
Ppclm	Cross-term dependence of pclm		0.0
Ppdiblc1	Cross-term dependence of pdiblc1		0.0
Ppdiblc2	Cross-term dependence of pdiblc2		0.0
Ppdiblcb	Cross-term dependence of pdiblcb		0.0
Pfprout	Cross-term dependence of pdiblcb		0.0
Ppdits	Cross-term dependence of pdits		0.0
Ppditsd	Cross-term dependence of pditsd		0.0
Ppscbe1	Cross-term dependence of pscbe1		0.0
Ppscbe2	Cross-term dependence of pscbe2		0.0
Ppvag	Cross-term dependence of pvag		0.0
Pwr	Cross-term dependence of wr		0.0
Pdwg	Cross-term dependence of dwg		0.0
Pdwb	Cross-term dependence of dwb		0.0
Pb0	Cross-term dependence of b0		0.0
Pb1	Cross-term dependence of b1		0.0
Pcgsl	Cross-term dependence of cgsl		0.0
Pcgdl	Cross-term dependence of cgdl		0.0
Pckappas	Cross-term dependence of ckappas		0.0
Pckappad	Cross-term dependence of ckappad		0.0
Pcf	Cross-term dependence of cf		0.0

Name	Description	Unit	Default
Pclc	Cross-term dependence of clc		0.0
Pcle	Cross-term dependence of cle		0.0
Palpha0	Cross-term dependence of alpha0		0.0
Palpha1	Cross-term dependence of alpha1		0.0
Pbeta0	Cross-term dependence of beta0		0.0
Pagidl	Cross-term dependence of agidl		0.0
Pbgidl	Cross-term dependence of bgidl		0.0
Pcgidl	Cross-term dependence of cgidl		0.0
Pegidl	Cross-term dependence of egidl		0.0
Paigc	Cross-term dependence of aigc		0.0
Pbigc	Cross-term dependence of bigc		0.0
Pcigc	Cross-term dependence of cigc		0.0
Paigsd	Cross-term dependence of aigsd		0.0
Pbigsd	Cross-term dependence of bigsd		0.0
Pcigsd	Cross-term dependence of cigsd		0.0
Paigbacc	Cross-term dependence of aigbacc		0.0
Pbigbacc	Cross-term dependence of bigbacc		0.0
Pcigbacc	Cross-term dependence of cigbacc		0.0
Paigbinv	Cross-term dependence of aigbinv		0.0
Pbigbinv	Cross-term dependence of bigbinv		0.0
Pcigbinv	Cross-term dependence of cigbinv		0.0
Pnigc	Cross-term dependence of nigc		0.0
Pnigbinv	Cross-term dependence of nigbinv		0.0
Pnigbacc	Cross-term dependence of nigbacc		0.0
Pntox	Cross-term dependence of ntox		0.0
Peigbinv	Cross-term dependence for eigbinv		0.0
Ppigcd	Cross-term dependence for pigcd		0.0
Ppoxedge	Cross-term dependence for poxedge		0.0
Pvfbcv	Cross-term dependence of vfbcv		0.0
Pvfb	Cross-term dependence of vfb		0.0
Pacde	Cross-term dependence of acde		0.0

Name	**Description**	**Unit**	**Default**
Pmoin	Cross-term dependence of moin		0.0
Pnoff	Cross-term dependence of noff		0.0
Pvoffcv	Cross-term dependence of voffcv		0.0
Pxrcrg1	Cross-term dependence of xrcrg1		0.0
Pxrcrg2	Cross-term dependence of xrcrg2		0.0
Peu	Cross-term dependence of eu		0.0
Noia	Flicker noise parameter		6.25e41 (NMOS), 6.188e40 (PMOS)
Noib	Flicker noise parameter		3.125e26 (NMOS), 1.5e25 (PMOS)
Noic	Flicker noise parameter		8.75
Tnoia	Thermal noise parameter		1.5
Tnoib	Thermal noise parameter		3.5
Ntnoi	Thermal noise parameter		1.0
Em	Flicker noise parameter	V/m	4.1e7
Ef	Flicker noise frequency exponent		1.0
Af	Flicker noise exponent		1.0
Kf	Flicker noise coefficient		0.0
wBvsub	substrate jujction reverse breakdown voltage warning	V	
wBvds	gate oxide 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 (DAC)-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch7 BSIM4 \
  Vtho=0.7 Cj=3e-4  NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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=lkl, P_W=wkl, P_P=pkl. 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}=0.5μm and W_{eff}=10μm, 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:

$$Vsat = 1e5 + 1e\text{-}2/0.5e6 + 2e{-}2/10e{-}6 + 3e\ {-}8/(0.5e\text{-}6 \times 10e{-}6) = 1.28e5$$

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 doing this is described in the *Circuit Simulation* manual. 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 γ_1 is not given, it is calculated by $\gamma_1 = \frac{\sqrt{2q\varepsilon_{si}NDEP}}{C_{oxe}}$

   If γ_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 γ_1 is given, *NDEP* is calculated from $NDEP = \frac{\gamma_1^2 C_{oxe}^2}{2q\varepsilon_{si}}$

   If both γ_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

    $Cgso = DLC \times C_{\text{oxe}} - CGSL$

    if $Cgso < 0.0$, $CGSO = 0.0$

    Else

    $CGSO = 0.6 \times XJ \times C_{\text{oxe}}$

    If *CGDO* is not given, it is calculated by:

    If *DLC* is given and > 0.0)

    $CGDO = DLC \times C_{\text{oxe}} - CGDL$

    if $CGDO < 0.0$, $CGDO = 0.0$

    Else

    $CGDO = 0.6 \times XJ \times C_{\text{oxe}}$

    If *CGBO* is not given, it is calculated by:

    $CGBO = 2 \times DWC \times C_{\text{oxe}}$

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.

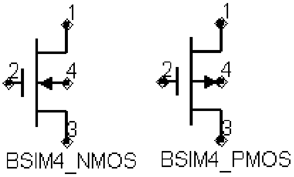
    If Ijthsfwd is not specified and Ijth is specified, Ijthsfwd = Ijth.
    If Ijthsrev is not specified and Ijth is specified, Ijthsrev = Ijth.
    If Ijthdfwd is not specified and Ijth is specified, Ijthdfwd = Ijth.
    If Ijthdrev is not specified and Ijth is specified, Ijthdrev = Ijth.

    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). 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	Unit	Default
Model	model instance name		
Length	channel length	um, mm, cm, meter, mil, in	5.0e-6 m
Width	channel width	um, mm, cm, meter, mil, in	5.0e-6 m
Nf	number of fingers		1.0
Min	minimize either D or S		0
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		1.0
Nrs	number of squares of the source diffusion		1.0
Off	device is initially off		0.0
Rbdb	body resistance		model Rbdb
Rbsb	body resistance		model Rbsb
Rbpb	body resistance		model Rbpb
Rbps	body resistance		model Rbps

Name	Description	Unit	Default
Rbpd	body resistance		model Rbpd
Trnqsmod	transient NQS model selector		model Trnqsmod
Acnqsmod	AC NQS model selector		model Acnqsmod
Rbodymod	distributed model R model selector		model Rbodymod
Rgatemod	gate resistance model selector		model Rgatemod
Geomod	geometry dependent parasitics model selector		model Geomod
Rgeomod	source/drain resistance and contact model selector		model Rgeomod
Temp	device operating temperature	^oC	25
Mode	simulation mode for this device: linear, nonlinear		nonlinear
Noise	noise generation option (yes = 1, no = 0)		yes
_M	number of devices in parallel		1

Notes/Equations

1. Table 5-4 lists the DC operating point parameters that can be sent to the dataset.

Table 5-4. DC Operating Point Information

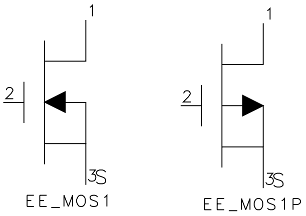
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gmb	Backgate transconductance (dIds/dVbs)	S
Gds	Output conductance (dIds/dVds)	S
Vth	Threshold voltage	V

Table 5-4. DC Operating Point Information (continued)

Name	**Description**	**Units**
Vdsat	Drain-source saturation voltage	V
DqgDvgb	(dQg/dVgb)	F
DqgDvdb	(dQg/dVdb)	F
DqgDvsb	(dQg/dVsb)	F
DqbDvgb	(dQb/dVgb)	F
DqbDvdb	(dQb/dVdb)	F
DqbDvsb	(dQb/dVsb)	F
DqdDvgb	(dQd/dVgb)	F
DqdDvdb	(dQd/dVdb)	F
DqdDvsb	(dQd/dVsb)	F
Vgs	Internal gate-internal source voltage	V
Vds	Internal drain-internal source voltage	V
Vbs	Internal bulk-internal source voltage	V
Vgms	Midgate-source voltage	V
Vges	External gate-source voltage	V
Vdbs	Drain body-internal source voltage	V
Vsbs	Source body-internal source voltage	V

EE_MOS1, EE_MOS1P (EEsof Nonlinear MOSFETs, N-Channel, P-Chanel)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of an EE_MOS1_Model		
Temp	device operating temperature	°C	25.0
Noise	noise generation (yes= 1) (no =0)		1.0
_M	number of devices in parallel		1

Notes/Equations

1. Table 5-5 lists the DC operating point parameters that can be sent to the dataset.

Table 5-5. DC Operating Point Information

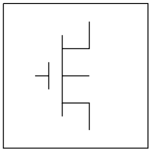
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gds	Output conductance (dIds/dVds)	S
GmAc	Forward transconductance (dIds/dVgs + dIdb/dVgs)	S
GdsAc	Output conductance (dIds/dVds + dIdb/dVgd)	S
dIdb_dVgs	(dIdb/dVgs)	S
dIdb_dVgd	(dIdb/dVgd)	S

Table 5-5. DC Operating Point Information (continued)

Name	**Description**	**Units**
dIdb_dVds	(dIdb/dVds)	S
Cgc	Gate-source capacitance (dQgc/dVgc)	F
Cgy	Gate-drain capacitance (dQgy/dVgy)	F
Cds	Drain-source capacitance	F
dQgc_dVgy	(dQgc/dVgy)	F
dQgy_dVgc	(dQgy_dVgc)	F
Vgs	Gate-source voltage	V
Vds	Gate-drain voltage	V

EE_MOS1_Model (EEsof Nonlinear MOSFET Model)

Symbol



Parameters

Name	Description	Unit	Default
Is	reverse saturation current	A	10^{-14}
N	junction ideality factor		1.0
Cdso	zero-bias output capacitance	F	0.0
Vbi	diode built-in potential	V	0.7
Mj	junction grading coefficient		0.5
Fc	depletion capacitance linearization point		10^{-4}
Vbr	drain-source voltage where breakdown current begins conducting	V	10^{-4}
Kbo	breakdown current coefficient		10^{-4}
Nbr	breakdown current exponent		2.0
Vinfl	inflection point in Cgs-Vgs characteristic	V	5.0
Deltds	linear region to saturation region transition	V	1.0
Deltgs	Cgs-Vgs transition voltage	V	1.0
Cgsmax	maximum value of Cgs	F	10^{-12}
Cgso	constant portion of gate-source capacitance	F	10^{-13}
Cgdo	constant portion of gate-drain capacitance	F	10^{-13}
Vgo	gate-source voltage where transconductance is a maximum	V	7.0
Vto	zero bias threshold voltage	V	1.0
Gamma	vds dependent threshold	1/V	0.0
Gmmax	peak transconductance	S	10×10^{-3}
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

Name	**Description**	**Unit**	**Default**
Vsatm	maximum value of saturation voltage	V	10.0
Vgm	gate-source voltage where saturation voltage is Vsatm	V	5.0
Rdb	dispersion source output impedance	ohms	10^9
Cbs	dispersion source capacitance	F	1.6×10^{-13}
Gmmaxac	ac value of Gmmax	S	60×10^{-3}
Deltac	ac value of Delt	V	2.0
Vbreakac	ac value of Vbreak	V	4.0
Vgoac	ac value of Vgo	V	7
Lambdaac	ac value of Lambda	1/V	0.0
Vsatmac	maximum value of saturation voltage (ac)	V	10.0
Vgmac	gate-source voltage where saturation voltage is Vsatm (ac)	V	5.0
Gdbm	additional d-b branch conductance at Vdsm	S	0.0
Kdb	controls Vds dependence of D-B branch conductance		0.0
Vdsm	voltage where D-B branch conductance becomes constant	V	1.0
Rd	drain contact resistance	ohms	1.0
Rs	source contact resistance	ohms	1.0
Rg	gate metallization resistance	ohms	1.0
Ris	source end channel resistance	ohms	1.0
Rid	drain end channel resistance	ohms	1.0
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
AllParams	DataAccessComponent-based parameters		

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). 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].

$$I_{ds} = I_{dso}(1 + Lambda \times V_{ds})\tanh\left(\frac{3V_{ds}}{V_{sat}}\right)$$

$$g_{m} = \left[g_{mo}\tanh\left(\frac{3V_{ds}}{V_{sat}}\right) - I_{dso}\operatorname{sech}^{2}\left(\frac{3V_{ds}}{V_{sat}}\right) \times \left[\frac{3V_{ds}}{V_{sat}^{2}}\frac{\partial V_{sat}}{\partial V_{gs}}\right]\right]$$
$$\times (1 + Lambda \times V_{ds})$$

$$g_{ds} = \{g_{dso}(1 + Lambda \times V_{ds}) + I_{dso}Lambda\}\tanh\left(\frac{3V_{ds}}{V_{sat}}\right)$$
$$+ I_{dso} \times \frac{3\left(V_{sat} - V_{ds}\frac{\partial V_{sat}}{\partial V_{ds}}\right)(1 + Lambda \times V_{ds})}{V_{sat}^{2}}\operatorname{sech}^{2}\left(\frac{3V_{ds}}{V_{sat}}\right)$$

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 illustrated in Figure 5-1.

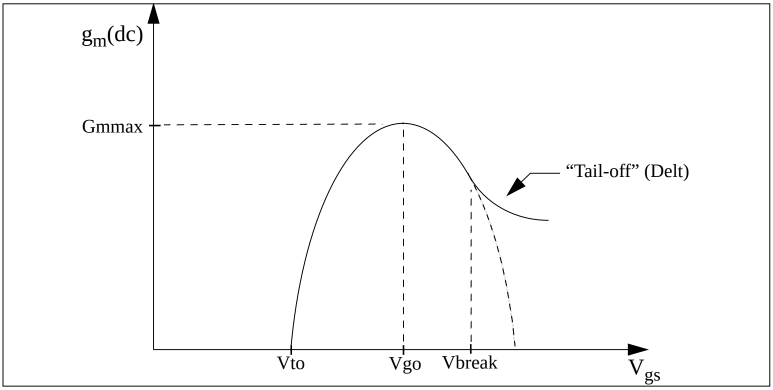


Figure 5-1. EEMOS1 g_m-V_{gs} Parameters

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 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 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 $V_{ds} \leq$ Vbr

$$I_{bkdn}(V_{ds}) = 0$$

Total current flowing through the substrate (body) diode from source to drain is given by:

$$I_{sub}(V_{ds}) = I_{for}(V_{ds}) - I_{bkdn}(V_{d}$$

Noise Model

Thermal noise generated by resistors Rg, Rs, Rd, Ris, Rid, and Rdb is characterized by the following spectral density.

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

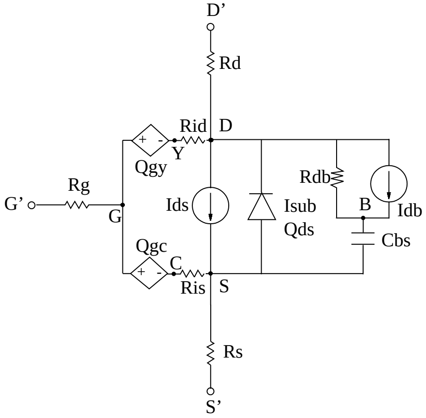
Channel noise generated by the DC transconductance g_m is characterized by the following spectral density:

$$\frac{< i_{ds}^2 >}{\Delta f} = \frac{8kTg_m}{3}$$

In the preceding expressions, k is Boltzmann's constant, T is the operating temperature in Kelvin, q is the electron charge, and Δf 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

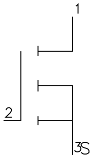
[1] W. R. Curtice, “A MESFET model for use in the design of GaAs integrated circuits,” *IEEE Transactions of Microwave Theory and Techniques*, Vol. MTT-28, pp. 448-456, May 1980.

[2] 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.

HP_MOS (HP_Root MOS Transistor)

Symbol



Parameters

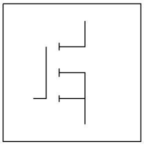
Name	Description	Default
Model	name of an EE_MOS_Model	
Wtot	number of gate fingers	10^{-4}
N	numer of gate fingers	1
_M	number of devices in parallel	1

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.

HP_MOS_Model (HP_Root MOS Transistor Model))

Symbol



Parameters

File = name of rawfile

Rs = source resistance

Rg = gate resistance

Rd = drain resistance

Ls = source inductance

Lg = gate inductance

Ld = drain inductance

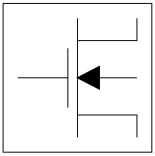
AllParams = DataAccessComponent-based parameters

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). 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 HP Root Model references, refer to "HP_Diode_Model (HP_Root Diode Model)" on page 1-26.

LEVEL1_Model (MOSFET Level-1 Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NMOS	N-channel model		yes
PMOS	P-channel model		no
Idsmod	IDS model		1
Capmod	capacitance model selector		1
Vto†	zero-bias threshold voltage	V	0.0
Kp†	transconductance coefficient	A/m^2	2×10^{-5}
Gamma	bulk threshold	$\sqrt{V}$	0.0
Phi†	surface potential	V	0.6
Lambda	channel-length modulation parameter	1/V	0.0
Rd	drain ohmic resistance	ohms	0.0
Rs	source ohmic resistance	ohms	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	10^{-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

† Parameter value varies with temperature based on model Tnom and device Temp.

†† Value of 0.0 is interpreted as infinity.

Name	Description	Unit	Default
Rsh	drain and source diffusion sheet resistance	ohms/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		0.5
Cjsw†	zero-bias bulk junction periphery capacitance per meter of junction perimeter	F/m	0.0
Mjsw	bulk junction periphery grading coefficient		0.33
Js†	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	10^{-7}
Nsub	substrate (bulk) doping density	$1/Cm^3$	0.0
Nss	surface state density	$1/Cm^2$	0.0
Tpg	gate material type: 0 = aluminum; –1 = same as bulk; 1 = opposite to bulk		1
Ld	lateral diffusion length	m	0.0
Uo†	surface mobility	$Cm^2/(V \times S)$	600.0
Nlev	noise model level		-1
Gdsnoi	drain noise parameters for Nlev=3		1
Kf	flicker-noise coefficient		0.0
Af	flicker-noise exponent		1.0
Fc	bulk junction forward-bias depletion capacitance coefficient		0.5
Rg	gate ohmic resistance	ohms	0.0
Rds	drain-source shunt resistance	ohms	infinity††
Tnom	nominal ambient temp. at which model parameters were derived	°C	25
Trise	temperature rise above ambient	°C	0
N	bulk P-N emission coefficient		1.0
Tt	bulk P-N transit time	sec	0.0
Ffe (Ef)	flicker noise frequency exponent		1.0
Imax	explosion current	A	10.0

† Parameter value varies with temperature based on model Tnom and device Temp.

†† Value of 0.0 is interpreted as infinity.

Name	Description	Unit	Default
Imelt	(similar to Imax; refer to Note 10)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
Acm	area calculation method		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		1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	ohms	0.0
Rsc	additional source resistance due to contact resistance	ohms	0.0
AllParams	DataAccessComponent-based parameters		

† 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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch1 MOSFET Idsmod=1 \
  Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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:

   $$\text{Cbd} = \text{Cj} \times \text{Ad}, \quad \text{Cbs} = \text{Cj} \times \text{As}$$

   If Js > 0.0 and Ad > 0.0 and As > 0.0, then Is for drain and source will be calculated:

   $$\text{Is(drain)} = \text{Js} \times \text{Ad}, \quad \text{Is(source)} = \text{Js} \times \text{As}$$

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:

   $$Rd = Rsh \times Nrd, \quad Rs = Rsh \times Nrs$$

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). 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:

$$\frac{<i_{ds}^2>}{\Delta f} = \frac{8kTg_m}{3} + \mathrm{k}_f \frac{I_{DS}^{a_f}}{f^{f_{fe}}}$$

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 Δf is noise bandwidth.

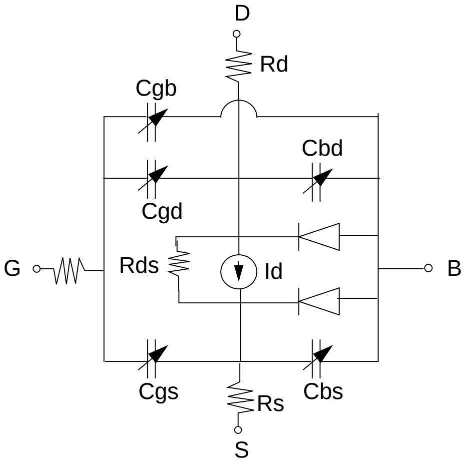
References

[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.

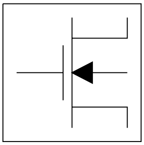
[3] P. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE*, New York: McGraw-Hill, Second Edition 1993.

Equivalent Circuit



LEVEL2_Model (MOSFET Level-2 Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	**Description**	**Unit**	**Default**
NMOS	N-channel model		yes
PMOS	P-channel model		no
Idsmod	IDS model		2
Capmod	capacitance model selector		1
Vto†	zero-bias threshold voltage	V	0.0
Kp†	transconductance coefficient	A/V^2	2×10^{-5}
Gamma	bulk threshold parameter	$\sqrt{V}$	0.0
Phi†	surface potential	V	0.6
Lambda	channel-length modulation parameter	1/V	0.0
Rd	drain ohmic resistance	ohms	0.0
Rs	source ohmic resistance	ohms	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	10^{-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	ohms/sq	0.0

† 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.

Name	Description	Unit	Default
Cj[†]	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0[††]
Mj	bulk junction bottom grading coefficient		0.5
Cjsw[†]	zero-bias bulk junction periphery capacitance per meter of junction perimeter	F/m	0.0
Mjsw	bulk junction periphery grading coefficient		0.33
Js[†]	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	10^{-7}
Nsub	substrate (bulk) doping density	1/Cm^3	0.0
Nss	surface state density	1/Cm^2	0.0
Nfs	fast surface state density	1/Cm^2	0.0
Tpg	gate material type: 0 = aluminum; –1 = same as bulk; 1 = opposite to bulk		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	10^4
Uexp	critical field exponent in mobility degradation		0.0
Vmax	carriers maximum drift velocity	m/s	0.0
Neff	total channel charge coefficient		1.0
Xqc (Xpart)	fraction of channel charge attributed to drain		1.0
Nlev	noise model level		-1
Gdsnoi	drain noise parameters for Nlev=3		1
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Fc	bulk junction forward-bias depletion capacitance coefficient		0.5
Delta	width effect on threshold voltage		0.0
Rg	gate ohmic resistance	ohms	0.0

[†] 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.

Name	**Description**	**Unit**	**Default**
Rds	drain-source shunt resistance	ohms	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		1.0
Tt	bulk P-N transit time	sec	0.0
Ffe (Ef)	flicker noise frequency exponent		1.0
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 10)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
Acm	area calculation method		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		1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	ohms	0.0
Rsc	additional source resistance due to contact resistance	ohms	0.0
AllParams	DataAccessComponent-based parameters		

† 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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch2 MOSFET Idsmod=2 \
  Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

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:

   $Cbd = Cj \times Ad, \quad Cbs = Cj \times As$

   If Js > 0.0 and Ad > 0.0 and As > 0.0, then Is for drain and source will be calculated:

   $Is(drain) = Js \times Ad, \quad Is(source) = Js \times As$
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:

   $Rd = Rsh \times Nrd, \quad Rs = Rsh \times Nrs$
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 $Xqc \leq 0.5$. 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). 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:

$$Cbd^{NEW} = Cbd\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cbs^{NEW} = Cbs\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cj^{NEW} = Cj\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cjsw^{NEW} = Cjsw\left[\frac{1 + Mjsw[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mjsw[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

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:

$$\frac{< i_{ds}^{2} >}{\Delta f} = \frac{8 k T g_m}{3} + \mathrm{k}_f \frac{I_{DS}^{a_f}}{f^{f_{fe}}}$$

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

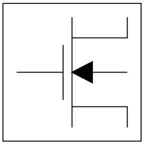
[1] Vladimirescu and S. Liu. The Simulation of MOS Integrated Circuits Using SPICE2, Memorandum No. M80/7, February 1980.

[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	Unit	Default
NMOS	N-channel model		yes
PMOS	P-channel model		no
Idsmod	IDS model		3
Capmod	capacitance model selector		1
Vto†	zero-bias threshold voltage	V	0.0
Kp†	transconductance coefficient	A/V^2	2×10^{-5}
Gamma	bulk threshold	$\sqrt{V}$	0.0
Phi†	surface potential	V	0.6
Rd	drain ohmic resistance	ohms	0.0
Rs	source ohmic resistance	ohms	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	10^{-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	ohms/sq	0.0

† Parameter value varies with temperature based on Tnom of model and Temp of device.

†† Value of 0.0 is interpreted as infinity.

Name	**Description**	**Unit**	**Default**
Cj†	zero-bias bulk junction bottom capacitance per square meter of junction area	F/m^2	0.0
Mj	bulk junction bottom grading coefficient		0.5
Cjsw†	zero-bias bulk junction periphery capacitance per meter of junction perimeter	F/m	0.0
Mjsw	bulk junction periphery grading coefficient		0.33
Js†	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	10^{-7}
Nsub	substrate (bulk) doping density	$1/cm^3$	0.0
Nss	surface state density	$1/cm^2$	0.0
Nfs	fast surface state density	$1/cm^2$	0.0
Tpg	gate material type: 0=aluminum; –1=same as substrate; 1=opposite substrate		1
Xj	metallurgical junction depth	m	0.0
Ld	lateral diffusion length	m	0.0
Uo†	surface mobility	$cm^2/(V \times s)$	600.0
Vmax	carriers maximum drift velocity	m/s	0.0
Xqc (Xpart)	coefficient of channel charge share		1.0
Nlev	noise model level		-1
Gdsnoi	drain noise parameters for Nlev=3		1
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Fc	bulk junction forward-bias depletion capacitance coefficient		0.5
Delta	width effect on threshold voltage		0.0
Theta	mobility modulation	1/V	0.0
Eta	static feedback		0.0
Kappa	saturation field factor		0.2
Rg	gate ohmic resistance	ohms	0.0

† Parameter value varies with temperature based on Tnom of model and Temp of device.

†† Value of 0.0 is interpreted as infinity.

Name	Description	Unit	Default
Rds	drain-source shunt resistance	ohms	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		1.0
Tt	bulk P-N transit time	sec	0.0
Ffe (Ef)	flicker noise frequency exponent		1.0
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 8)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
Acm	area calculation method		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		1.0
Xw	accounts for masking and etching effects	m	0.0
Rdc	additional drain resistance due to contact resistance	ohms	0.0
Rsc	additional source resistance due to contact resistance	ohms	0.0
AllParams	DataAccessComponent-based parameters		

† 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 the *Design Kit Development book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch3 MOSFET Idsmod=3 \
  Kp=4e-5 Vto=0.7 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

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:

   $$\text{Cbd} = \text{Cj} \times \text{Ad} \qquad \text{Cbs} = \text{Cj} \times \text{As}$$

   If Js>0.0 and Ad>0.0 and As>0.0, Is for drain and source will be calculated:

   $$\text{Is(drain)} = \text{Js} \times \text{Ad} \qquad \text{Is(source)} = \text{Js} \times \text{As}$$

   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:

   $$\text{Rd} = \text{Rsh} \times \text{Nrd} \qquad \text{Rs} = \text{Rsh} \times \text{Nrs}$$

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). 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:

$$Cbd^{NEW} = Cbd\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cbs^{NEW} = Cbs\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cj^{NEW} = Cj\left[\frac{1 + Mj[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mj[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

$$Cjsw^{NEW} = Cjsw\left[\frac{1 + Mjsw[4\times10^{-4}(Temp - T_{REF}) - \gamma^{Temp}]}{1 + Mjsw[4\times10^{-4}(Tnom - T_{REF}) - \gamma^{Temp}]}\right]$$

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 Δf is the noise bandwidth.

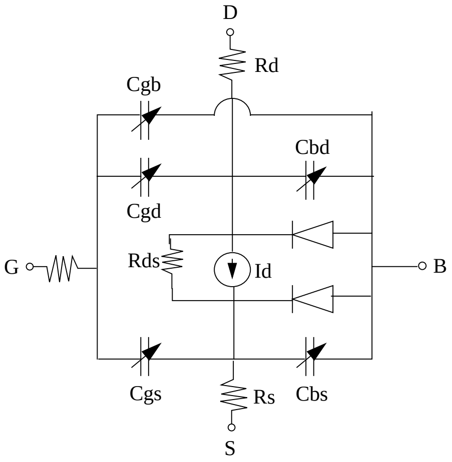
References

[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.

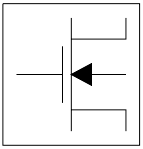
[3] P. Antognetti and G. Massobrio. *Semiconductor device modeling with SPICE*, New York: McGraw-Hill, Second Edition 1993.

Equivalent Circuit



LEVEL3_MOD_Model (Level-3 NMOD MOSFET Model)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	Description	Unit	Default
NMOS	N-channel model		yes
PMOS	P-channel model		no
Idsmod	IDS model		6
Capmod	capacitance model selector		1
Vto†	zero-bias threshold voltage	V	0.0
Kp†	transconductance coefficient	A/V^2	0.0
Gamma	bulk threshold parameter	$\sqrt{V}$	0.0
Gamma2	bulk threshold parameter deep in substrate	$\sqrt{V}$	0.0
Zeta	mobility modulation with substrate bias parameter		0.0
Phi†	surface potential	V	0.6
Rd	drain ohmic resistance	ohms	0.0
Rs	source ohmic resistance	ohms	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	10^{-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

† Parameter value varies with temperature based on Tnom of model and Temp of device.

†† Value of 0.0 is interpreted as infinity.

Name	Description	Unit	Default
Rsh	drain and source diffusion sheet resistance	ohms/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		0.5
Cjsw†	zero-bias bulk junction periphery capacitance perimeter of junction perimeter	F/m	0.0
Mjsw	bulk junction periphery grading coefficient		0.33
Js†	bulk junction saturation current per square meter of junction area	A/m^2	0.0
Tox	oxide thickness	m	10^{-7}
Nsub	substrate (bulk) doping density	1/cm^3	0.0
Nss	surface state density	1/cm^2	0.0
Nfs	fast surface state density	1/cm^2	0.0
Tpg	gate material type: 0=aluminum; -1=same as substrate; 1=opposite substrate		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	10^{-4}
Uexp	field exponent in mobility degradation		0.0
Vmax	carriers maximum drift velocity	m/s	0.0
Xqc (Xpart)	coefficient of channel charge share		1.0
Kf	flicker noise coefficient		0.0
Af	flicker noise exponent		1.0
Fc	bulk junction forward-bias depletion cap. coefficient		0.5
Delta	width effect on threshold voltage		0.0
Theta	mobility modulation	1/V	0.0
Eta	static feedback		0.0
Kappa	saturation field factor		0.2

† Parameter value varies with temperature based on Tnom of model and Temp of device.

†† Value of 0.0 is interpreted as infinity.

Name	Description	Unit	Default
Kappag	field correction factor gate drive dependence		0.0
Xmu	subthreshold fitting model parameter for NMOD		1.0
Rg	gate resistance	ohms	0.0
Rds	drain-source shunt resistance	ohms	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		1.0
Tt	bulk P-N transit time	sec	0.0
Ffe (Ef)	flicker noise frequency exponent		1.0
Imax	explosion current	A	10.0
Imelt	(similar to Imax; refer to Note 2)	A	10.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
AllParams	DataAccessComponent-based parameters		

[†] 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).

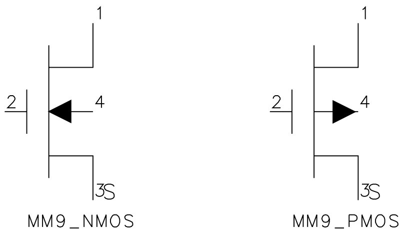
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

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	Unit	Default
Model	name of a MOS_Model9		
Length	channel length, in length units		10^{-4}
Width	channel width, in length units		10^{-4}
Ab	diffusion area		10^{-12}
Ls	length of sidewall not under gate, in length units		10^{-4}
Lg	length of sidewall under gate, in length units		10^{-4}
Region	dc operating region: off, on, rev, sat		on
Temp (Ta)	device operating temperature	°C	25
Trise	temperature rise above ambient	°C	0
Mult	number of devices in parallel		1
Mode	device simulation mode: nonlinear, linear		nonlinear
_M	number of devices in parallel		1

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.semiconductors.com/Philips_Models/documentation/mosmodel9

3. Table 5-6 lists the DC operating point parameters that can be sent to the dataset.

Table 5-6. DC Operating Point Information

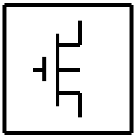
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
Gid_ds	(dId/dVds)	S
Gid_gs	(dId/dVgs)	S
Gid_sb	(dId/dVsb)	S
Gib_ds	(dIb/dVds)	S
Gib_gs	(dIb/dVgs)	S
Gib_sb	(dIb/dVsb)	S
Gis_ds	(dIs/dVds)	S
Gis_gs	(dIs/dVgs)	S
Gis_sb	(dIs/dVsb)	S
Cg_ds	(dQg/dVds)	F
Cg_gs	(dQg/dVgs)	F
Cg_sb	(dQg/dVsb)	F
Cb_ds	(dQb/dVds)	F
Cb_gs	(dQb/dVgs)	F
Cb_sb	(dQb/dVsb)	F
Cs_ds	(dQs/dVds)	F
Cs_gs	(dQs/dVgs)	F
Cs_sb	(dQs/dVsb)	F

Table 5-6. DC Operating Point Information (continued)

Name	Description	Units
Cd_ds	(dQd/dVds)	F
Cd_gs	(dQd/dVgs)	F
Cd_sb	(dQd/dVsb)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V

MM30_Model (Philips MOS Model 30)

Symbol



Parameters

Name	Description	Unit	Default
NMOS	NMOS Model Type; yes, no		yes
PMOS	PMOS Model Type; yes, no		no
Ron	ohmic resistance at zero-bias	ohms	1.0
Rsat	space charge resistance at zero-bias	ohms	1.0
Vsat	critical drain-source voltage for hot carrier	volts	10.0
Psat	velocity saturation coefficient		1.0
Vp	pinchoff voltage at zero gate and substrate voltages	volts	-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	volts	0.6
Cgate	gate capacitance at zero-bias	farads	0.0
Csub	substrate capacitance at zero-bias	farads	0.0
Tausc	space charge transit time of the channel	farads	0.0
Tref (Tr, Tnom)	reference temperature	°C	25.0
Trise	temperature rise above ambient	°C	0
Vgap	bandgap voltage channel	volts	1.2
Ach	temperature coefficient resistivity of the channel		0.0
AllParams	Data Access Component (DAC) based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch9 MOS30 \
  Ron=5 Dsub=3e15 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

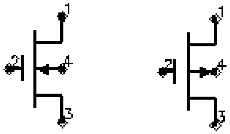
---

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 Philips report *The MOS model, level 3002*. The *pdf* file MOSModel 30.02 is downloadable at the following web site:

   http://www.semiconductors.com/Philips_Models/documentation/add_models/

MM30_NMOS, MM30_PMOS (Philips MOS Model 30, NMOS, PMOS)

Symbol



Parameters

Name	Description	Unit	Default
Model	model instance name (can be file-based)		
Temp	temperature	°C	25.0
Trise	temperature rise above ambient	°C	0
Mult	multiplication factor		1.0
_M	number of devices in parallel		1

1. Table 5-7 lists the DC operating point parameters that can be sent to the dataset.

Table 5-7. DC Operating Point Information

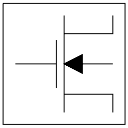
Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
gds_s	(dIds/dVs)	S
gds_d	(dIds/dVd)	S
gds_g	(dIds/dVg)	S
gds_b	(dIds/dVb)	S
cgs_s	(dQgs/dVs)	F
cgs_d	(dQgs/dVd)	F
cgs_g	(dQgs/dVg)	F
cgs_b	(dQgs/dVb)	F

Table 5-7. DC Operating Point Information (continued)

Name	Description	Units
cgd_s	(dQgd/dVs)	F
cgd_d	(dQgd/dVd)	F
cgd_g	(dQgd/dVg)	F
cgd_b	(dQgd/dVb)	F
cbs_s	(dQbs/dVs)	F
cbs_d	(dQbs/dVd)	F
cbs_g	(dQbs/dVg)	F
cbs_b	(dQbs/dVb)	F
cbd_s	(dQbd/dVs)	F
cbd_d	(dQbd/dVd)	F
cbd_g	(dQbd/dVg)	F
cbd_b	(dQbd/dVb)	F
cds_s	(dQds/dVs)	F
cds_d	(dQds/dVd)	F
cds_g	(dQds/dVg)	F
cds_b	(dQds/dVb)	F
Qgs	Gate-source charge	C
Qgd	Gate-drain charge	C
Qbs	Bulk-source charge	C
Qbd	Bulk-drain charge	C
Qds	Drain-source charge	C
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V

MOS_Model9_Process (Philips MOS Model 9, Process Based)

Symbol



Parameters

Model parameters must be specified in SI units.

Name	**Description**	**Units**	**Default**
NMOS	N-channel type MOSFET		yes
PMOS	P-channel type MOSFET		no
Type	process-based model type		2
Ler	effective channel length of reference transistor	m	10^{-4}
Wer	effective channel width of reference transistor	m	10^{-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	m	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	$\sqrt{V}$	0.74368
Slko	coefficient of length dependence of Ko	$\sqrt{V} \times m$	0.0

Name	Description	Units	Default
Swko	coefficient of width dependence of Ko	$\sqrt{\ } V\times m$	0.0
Kr	high back-bias body factor	$\sqrt{\ } V$	0.55237
Slk	coefficient of length dependence of K	$\sqrt{\ } V\times m$	0.0
Swk	coefficient of width dependence of K	$\sqrt{\ } V\times m$	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	$V\times m$	0.0
Swvsbx	coefficient of width dependence of Vsbx	$V\times m$	0.0
Betsq	gain factor	A/V^2	0.12069×10^{-3}
Etabet	exponent of temperature dependence of gain factor		0.0
The1r	coefficient of mobility due to gate-induced field	1/V	0.99507×10^{-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		0.0
The2r	coefficient of mobility due to back-bias	$\sqrt{\ } V$	0.43225×10^{-1}
Stthe2r	coefficient of temperature dependence of The2	$\sqrt{\ }\varsigma/K$	0.0
Slthe2r	coefficient of length dependence of The2	$m/\sqrt{\ } V$	0.0
Stlthe2	coefficient of temperature dependence of length dependence of The2	$m/\sqrt{\ } V/K$	0.0
Swthe2	coefficient of width dependence of The2	$m/\sqrt{\ } V)$	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

Name	Description	Units	Default
Swthe3	coefficient of width dependence of The3	m/V	0.0
Gam1r	coefficient for drain-induced threshold shift for large gate drive	$V^{(1-Etads)}$	0.38096×10^{-2}
Slgam1	coefficient of length dependence of Gam1	$V^{(1-Etads)}m$	0.0
Swgam1	coefficient of width dependence of Gam1	$V^{(1-Etads)}m$	0.0
Etadsr	exponent of Vds dependence of Gam1		0.6
Alpr	factor of channel-length modulation		0.1×10^{-1}
Etaalp	exponent of length dependence of Alp		0.0
Slalp	coefficient of length dependence of Alp	$m^{(Etaalp)}$	0.0
Swalp	coefficient of width dependence of Alp	m	0.0
Vpr	characteristic voltage of channel length modulation	V	0.67876×10^{1}
Gamoor	coefficient of drain-induced threshold shift at zero gate drive		0.29702×10^{-4}
Slgamoo	coefficient of length dependence of Gamo	m^2	0.0
Etagamr	exponent of back-bias dependence of Gamo		2.0
Mor	factor of subthreshold slope		0.44
Stmo	coefficient of temperature dependence of Mo	1/K	0.0
Slmo	coefficient of length dependence of Mo	$\sqrt{m}$	0.0
Etamr	exponent of back-bias dependence of M		2.0
Zet1r	weak-inversion correction factor		0.2015×10^{1}
Etazet	exponent of length dependence of Zet1		0.0
Slzet1	coefficient of length dependence of Zet1	$m^{(Etazet)}$	0.0
Vsbtr	limiting voltage of VSB dependence of M and Gamo	V	0.61268×10^{1}
Slvsbt	coefficient of length dependence of Vsbt	$m\times V$	0.0
A1r	factor of weak-avalanche current		0.20348×10^{2}
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	0.33932×10^{2}

Name	Description	Units	Default
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		0.10078×10^{1}
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	10^{-6}
Col	gate overlap per unit channel width	F/m	0.0
Ntr	coefficient of thermal noise	J	0.0
Nfmod	noise model selector		0
Nfr	coefficient of flicker noise	V^2	0.0
Nfar	first coefficient of flicker noise (Nfmod=1)	1/V×m	
Nfbr	second coefficient of flicker noise (Nfmod=1)	$1/V\times m^2$	
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	10^{-14}
Jsdbr	bottom saturation current density due to diffusion from back contact	A/m^2	10^{-14}
Jsgsr	sidewall saturation current density due to electron-hole generation at V=Vr	A/m	10^{-14}
Jsdsr	sidewall saturation current density due to diffusion from back contact	A/m	10^{-14}
Jsggr	gate edge saturation current density due to electron-hole generation at V=Vr	A/m	10^{-14}
Jsdgr	gate edge saturation current density due to diffusion from back contact	A/m	10^{-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

Name	Description	Units	Default
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		0.5
Ps	sidewall-junction grading coefficient		0.5
Pg	gate-edge-junction grading coefficient		0.5
Nb	emission coefficient of bottom forward current		1.0
Ns	emission coefficient of sidewall forward current		1.0
Ng	emission coefficient of gate-edge forward current		1.0
wVsubfwd	substrate junction forward bias warning	V	
wBvsub	substrate junction reverse breakdown voltage warning	V	
wBvg	gate oxide breakdown voltage warning	V	
wBvds	drain-source breakdown voltage warning	V	
wIdsmax	maximum drain-source current warning	A	
wPmax	maximum power dissipation warning	W	
The3Clipping	flag for The3 clipping: no, yes		no
AllParams	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch10 MOS9 \
  Vtor=0.7 Etabetr=0.4 NMOS=yes
```

Notes/Equations/References

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

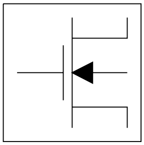
---

1. This model supplies values for an MM9 device.
2. Information about this model is available at

   http://www.semiconductors.philips.com/Philips_Models/mos_models/model9/index.html
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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

Model parameters must be specified in SI units.

Name	Description	Units	Default
NMOS	N-channel type MOSFET		yes
PMOS	P-channel type MOSFET		no
Type	single device type		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	0.12069×10^{-3}
The1	coefficient of mobility reduction due to gate-induced field	1/V	0.99507×10^{-1}
The2	coefficient of mobility reduction due to back-bias	$V^{(1/2)}$	0.43225×10^{-1}
The3	coefficient of mobility reduction due to lateral field	1/V	0.0
Gam1	coefficient for drain-induced threshold shift for large gate drive	$V^{(1-Etads)}$	0.38096×10^{-2}
Etads	exponent of VDS dependence of Gam1		0.6
Alp	factor of channel-length modulation		0.1×10^{-1}
Vp	characteristic voltage of channel length modulation	V	0.67876×10^{1}
Gamoo	coefficient of drain-induced threshold shift at zero gate drive		0.29702×10^{-4}
Etagam	exponent of back-bias dependence of Gamo		2.0
Mo	factor of subthreshold slope		0.44

Name	**Description**	**Units**	**Default**
Etam	exponent of back-bias dependence of M		2.0
Zet1	weak-inversion correction factor		0.20153×10^{1}
Vsbt	limiting voltage of vsb dependence of M and Gamo	V	$0.61268 \times 10^{+1}$
A1	factor of weak-avalanche current		0.20348×10^{2}
A2	exponent of weak-avalanche current	V	0.33932×10^{2}
A3	factor of drain-source voltage above which weak-avalanche occurs		0.10078×10^{1}
Cox	gate-to-channel capacitance	F	10^{-12}
Cgdo	gate-drain overlap capacitance	F	10^{-12}
Cgso	gate-source overlap capacitance	F	10^{-12}
Nt	coefficient of thermal noise	J	0.0
Nfmod	noise model selector		0
Nf	coefficient of flicker noise (Nfmod=0)		0.0
Nfa	first coefficient of flicker noise (Nfmod=1)	1/V×m	
Nfb	second coefficient of flicker noise (Nfmod=1)	$1/V \times m^{2}$	
Nfc	third coefficient of flicker noise (Nfmod=1)	1/V	0.0
Isgb	generation saturation current of bottom area AB	A	10^{-14}
Isdb	diffusion saturation current of bottom area AB	A	10^{-14}
Isgs	generation saturation current of locos-edge LS	A	10^{-14}
Isds	diffusion saturation current of locos-edge LS	A	10^{-14}
Isgg	generation saturation current of gate-edge LG	A	10^{-14}
Isdg	diffusion saturation current of gate-edge LG	A	10^{-14}
Cjb	bottom junction capacitance	F	10^{-15}
Cjs	sidewall junction capacitance	F	10^{-15}
Cjg	gate edge junction capacitance	F	10^{-15}
Vdb	diffusion voltage of bottom area Ab	V	1.0
Vds	diffusion voltage of Locos-edge Ls	V	1.0
Vdg	diffusion voltage of gate edge Lg	V	1.0

Name	Description	Units	Default
Pb	bottom-junction grading coefficient		0.8
Ps	sidewall-junction grading coefficient		0.8
Pg	gate-edge-junction grading coefficient		0.8
Nb	emission coefficient of bottom forward current		1.0
Ns	emission coefficient of sidewall forward current		1.0
Ng	emission coefficient of gate-edge forward current		1.0
wVsubfwd	substrate junction forward bias (warning)	V	infinite
wBvsub	substrate junction reverse breakdown voltage (warning)	V	infinite
wBvg	gate oxide breakdown voltage (warning)	V	infinite
wBvds	drain-source breakdown voltage (warning)	V	infinite
wIdsmax	maximum drain-source current (warning)	A	infinite
wPmax	maximum power dissipation (warning)	W	infinite
The3Clipping	flag for The3 clipping		no
AllParams	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model  Nch11 MOS9 \
  Vtor=0.7 Etabet=0.4 NMOS=yes
```

Notes/Equations/References

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

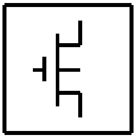
---

1. This model supplies values for an MM9 device.
2. Information about this model is available at

   http://www.semiconductors.philips.com/Philips_Models/mos_models/model9/index.html
3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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	NMOS type MOS11		yes
PMOS	PMOS type MOS11		no
Tr (Tref, Tnom)	Temperature at which the parameters for the reference transistor have been determined	°C	25
Dta (Trise)	Temperature offset of the device with respect to Ta	K	0
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
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) 3.814e-4 (pmos)
Etabet	Exponent of the temperature dependence of the gain factor		1.3 (nmos) 0.5 (pmos)
Thesrr	Coefficient of the mobility reduction due to surface roughness scattering for the reference transistor at the reference temperature	V^{-1}	0.4
Etasr	Exponent of the temperature dependence of THESR for the reference transistor		0.65 (nmos) 0.5 (pmos)
Theph	Coefficient of the mobility reduction due to phonon scattering	V^{-1}	1.29e-2 (nmos) 1.0e-3 (pmos)

Parameter	**Description**	**Units**	**Default**
Etaph	Exponent of the temperature dependence of THESR for the reference transistor		1.35 (nmos) 3.75 (pmos)
Etamob	Effective field parameter for dependence on depletion/inversion charge		1.4 (nmos) 3.0 (pmos)
Stetamob	Coefficient of the temperature dependence of ETAMOB	K^{-1}	0
Nu	Exponent of the field dependence of the mobility model minus 1 at the reference temperature		2.0
Nuexp	Exponent of the temperature dependence of NU		5.25 (nmos) 3.23 (pmos)
Ther	Coefficient of the series resistance	V^{-1}	8.12e-2 (nmos) 7.9e-2 (pmos)
Etar	Exponent of the temperature dependence of ETA		0.95 (nmos) 0.4 (pmos)
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Thesat	Velocity saturation parameter due to optical/acoustic phonon scattering	V^{-1}	0.5 (nmos) 0.2 (pmos)
Etasat	Exponent of the temperature dependence of THESAT		1.04 (nmos) 0.86 (pmos)
Theth	Coefficient on self-heating	V^{-3}	1.0e-5 (nmos) 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		0
Ssf	Static feedback parameter	$V^{-1/2}$	0.012 (nmos) 0.010 (pmos)
Alp	Factor of the channel-length modulation		0.025
Vp	Characteristic voltage of channel length modulation	V	0.05
Mexp	Smoothing factor for the actual transistor		5.0
A1	Factor of the weak-avalanche current		6.0221 (nmos) 6.8583 (pmos)
Sta1	Coefficient of the temperature dependence of A1	K^{-1}	0

Parameter	Description	Units	Default
A2	Exponent of the weak-avalanche current	V	38.017 (nmos) 57.324 (pmos)
A3	Factor of the drain-source voltage above which weak-avalanche occurs		0.6407 (nmos) 0.4254 (pmos)
Iginv	Gain factor for intrinsic gate tunneling current in inversion	A/V^2	0
Binv	Probability factor for intrinsic gate tunneling current in inversion	V	48.0 (nmos) 87.5 (pmos)
Igacc	Gain factor for intrinsic gate tunneling current in accumulation	A/V^2	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
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
Cox	Gate-to-channel capacitance	F	2.980e-14 (nmos) 2.717e-14 (pmos)
Cgdo	G-D overlap capacitance	F	6.392e-15 (nmos) 6.358e-15 (pmos)
Cgso	G-S overlap capacitance	F	6.392e-15 (nmos) 6.358e-15 (pmos)
Gatenoise	Flag for in/exclusion of induced gate thermal noise		no
Nt	Coefficient of the thermal noise at the actual temperature	J	1.656e-20
Nfa	First coefficient of the flicker noise	$V^{-1}*m^{-1}$	8.323e+22 (nmos) 1.900e+22 (pmos)
Nfb	Second coefficient of the flicker noise	$V^{-1}*m^{-2}$	2.514e+7 (nmos) 5.043e+6 (pmos)
Nfc	Second coefficient of the flicker noise	$V^{-1}*m^{-2}$	0 (nmos) 3.627e-10 (pmos)
wVsubfwd	Substrate junction forward bias (warning)	V	
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	
wBvg	Gate oxide breakdown voltage (warning)	V	
wBvds	Drain-source breakdown voltage (warning)	V	

Parameter	Description	Units	Default
wIdsmax	Maximum drain-source current (warning)	A	
wPmax	Maximum power dissipation (warning)	W	
AllParams	DataAccessComponent-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
modelNch12 MOS11 \
  Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

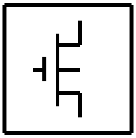
1. This model supplies values for an MM11 device.
2. Information about this model is available at

http://www.semiconductors.philips.com/Philips_Models/mos_models/model11/index.html

3. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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	NMOS type MOS11		yes
PMOS	PMOS type MOS11		no
Lvar	Difference between the actual and the programmed poly-silicon gate length	m	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
Wot	Effective reduction of the channel width per side due to the lateral diffusion of the channel-stop dopant ions	m	0
Tr (Tref, Tnom)	Temperature at which the parameters for the reference transistor have been determined	°C	25
Dta (Trise)	Temperature offset of the device with respect to Ta	K	0
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
Sl2ko	Second coefficient of the length dependence of KO	$m*V^{1/2}$	0
Swko	Coefficient of the width dependence of KO	$m*V^{1/2}$	0
Kpinv	Inverse of body-effect factor of the poly-silicon gate	$V^{-1/2}$	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

Parameter	Description	Units	Default
Slphib	Coefficient of the length dependence of PHIB	V*m	0
Sl2phib	Second coefficient of the length dependence of PHIB	V*m^2	0
Swphib	Coefficient of the width dependence of PHIB	V*m	0
Betsq	Gain factor for an infinite square transistor at the reference temperature	A/V^2	3.709e-4 (nmos) 1.150e-4 (pmos)
Etabetr	Exponent of the temperature dependence of the gain factor		1.3 (nmos) 0.5 (pmos)
Sletabet	Coefficient of the length dependence of ETABET	m	0
Fbet1	Relative mobility decrease due to first lateral profile		0
Lp1	Characteristic length of first lateral profile	m	8.0e-7
Fbet2	Relative mobility decrease due to second lateral profile		0
Lp2	Characteristic length of second lateral profile	m	8.0e-7
Thesrr	Coefficient of the mobility reduction due to surface roughness scattering for the reference transistor at the reference temperature	V^{-1}	0.4
Etasr	Exponent of the temperature dependence of THESR for the reference transistor		0.65 (nmos) 0.5 (pmos)
Swthesr	Coefficient of the width dependence of THESR	m	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) 1.0e-3 (pmos)
Etaph	Exponent of the temperature dependence of THESR for the reference transistor		1.35 (nmos) 3.75 (pmos)
Swtheph	Coefficient of the width dependence of THEPH	m	0
Etamobr	Effective field parameter for dependence on depletion/inversion charge for the reference transistor		1.4 (nmos) 3.0 (pmos)
Stetamob	Coefficient of the temperature dependence of ETAMOB	K^{-1}	0
Swetamob	Coefficient of the width dependence of ETAMOB	m	0
Nu	Exponent of the field dependence of the mobility model minus 1 at the reference temperature		2.0
Nuexp	Exponent of the temperature dependence of NU		5.25 (nmos) 3.23 (pmos)
Therr	Coefficient of the series resistance for the reference transistor at the reference temperature	V^{-1}	0.155 (nmos) 0.08 (pmos)

Parameter	Description	Units	Default
Etar	Exponent of the temperature dependence of ETA		0.95 (nmos) 0.4 (pmos)
Swther	Coefficient of the width dependence of THER	m	0
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Thesatr	Velocity saturation parameter due to optical/acoustic phonon scattering for the reference transistor at the reference temperature	V^{-1}	0.2513 (nmos) 0.1728 (pmos)
Etasat	Exponent of the temperature dependence of THESAT		1.04 (nmos) 0.86 (pmos)
Slthesat	Coefficient of the length dependence of THESAT		1.0
Thesatexp	Exponent of the length dependence of THESAT		1.0
Swthesat	Coefficient of the width dependence of THESAT	m	0
Thethr	Coefficient on self-heating for the reference transistor at the reference temperature	V^{-3}	1.0e-3 (nmos) 0.5e-3 (pmos)
Thethexp	Exponent of the length dependence of THETH		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		1.35
Mor	Parameter fr short-channel subthreshold slope for the reference transistor		0
Moexp	Exponent of the length dependence of MO		1.34
Ssfr	Static feedback parameter for the reference transistor	$V^{-1/2}$	0.00625
Slssf	Coefficient of the length dependence of SSF	m	1.0
Swssf	Coefficient of the width dependence of SSF	m	1.0
Alpr	Factor of the channel-length modulation for the reference transistor		0.01
Slalp	Coefficient of the length dependence of ALP		1.0
Alpexp	Exponent of the length dependence of ALP		1.0
Swalp	Coefficient of the width dependence of SSF	m	0.0
Vp	Characteristic voltage of channel length modulation	V	0.05

Parameter	**Description**	**Units**	**Default**
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		6.0
Sta1	Coefficient of the temperature dependence of A1	K^{-1}	0
Sla1	Coefficient of the length dependence of A1	m	0
Swa1	coefficient of the width dependence of A1	m	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
Swa2	Coefficient of the width dependence of A2	V*m	0
A3r	Factor of the drain-source voltage above which weak-avalanche occurs, for the reference transistor		1.0
Sla3	Coefficient of the length dependence of A3	m	0
Swa3	Coefficient of the width dependence of A3	m	0
Iginvr	Gain factor for intrinsic gate tunneling current in inversion for the reference transistor	A/V^2	0
Binv	Probability factor for intrinsic gate tunneling current in inversion	V	48.0 (nmos) 87.5 (pmos)
Igaccr	Gain factor for intrinsic gate tunneling current in accumulation for the reference transistor	A/V^2	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
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
Tox	Thickness of the gate oxide layer	m	3.2e-9
Col	Gate overlap capacitance per unit channel width	F/m	3.2e-16
Gatenoise	Flag for in/exclusion of induced gate thermal noise		no
Nt	Coefficient of the thermal noise at the actual temperature	J	1.656e-20

Parameter	Description	Units	Default
Nfar	First coefficient of the flicker noise for the reference transistor	$V^{-1}*m^{-1}$	1.573e+23 (nmos) 3.825e+24 (pmos)
Nfbr	Second coefficient of the flicker noise for the reference transistor	$V^{-1}*m^{-2}$	4.752e+9 (nmos) 1.015e+9 (pmos)
Nfcr	Second coefficient of the flicker noise for the reference transistor	$V^{-1}*m^{-2}$	0 (nmos) 7.3e-8 (pmos)
wVsubfwd	Substrate junction forward bias (warning)	V	
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	
wBvg	Gate oxide 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-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
     modelNch12 MOS11 \
       Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

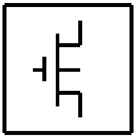
1. This model supplies values for an MM11 device.

   http://www.semiconductors.philips.com/Philips_Models/mos_models/model11/index.html

2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). 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	NMOS type MOS11		yes
PMOS	PMOS type MOS11		no
Dta (Trise)	Temperature offset of the device with respect to Ta	K	0
Kov	Body-effect factor for source/drain overlap extension	$V^{1/2}$	2.5
Lvar	Difference between the actual and the programmed poly-silicon gate length	m	0
Lap	Effective channel length reduction per side due to the lateral diffusion of the source/drain dopant ions	m	4.0e-8
Ther1	Numerator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Ther2	Denominator of the gate voltage dependent part of series resistance for the reference transistor	V	0
Tox	Thickness of gate oxide layer	m	3.2e-9
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
Vfbov	Flat-band voltage for source/drain overlap extension	V	0.0
Vp	Characteristic voltage of channel length modulation	V	0.05
Wvar	Difference between the actual and the programmed field-oxide opening	m	0
Wot	Effective reduction of the channel width per side due to the lateral diffusion of the channel-stop dopant ions	m	0
Poko	Coefficient for the geometry independent part of KO	$V^{1/2}$	0.5

Parameter	Description	Units	Default
Plko	Coefficient for the length dependence of KO	$V^{1/2}$	0
Pwko	Coefficient for the width dependence of KO	$V^{1/2}$	0
Plwko	Coefficient for the length times width dependence of KO	$V^{1/2}$	0
Pophib	Coefficient for the geometry independent part of PHIB	V	0.95
Plphib	Coefficient for the length dependence of PHIB	V	0
Pwphib	Coefficient for the width dependence of PHIB	V	0
Plwphib	Coefficient for the length times width dependence of PHIB	V	0
Pobet	Coefficient for the geometry independent part of BET	A/V^2	1.922e-3 (nmos) 3.814e-4 (pmos)
Plbet	Coefficient for the length dependence of BET	A/V^2	0
Pwbet	Coefficient for the width dependence of BET	A/V^2	0
Plwbet	Coefficient for the width over length dependence of BET	A/V^2	0
Pothesr	Coefficient for the geometry independent part of THES	V^{-1}	0.3562 (nmos) 0.73 (pmos)
Plthesr	Coefficient for the length dependence of THES	V^{-1}	0
Pwthesr	Coefficient for the width dependence of THES	V^{-1}	0
Plwthesr	Coefficient for the length times width dependence of THES	V^{-1}	0
Potheph	Coefficient for the geometry independent part of THEPH	V^{-1}	1.0e-3 (nmos) 1.29e-2 (pmos)
Pltheph	Coefficient for the length dependence of THEPH	V^{-1}	0
Pwtheph	Coefficient for the width dependence of THEPH	V^{-1}	0
Plwtheph	Coefficient for the length times width dependence of THEPH	V^{-1}	0
Poetamob	Coefficient for the geometry independent part of ETAMOB		1.4 (nmos) 3.0 (pmos)
Pletamob	Coefficient for the length dependence of ETAMOB		0
Pwetamob	Coefficient for the width dependence of ETAMOB		0
Plwetamob	Coefficient for the length times width dependence of ETAMOB		0

Parameter	Description	Units	Default
Pother	Coefficient for the geometry independent part of THER	V^{-1}	8.12e-2 (nmos) 7.9e-2 (pmos)
Plther	Coefficient for the length dependence of THER	V^{-1}	0
Pwther	Coefficient for the width dependence of THER	V^{-1}	0
Plwther	Coefficient for the length times width dependence of THER	V^{-1}	0
Pothesat	Coefficient for the geometry independent part of THESAT	V^{-1}	0.2513 (nmos) 0.1728 (pmos)
Plthesat	Coefficient for the length dependence of THESAT	V^{-1}	0
Pwthesat	Coefficient for the width dependence of THESAT	V^{-1}	0
Plwthesat	Coefficient for the length times width dependence of THESAT	V^{-1}	0
Potheth	Coefficient for the geometry independent part of THETH	V^{-3}	1.0e-5 (nmos) 0.0 (pmos)
Pltheth	Coefficient for the length dependence of THETH	V^{-3}	0
Pwtheth	Coefficient for the width dependence of THETH	V^{-3}	0
Plwtheth	Coefficient for the length times width dependence of THETH	V^{-3}	0
Posdibl	Coefficient for the geometry independent part of SDIBL	$V^{-1/2}$	8.53e-4 (nmos) 3.551e-5 (pmos)
Plsdibl	Coefficient for the length dependence of SDIBL	$V^{-1/2}$	0
Pwsdibl	Coefficient for the width dependence of SDIBL	$V^{-1/2}$	0
Plwsdibl	Coefficient for the length times width dependence of SDIBL	$V^{-1/2}$	0
Pomo	Coefficient for the geometry independent part of MO		0
Plmo	Coefficient for the length dependence of MO		0
Pwmo	Coefficient for the width dependence of MO		0
Plwmo	Coefficient for the length times width dependence of MO		0
Possf	Coefficient for the geometry independent part of SSF	$V^{-1/2}$	0.012 (nmos) 0.010 (pmos)
Plssf	Coefficient for the length dependence of SSF	$V^{-1/2}$	0
Pwssf	Coefficient for the width dependence of SSF	$V^{-1/2}$	0

Parameter	Description	Units	Default
Plwssf	Coefficient for the length times width dependence of SSF	$V^{-1/2}$	0
Poalp	Coefficient for the geometry independent part of ALP		0.025
Plalp	Coefficient for the length dependence of ALP		0
Pwalp	Coefficient for the width dependence of ALP		0
Plwalp	Coefficient for the length times width dependence of ALP		0
Pomexp	Coefficient for the geometry independent part of 1/m		0.2
Plmexp	Coefficient for the length dependence of 1/m		0
Pwmexp	Coefficient for the width dependence of 1/m		0
Plwmexp	Coefficient for the length times width dependence of 1/m		0
Poa1	Coefficient for the geometry independent part of A1		6.022 (nmos) 6.858 (pmos)
Pla1	Coefficient for the length dependence of A1		0
Pwa1	Coefficient for the width dependence of A1		0
Plwa1	Coefficient for the length times width dependence of A1		0
Poa2	Coefficient for the geometry independent part of A2	V	38.02 (nmos) 57.32 (pmos)
Pla2	Coefficient for the length dependence of A2	V	0
Pwa2	Coefficient for the width dependence of A2	V	0
Plwa2	Coefficient for the length times width dependence of A2	V	0
Poa3	Coefficient for the geometry independent part of A3		0.6407 (nmos) 0.4254 (pmos)
Pla3	Coefficient for the length dependence of A3		0
Pwa3	Coefficient for the width dependence of A3		0
Plwa3	Coefficient for the length times width dependence of A3		0
Poiginv	Coefficient for the geometry independent part of IGINV	A/V	0
Pliginv	Coefficient for the length dependence of IGINV		0
Pwiginv	Coefficient for the width dependence of IGINV		0
Plwiginv	Coefficient for the length times width dependence of IGINV		0
Pobinv	Coefficient for the geometry independent part of BINV	V	48
Plbinv	Coefficient for the length dependence of BINV	V	0
Pwbinv	Coefficient for the width dependence of BINV	V	0

Parameter	Description	Units	Default
Plwbinv	Coefficient for the length times width dependence of BINV	V	0
Poigacc	Coefficient for the geometry independent part of IGACC	A/V^2	0
Pligacc	Coefficient for the length dependence of IGACC	A/V^2	0
Pwigacc	Coefficient for the width dependence of IGACC	A/V^2	0
Plwigacc	Coefficient for the length times width dependence of IGACC	A/V^2	0
Pobacc	Coefficient for the geometry independent part of BACC	V	48.0 (nmos) 87.5 (pmos)
Plbacc	Coefficient for the length dependence of BACC	V	0
Pwbacc	Coefficient for the width dependence of BACC	V	0
Plwbacc	Coefficient for the length times width dependence of BACC	V	0
Poigov	Coefficient for the geometry independent part of IGOV	A/V^2	0
Pligov	Coefficient for the length dependence of IGOV	A/V^2	0
Pwigov	Coefficient for the width dependence of IGOV	A/V^2	0
Plwigov	Coefficient for the width over length dependence of IGOV	A/V^2	0
Pocox	Coefficient for the geometry independent part of COX	F	2.980e-14 (nmos) 2.717e-14 (pmos)
Plcox	Coefficient for the length dependence of COX	F	0
Pwcox	Coefficient for the width dependence of COX	F	0
Plwcox	Coefficient for the width over length dependence COX	F	0
Pocgdo	Coefficient for the geometry independent part of CGDO	F	6.392e-15 (nmos) 6.358e-15 (pmos)
Plcgdo	Coefficient for the length dependence of CGDO	F	0
Pwcgdo	Coefficient for the width dependence of CGDO	F	0
Plwcgdo	Coefficient for the width over length dependence CGDO	F	0
Pocgso	Coefficient for the geometry independent part of CGSO	F	6.392e-15 (nmos) 6.358e-15 (pmos)
Plcgso	Coefficient for the length dependence of CGSO	F	0

Parameter	**Description**	**Units**	**Default**
Pwcgso	Coefficient for the width dependence of CGSO	F	0
Plwcgso	Coefficient for the width over length dependence CGSO	F	0
Ponfa	Coefficient for the geometry independent part of NFA	$V^{-1}*m^{-1}$	8.323e+22 (nmos) 1.900e+22 (pmos)
Plnfa	Coefficient for the length dependence of NFA	$V^{-1}*m^{-1}$	0
Pwnfa	Coefficient for the width dependence of NFA	$V^{-1}*m^{-1}$	0
Plwnfa	Coefficient for the length times width dependence of NFA	$V^{-1}*m^{-1}$	0
Ponfb	Coefficient for the geometry independent part of NFB	$V^{-1}*m^{-2}$	2.514e+7 (nmos) 5.043e+6 (pmos)
Plnfb	Coefficient for the length dependence of NFB	$V^{-1}*m^{-2}$	0
Pwnfb	Coefficient for the width dependence of NFB	$V^{-1}*m^{-2}2$	0
Plwnfb	Coefficient for the length times width dependence of NFB	$V^{-1}*m^{-2}$	0
Ponfc	Coefficient for the geometry independent part of NFC	V^{-1}	0.0 (nmos) 3.627e-10 (pmos)
Plnfc	Coefficient for the length dependence of NFC	V^{-1}	0
Pwnfc	Coefficient for the width dependence of NFC	V^{-1}	0
Plwnfc	Coefficient for the length times width dependence of NFC	V^{-1}	0
Potvfb	Coefficient for the geometry independent part of STVFB	V/K	5.0e-4
Pltvfb	Coefficient for the length dependence of STVFB	V/K	0
Pwtvfb	Coefficient for the width dependence of STVFB	V/K	0
Plwtvfb	Coefficient for the length times width dependence of STVFB	V/K	0
Potphib	Coefficient for the geometry independent part of STPHIB	V/K	-8.5e-4
Pltphib	Coefficient for the length dependence of STPHIB	V/K	0
Pwtphib	Coefficient for the width dependence of STPHIB	V/K	0
Plwtphib	Coefficient for the length times width dependence of STPHIB	V/K	0
Potetabet	Coefficient for the geometry independent part of ETABET		1.3 (nmos) 0.5 (pmos)
Pltetabet	Coefficient for the length dependence of ETABET		0

Parameter	Description	Units	Default
Pwtetabet	Coefficient for the width dependence of ETABET		0
Plwtetabet	Coefficient for the length times width dependence of ETABET		0
Potetasr	Coefficient for the geometry independent part of ETASR		0.65 (nmos) 0.5 (pmos)
Pltetasr	Coefficient for the length dependence of ETASR		0
Pwtetasr	Coefficient for the width dependence of ETASR		0
Plwtetasr	Coefficient for the length times width dependence of ETASR		0
Potetaph	Coefficient for the geometry independent part of ETAPH		1.35 (nmos) 3.75 (pmos)
Pltetaph	Coefficient for the length dependence of ETAPH		0
Pwtetaph	Coefficient for the width dependence of ETAPH		0
Plwtetaph	Coefficient for the length times width dependence of ETAPH		0
Potetamob	Coefficient for the geometry independent part of ETAMOB	K^{-1}	0
Pltetamob	Coefficient for the length dependence of ETAMOB	K^{-1}	0
Pwtetamob	Coefficient for the width dependence of ETAMOB	K^{-1}	0
Plwtetamob	Coefficient for the length times width dependence of ETAMOB	K^{-1}	0
Potnuexp	Coefficient for the geometry independent part of NUEXP		5.25 (nmos) 3.23 (pmos)
Pltnuexp	Coefficient for the length dependence of NUEXP		0
Pwtnuexp	Coefficient for the width dependence of NUEXP		0
Plwtnuexp	Coefficient for the length times width dependence of NUEXP		0
Potetar	Coefficient for the geometry independent part of ETAR		0.95 (nmos) 0.40 (pmos)
Pltetar	Coefficient for the length dependence of ETAR		0
Pwtetar	Coefficient for the width dependence of ETAR		0
Plwtetar	Coefficient for the length times width dependence of ETAR		0
Potetasat	Coefficient for the geometry independent part of ETASAT		1.04 (nmos) 0.86 (pmos)

Parameter	Description	Units	Default
Pltetasat	Coefficient for the length dependence of ETASAT		0
Pwtetasat	Coefficient for the width dependence of ETASAT		0
Plwtetasat	Coefficient for the length times width dependence of ETASAT		0
Pota1	Coefficient for the geometry independent part of STA1	K^{-1}	0
Plta1	Coefficient for the length dependence of STA1	K^{-1}	0
Pwta1	Coefficient for the width dependence of STA1	K^{-1}	0
Plwta1	Coefficient for the length times width dependence of STA1	K^{-1}	0
Gatenoise	Flag for in/exclusion of induced gate thermal noise		0
Nt	coefficient of thermal noise at actual temperature	J	1.656e-20
wVsubfwd	Substrate junction forward bias (warning)	V	
wBvsub	Substrate junction reverse breakdown voltage (warning)	V	
wBvg	Gate oxide 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-based parameters		

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 book*.

```
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 Chapter 8, *ADS Simulator Input Syntax* in the *Circuit Simulation* book.

Example:

```
model Nch12 MOS11 \
  Vfbr=-1.0 Phibr=0.8 NMOS=yes
```

Notes/Equations

For RFDE Users Information about this model must be provided in a *model* file; refer to the *Netlist Format* section.

---

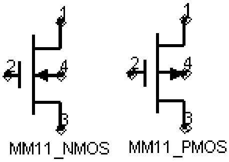
1. This model supplies values for an MM11 device.

   http://www.semiconductors.philips.com/Philips_Models/mos_models/model11/index.html

2. Use AllParams with a DataAccessComponent to specify file-based parameters (refer to DataAccessComponent). Note that model parameters that are explicitly specified take precedence over those specified via AllParams. Set AllParams to the DataAccessComponent instance name.

MM11_NMOS, MM11_PMOS (Philips MOS Model 11 NMOS, PMOS)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of a model		
L	channel length, in length units		10^{-4}
W	channel width	m	10^{-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		1
Mode	device simulation mode: nonlinear, linear		nonlinear
Noise	noise generation option: yes=1, no=0		yes
_M	number of devices in parallel		1

Notes/Equations

1. More information about the model can be obtained from:

   http://www.semiconductors.com/Philips_Models/

2. Table 5-8 lists the DC operating point parameters that can be sent to the dataset.

Table 5-8. DC Operating Point Information

Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A

Table 5-8. DC Operating Point Information (continued)

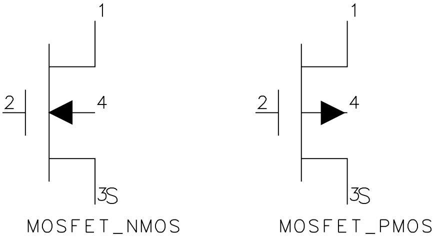
Name	Description	Units
Power	DC power dissipated	W
Gds	Output conductance (dIds/dVds)	S
Gm	Forward transconductance (dIds/dVgs)	S
Gmb	Backgate transconductance (dIds/dVbs)	S
Iavl	Drain-bulk weak avalanche current	A
Igs	Gate-source tunneling current	A
Igd	Gate-drain tunneling current	A
Igb	Gate-bulk tunneling current	A
Vto	Zero bias threshold voltage	V
Vts	Threshold voltage including back-bias effects	V
Vth	Threshold voltage including back-bias and drain-bias effects	V
Vgt	Effective gate drive voltage including back-bias and drain-bias effects	V
Vdss	Drain saturation voltage	V
Vsat	Saturation limit (Vds-Vdsat)	V
Cdd	(dQd/dVds)	F
Cdg	(-dQd/dVgs)	F
Cds	(Cdd-Cdg-Cdb)	F
Cdb	(dQd/dVsb)	F
Cgd	(-dQg/dVds)	F
Cgg	(dQg/dVgs)	F
Cgs	(Cgg-Cgd-Cgb)	F
Cgb	(dQg/dVsb)	F
Csd	(-dQs/dVds)	F
Csg	(-dQs/dVgs)	F
Css	(Csg+Csd+Csb)	F
Csb	(dQs/dVsb)	F
Cbd	(-dQb/dVds)	F
Cbg	(-dQb/dVgs)	F
Cbs	(Cbb-Cbd-Cbg)	F
Cbb	(-dQb/dVsb)	F

Table 5-8. DC Operating Point Information (continued)

Name	Description	Units
Cgdol	Gate-drain overlap capacitance	F
Cgsol	Gate-source overlap capacitance	F
Weff	Effective gate width	m
Leff	Effective gate length	m
Fknee	Flicker noise corner frequency	Hz
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V

MOSFET_NMOS, MOSFET_PMOS (Nonlinear MOSFETs, NMOS, PMOS)

Symbol



Parameters

Name	Description	Unit	Default
Model	name of BSIM1_Model, BSIM2_Model, BSIM3_Model, LEVEL1_Model, LEVEL2_Model, LEVEL3_Model, or LEVEL3_MOD_Model		
Length	channel length:	um, mm, cm, meter, mil, in	10^{-4} m
Width	channel width		10^{-4} m
Ad	drain diffusion area	m^2	0.0
As	source diffusion area	m^2	0.0
Pd	drain junction perimeter	um, mm, cm, meter, mil, in	0.0 m
Ps	source junction perimeter	um, mm, cm, meter, mil, in	0.0 m
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		1
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		1
Mult	(obsolete: use _M instead)		

Name	Description	Unit	Default
Region	dc operating region: off, on, rev, sat		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)		nonlinear
Noise	noise generation option: yes=1, no=0		yes
Nqsmod	non-quasi static model option: 1=on or 0=off		0
Geo	source/drain sharing selector		0
_M	number of devices in parallel		1

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. Table 5-9 lists the DC operating point parameters that can be sent to the dataset.

Table 5-9. DC Operating Point Information

Name	Description	Units
Id	Drain current	A
Ig	Gate current	A
Is	Source current	A
Ib	Bulk current	A
Power	DC power dissipated	W
Gm	Forward transconductance (dIds/dVgs)	S
Gmb	Backgate transconductance (dIds/dVbs)	S
Gds	Output conductance (dIds/dVds)	S
Vth	Threshold voltage	V
Vdsat	Drain-source saturation voltage	V
Capbd	Bulk-drain capacitance	F
Capbs	Bulk-source capacitance	F
CgdM	Gate-drain Meyer capacitance	F
CgbM	Gate-bulk Meyer capacitance	F
CgsM	Gate-source Meyer capacitance	F
DqgDvgb	(dQg/dVgb)	F
DqgDvdb	(dQg/dVdb)	F

Table 5-9. DC Operating Point Information (continued)

Name	Description	Units
DqgDvsb	(dQg/dVsb)	F
DqbDvgb	(dQb/dVgb)	F
DqbDvdb	(dQb/dVdb)	F
DqbDvsb	(dQb/dVsb)	F
DqdDvgb	(dQd/dVgb)	F
DqdDvdb	(dQd/dVdb)	F
DqdDvsb	(dQd/dVsb)	F
Vgs	Gate-source voltage	V
Vds	Drain-source voltage	V
Vbs	Bulk-source voltage	V

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.

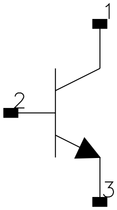
[3] P. Antognetti and G. Massobrio. *Semiconductor Device Modeling with SPICE*, McGraw-Hill, Inc., 1988.

[4] D. A. Divekar, *FET Modeling for Circuit Simulation*, Kluwer Academic Publishers, 1988.

Chapter 6: Linear Devices

BIP (Bipolar Transistor with Alpha Current Gain)

Symbol



Parameters

Name	Description	Units	Default
A	magnitude of current gain (alpha) at dc		0.99
T	time delay associated with current gain	fsec, psec, nsec, usec, msec	1.0 nsec
F	–3 dB frequency for current gain	Hz, kHz, MHz, GHz	0.1 GHz
Cc	collector capacitance	fF, pF, nF, uF, mF	10.0 pF
Gc	collector conductance	pS, nS, uS, mS	1.0 uS
Rb	base resistance	mOhm, Ohm, kOhm, MOhm, GOhm	2.0 Ohm
Lb	base inductance	fH, pH, nH, uH, mH	1.0 nH
Ce	emitter capacitance	fF, pF, nF, uF, mF	10.0 pF
Re	emitter resistance	mOhm, Ohm, kOhm, MOhm, GOhm	2.0 Ohm
Le	emitter inductance	fH, pH, nH, uH, mH	1.0 nH

Range of Usage

$0 < A < 1.0$

Notes/Equations

1. $$(f) = A \times \frac{e^{-(j2\pi fT)}}{1 + j\left(\frac{f}{F}\right)} \text{ (for F > 0)}$$

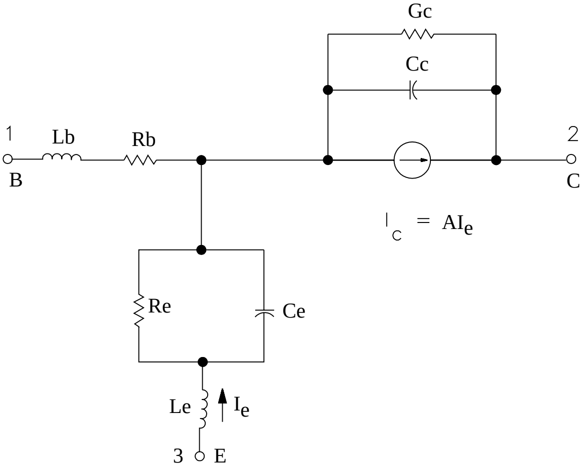
$$(f) = A \times e^{-(j2\pi fT)} \text{ (for F = 0)}$$

where

f = simulation frequency
F = reference frequency

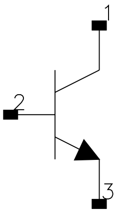
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



BIPB (Bipolar Transistor, with Beta Current Gain)

Symbol



Parameters

Name	Description	Unit	Default
B	magnitude of current gain (Beta) at dc		20.0
A	phase offset of current gain	degrees	0.0
T	time delay associated with current gain	nsec, usec, msec, sec	1.0 nsec
Cc	collector capacitance	fF, pF, nF, uF, mF	10.0 pF
Gc	collector conductance	pS, nS, uS, mS	1.0 uS
Rb	base resistance	mOhm, Ohm, kOhm, MOhm, GOhm	2.0 Ohm
Lb	base inductance	fH, pH, nH, uH, mH	1.0 nH
Ce	emitter capacitance	fF, pF, nF, uF, mF	10.0 pF
Re	emitter resistance	mOhm, Ohm, kOhm, MOhm, GOhm	2.0 Ohm
Le	emitter lead inductance	fH, pH, nH, uH, mH	1.0 nH
Rel	emitter lead resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.2 Ohm

Range of Usage

$B > 0$

Notes/Equations

1. $\beta(f) = B \times e^{-j(2\pi f T_{\text{sec}} - A_{radians})}$

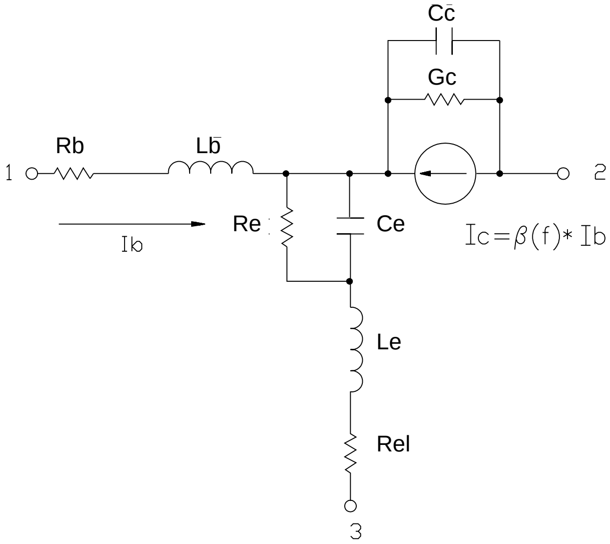
   where

   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.

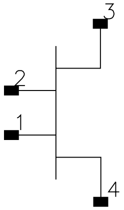
4. This component has no default artwork associated with it.

Equivalent Circuit



DFET (Dual-Gate Field Effect Transistor)

Symbol



Parameters

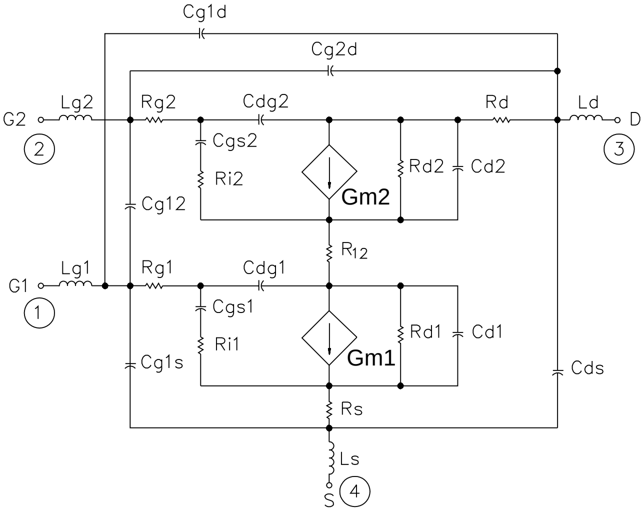
Name	Description	Unit	Default
Gm1	dc transconductance - gate 1	pS, nS, uS, mS	20.0 uS
T1	time delay of Gm1	fsec, psec, nsec, usec, msec	1.0 nsec
F1	–3 dB frequency for Gm1	Hz, kHz, MHz, GHz	1.0 GHz
Cgs1	gate-to-source capacitance - gate 1	fF, pF, nF, uF, mF	10.0 pF
Ri1	input resistance - gate 1	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Cdg1	drain-to-gate capacitance - gate 1	fF, pF, nF, uF, mF	10.0 pF
Cds1	drain-to-source capacitance - gate 1	fF, pF, nF, uF, mF	10.0 pF
Rds1	drain-to-source resistance - gate 1	mOhm, Ohm, kOhm, MOhm, GOhm	500.0 Ohm
Rg1	gate1 resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Lg1	gate1 inductance	fH, pH, nH, uH, mH	10.0 nH
Gm2	dc transconductance - gate 2	pS, nS, uS, mS	20.0 uS
T2	time delay of Gm2	fsec, psec, nsec, usec, msec	1.0 nsec
F2	–3 dB frequency for Gm2	Hz, kHz, MHz, GHz	1.0 GHz
Cgs2	gate-to-source capacitance - gate 2	fF, pF, nF, uF, mF	10.0 pF
Ri2	input resistance - gate 2	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Cdg2	drain-to-gate capacitance - gate 2	fF, pF, nF, uF, mF	10.0 pF
Cds2	drain-to-source capacitance - gate 2	fF, pF, nF, uF, mF	10.0 pF
Rds2	drain-to-source resistance - gate 2	mOhm, Ohm, kOhm, MOhm, GOhm	500.0 Ohm
Rg2	gate 2 resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Lg2	gate 2 inductance	fH, pH, nH, uH, mH	10.0 nH
Rd	drain resistance	mOhm, Ohm, kOhm, MOhm, GOhm	25.0e-6 Ohm
Ld	drain inductance	fH, pH, nH, uH, mH	1.0 nH

Name	Description	Unit	Default
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	1.0 Ohm
Ls	source inductance	fH, pH, nH, uH, mH	10.0 nH
Cg1s	gate1-to-source capacitance	fF, pF, nF, uF, mF	10.0 pF
Cg12	gate1-to-gate2 capacitance	fF, pF, nF, uF, mF	5.0 pF
Cg1d	gate1-to-drain capacitance	fF, pF, nF, uF, mF	10.0 pF
Cg2d	gate2-to-drain capacitance	fF, pF, nF, uF, mF	1.0 pF
Cds	drain-to-source capacitance	fF, pF, nF, uF, mF	1.0 pF
R12	resistance between drain 1 and source 2	mOhm, Ohm, kOhm, MOhm, GOhm	1.0 Ohm

Notes/Equations

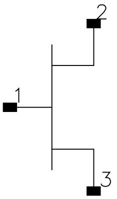
1. For time-domain analysis, the frequency-domain analytical model is used.
2. This component is assumed to be noiseless.
3. This component has no default artwork associated with it.

Equivalent Circuit



FET (Field Effect Transistor)

Symbol



Parameters

Name	Description	Units	Default
G	magnitude of transconductance at dc	pS, nS, uS, mS	20.0 uS
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	1.0 nsec
F	transconductance roll-off frequency	Hz, kHz, MHz, GHz	1.0 GHz
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	10.0 pF
Ggs	gate-to-source conductance	pS, nS, uS, mS	1.0 uS
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Cdg	drain-to-gate capacitance	fF, pF, nF, uF, mF	10.0 pF
Cdc	dipole layer capacitance	fF, pF, nF, uF, mF	10.0 pF
Cds	drain-to-source capacitance	fF, pF, nF, uF, mF	10.0 pF
Rds	drain-to-source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	500.0 Ohm

Notes/Equations

1. Setting F = 0 gives constant transconductance magnitude with respect to frequency:

$$\text{Transconductance} = \text{G(f)} = \text{G} \times \left(\frac{e^{-(j2\pi fT)}}{1 + j\frac{f}{F}}\right) \quad \text{(for F > 0)}$$

$$\text{Transconductance} = \text{G(f)} = \text{G} \times e^{-(j2\pi fT)} \quad \text{(for F = 0)}$$

where

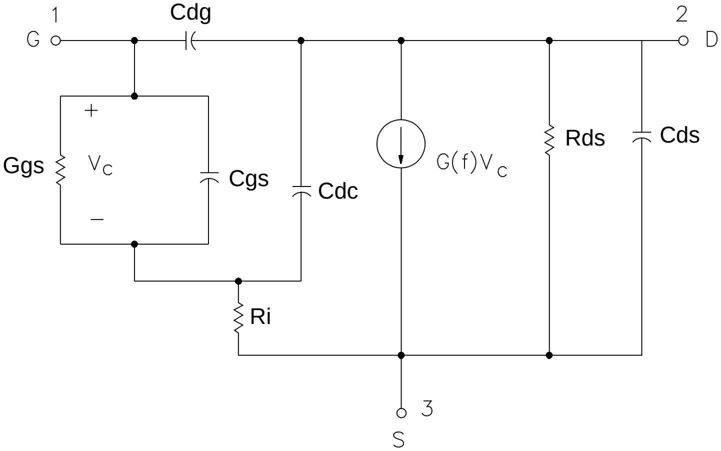
f = simulation frequency, in Hz

F = reference frequency, in Hz

T = time delay, in seconds

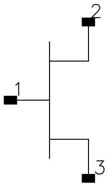
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



FET2 (Field Effect Transistor with Source Resistance)

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance at dc	pS, nS, uS, mS	20.0 uS
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	1.0 nsec
F	transconductance roll-off frequency	Hz, kHz, MHz, GHz	1.0 GHz
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	10.0 pF
Ggs	gate-to-source conductance	pS, nS, uS, mS	1.0 uS
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm
Cdg	drain-to-gate capacitance	fF, pF, nF, uF, mF	10.0 pF
Cdc	dipole layer capacitance	fF, pF, nF, uF, mF	10.0 pF
Cds	drain-to-source capacitance	fF, pF, nF, uF, mF	10.0 pF
Rds	drain-to-source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	500.0 Ohm
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.1 Ohm

Notes/Equations

1. Setting F = 0 gives constant transconductance magnitude with respect to frequency:

$$\text{Transconductance} = \text{G(f)} = \text{G} \times \left(\frac{e^{-(j2\pi fT)}}{1 + j\dfrac{f}{F}} \right) \qquad \text{(for F > 0)}$$

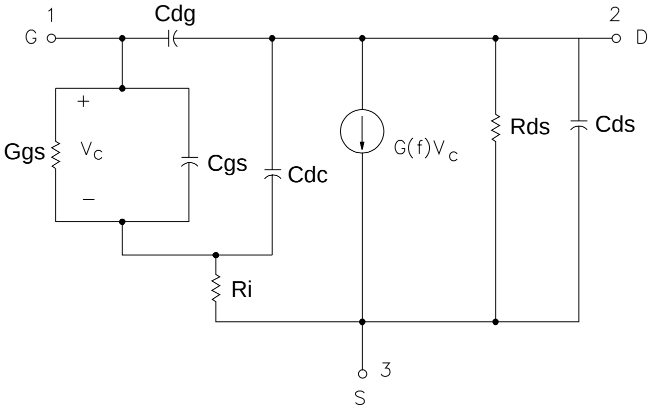
$$\text{Transconductance} = \text{G(f)} = \text{G} \times e^{-(j2\pi fT)} \qquad \text{(for F = 0)}$$

   where

f = simulation frequency, in Hz
F = reference frequency, in Hz
T = time delay, in seconds

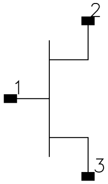
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component is assumed to be noiseless.
4. This component has no default artwork associated with it.

Equivalent Circuit



FETN1 (FET Noise Model (Van der Ziel))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cg	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 Ohm
Rds	drain-to-source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	300.0 Ohm
P	noise parameter P (see references)		0.8
R	noise parameter R (see references)		1.2
C	noise parameter C (see references)		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.

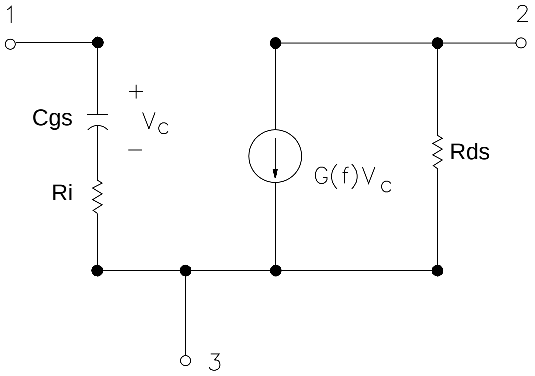
References

[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.

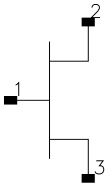
[3] A. Van der Ziel, “Thermal Noise in Field Effect Transistors,” *Proceedings of the IRE*, Vol. 50, August 1962, pp. 1808-1812.

Equivalent Circuit



FETN2 (FET Noise Model (Statz, et al))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 Ohm
Rs	drain-to-source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.70 Ohm
Rg	gate resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.80 Ohm
Kr	noise parameter Kr (see references)		0.050
Kc	noise parameter Kc (see references)		1.4
Kg	noise parameter Kg (see references)		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.

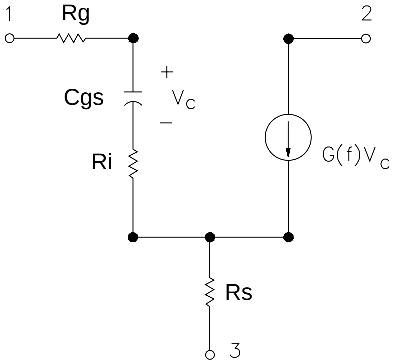
References

[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.

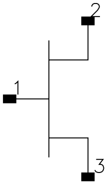
[3] H. Statz, H. Haus, and R. Pucel. “Noise Characteristics of Gallium Arsenide Field-Effect Transistors,” *IEEE Transactions on Electron Devices*, Vol. ED-21, September 1974, pp. 549-562.

Equivalent Circuit



FETN3 (FET Noise Model (Fukui))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 Ohm
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.70 Ohm
Rg	gate resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.80 Ohm
K1	noise parameter K1 (see references)		0.020
K2	noise parameter K2 (see references)		0.800
K3	noise parameter K3 (see references)		2.2
K4	noise parameter K4 (see references)		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.)

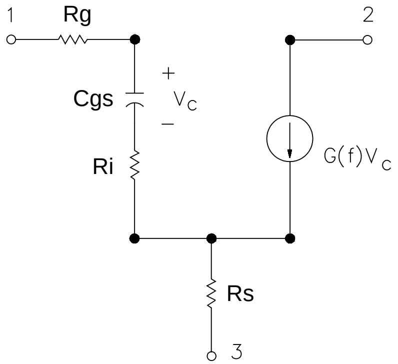
4. For time-domain analysis, the frequency-domain analytical model is used.
5. This component has no default artwork associated with it.

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.

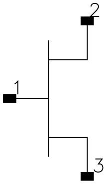
[2] H. Fukui, Addendum to “Design of Microwave GaAs MESFET’s for Broad-Band Low-Noise Amplifiers,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-29, October 1981.

Equivalent Circuit



FETN4 (FET Noise Model (Podell))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 Ohm
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.70 Ohm
Rg	gate resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.80 Ohm
NFmin	minimum noise figure	dB	2.0
FRef	reference frequency at which NFMin is measured	Hz, kHz, MHz, GHz	

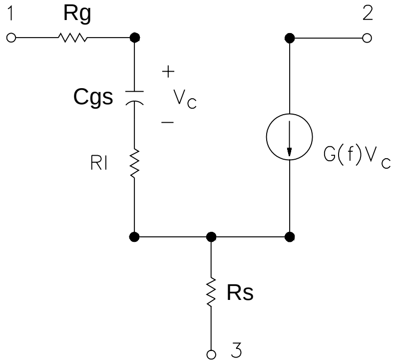
Notes/Equations

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.

References

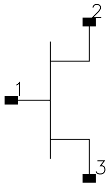
[1] A. Podell, “A Functional GaAs FET Noise Model,” *IEEE Transactions on Electron Devices*, Vol. ED-28, No. 5, May 1981, pp. 511-517.

Equivalent Circuit



FETN4a (FET Noise Model (Podell))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 Ohm
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.70 Ohm
Rg	gate resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.80 Ohm
K	noise parameter K (see references)		1.0

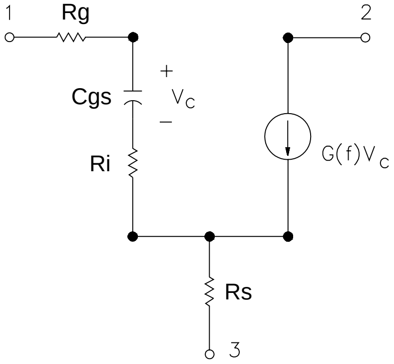
Notes/Equations

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 those for FETN4 are 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.

References

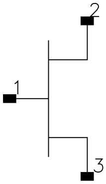
[1] A. Podell, “A Functional GaAs FET Noise Model,” *IEEE Transactions on Electron Devices,* Vol. ED-28, No. 5, May 1981, pp. 511-517.

Equivalent Circuit



FETN5 (FET Noise Model Gupta, et al))

Symbol



Parameters

Name	Description	Unit	Default
G	magnitude of transconductance	pS, nS, uS, mS	0.03 S
T	time delay associated with transconductance	fsec, psec, nsec, usec, msec	3.0 psec
Cgs	gate-to-source capacitance	fF, pF, nF, uF, mF	0.40 pF
Ri	channel resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.0 ohms
Rds	drain-to-source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	450.0 ohms
Rs	source resistance	mOhm, Ohm, kOhm, MOhm, GOhm	3.70 ohms
Rg	gate resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.80 ohm
Sio	noise parameter Sio	picoamperes squared per Hertz (see references)	710

Notes/Equations

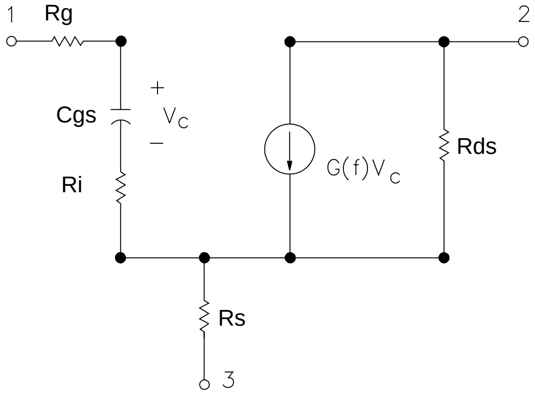
1. This component provides a linear bias-independent FET noise model (by Gupta, et al.) for use during a noise analysis. The signal performance of the component is determined by the equivalent circuit shown following these notes.
2. The effect of feedback or parasitics on the noise performance of FETN5 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.

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.

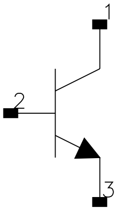
[2] M. Gupta and P. Greiling. “Microwave Noise Characterization of GaAs MESFET’s: Determination of Extrinsic Noise Parameters,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 36, No. 4, April 1988, pp. 745-751.

Equivalent Circuit



HYBPI (Hybrid-Pi Bipolar Transistor with Alpha Current Gain)

Symbol



Parameters

Name	Description	Unit	Default
G	transconductance	pS, nS, uS, mS	20.0 uS
T	transit time	fsec, psec, nsec, usec, msec	1.0 nsec
Cpi	base-emitter (pi) capacitance	fF, pF, nF, uF, mF	10.0 pF
Rpi	base-emitter (pi) resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.01 ohm
Cmu	base-collector (mu) capacitance	fF, pF, nF, uF, mF	5.0 pF
Rmu	base-collector (mu) resistance	mOhm, Ohm, kOhm, MOhm, GOhm	1000.0 ohms
Rb	base resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.02 ohm
Rc	collector resistance	mOhm, Ohm, kOhm, MOhm, GOhm	500.0 ohms
Re	emitter resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.04 ohm

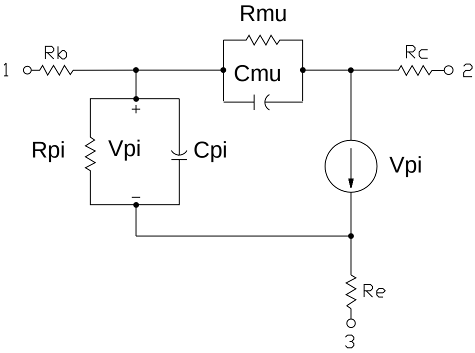
Range of Usage

Rpi > 0
Rmu > 0

Notes/Equations

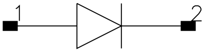
1. For time-domain analysis, the frequency-domain analytical model is used.
2. This component is assumed to be noiseless.
3. This component has no default artwork associated with it.

Equivalent Circuit



PIN (PIN Diode, Chip Model)

Symbol



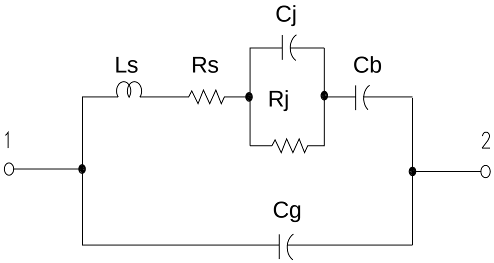
Parameters

Name	Description	Unit	Default
Cj	junction capacitance	fF, pF, nF, uF, mF	0.1 nF
Rj	junction resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.01 ohm
Rs	diode series resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.01 ohm
Ls	bond wire inductance	fH, pH, nH, uH, mH	1.0 nH
Cb	by-pass capacitance	fF, pF, nF, uF, mF	0.1 nF
Cg	capacitance of gap across which diode is connected	fF, pF, nF, uF, mF	0.1 nF

Notes/Equations

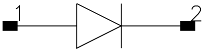
1. This component is assumed to be noiseless.
2. This component has no default artwork associated with it.

Equivalent Circuit



PIN2 (PIN Diode, Packaged Model)

Symbol



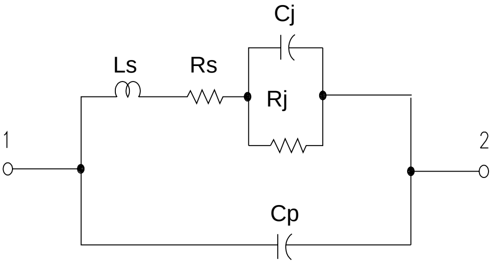
Parameters

Name	Description	Unit	Default
Cj	junction capacitance	fF, pF, nF, uF, mF	0.01 nF
Rj	junction resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.01 Ohm
Rs	series resistance	mOhm, Ohm, kOhm, MOhm, GOhm	0.01 Ohm
Ls	series inductance	fH, pH, nH, uH, mH	1.0 nH
Cp	package capacitance	fF, pF, nF, uF, mF	0.1 nF

Notes/Equations

1. This component is assumed to be noiseless.
2. This component has no default artwork associated with it.

Equivalent Circuit

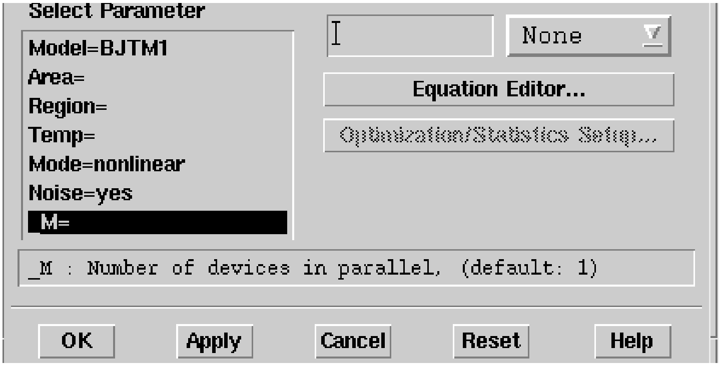


Chapter 7: Equation-Based Non-Linear Components

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 don't 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.)

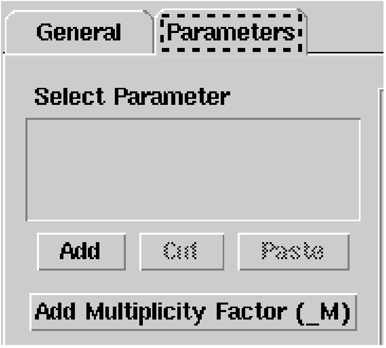


Select Parameter

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

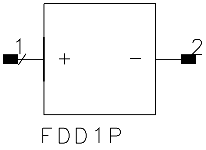
_M : Number of devices in parallel, (default: 1)

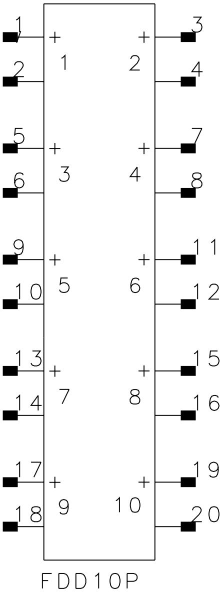
For sub-circuits, the parameter is enabled by selecting **File** > **Design Parameter**s from the Schematic window. In the dialog box, select the **Parameters** tab. To add the Multiplicity parameter, choose **Add Multiplicity Factor_M**.


General
Parameters
Select Parameter
Add
Cut
Paste
Add Multiplicity Factor (_M)

FDD1P to FDD10P (1- to 10-Port Frequency-Domain Defined Devices)

Symbol





Parameters

I[i, j]] = current equation that describes spectral current. *i* refers to the port number. *j* refers to a frequency index

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, in Hertz

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 Chapter 6 *Custom Modeling with Frequency_Domain Defined Devices* in the *Analog/RF User-Defined Models* manual.
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())

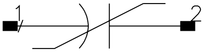
   where *port* is the port number and *findex* is a frequency index.

   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

Coeff = list of coefficients that describe a polynomial that defines capacitance as a function of voltage v across the capacitor where

$$cap = Coeff[0] + Coeff[1] \times v + Coeff[2] \times v^2 +, \ldots , + Coeff[n] \times v^n$$

and coefficients are entered using the list function

Coeff = list (Coeff[0], Coeff[1],Coeff[2], ... , Coeff[n])

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

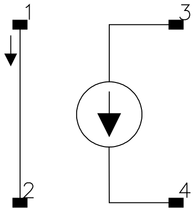
   Coefficients are entered using the list function. For example, if
   $C = 5V^2 + 4V^4$
   the parameter entry is
   Coeff = list(0,0,5,0,4)

2. The controlling voltage V is the voltage across the capacitor, with pin 1 being positive and pin 2 being negative.

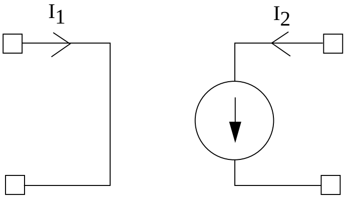
3. This component has no default artwork associated with it.

NonlinCCCS (Nonlinear Current-Controlled Current Source)

Symbol



Illustration



Parameters

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

$I_2 = \text{Coeff}[0] \times I_1$

the coefficient is entered using the list function

Coeff = list(Coeff[0])

otherwise

$I_2 = \text{Coeff}[0] + \text{Coeff}[1] \times I_1 + \text{Coeff}[2] \times I_1^2 +, \ldots , + \text{Coeff}[n] \times I_1^n$

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 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)

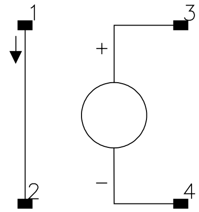
If $I_2 = 5I_1$, then Coeff = list(5)

If $I_2 = 5$, then Coeff = list(5,0)

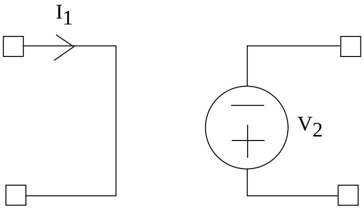
2. This component has no default artwork associated with it.
3. Output current is in Amperes.

NonlinCCVS (Nonlinear Current-Controlled Voltage Source)

Symbol



Illustration



Parameters

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

Coeff = a list of coefficients that describe a polynomial that defines inductance as a function of current through the inductor:

$$L = \mathrm{Coeff}[0] + \mathrm{Coeff}[1] \times I + \mathrm{Coeff}[2] \times I^2 +, \ldots , +\mathrm{Coeff}[n] \times I^n$$

and coefficients are entered using the list function

Coeff = list(Coeff[0],Coeff[1],Coeff[2] , ... , Coeff[n])

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

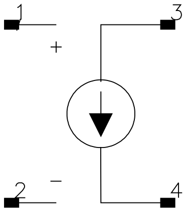
   Coefficients are entered using the list function. For example, if
   $L= 5I^2 + 4I^4$
   the parameter entry is
   Coeff = list(0,0,5,0,4)

2. The controlling current I is the current flowing from pin 1 to pin 2.

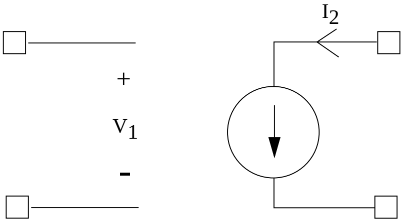
3. This component has no default artwork associated with it.

NonlinVCCS (Nonlinear Voltage-Controlled Current Source)

Symbol



Illustration



Parameters

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

$I_2 = \text{Coeff}[0] \times V_1$

the coefficient is entered using the list function

Coeff = list(Coeff[0])

otherwise

$I_2 = \text{Coeff}[0] + \text{Coeff}[1] \times V_1 + \text{Coeff}[2] \times V_1^2 +, \ldots , +\text{Coeff}[n] \times V_1^n$

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

   $I_2 = 3 - 2V_1^2 + 5V_1^6$

   the parameter entry is

   Coeff = list(3,0,-2,0,0,0,5)

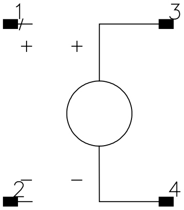
   If $I_2 = 5V_1$, then Coeff = list(5)

   If $I_2 = 5$, then Coeff = list(5,0)

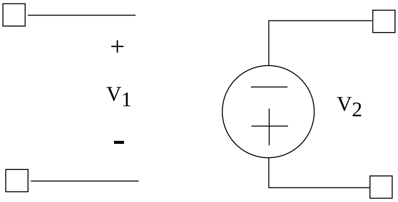
2. This component has no default artwork associated with it.
3. Output current is in Amperes.

NonlinVCVS (Nonlinear Voltage-Controlled Voltage Source)

Symbol



Illustration



Parameters

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] × V_1 + 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])

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)

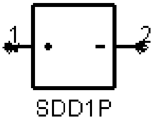
   If $V_2 = 5V_1$, then Coeff = list(5)

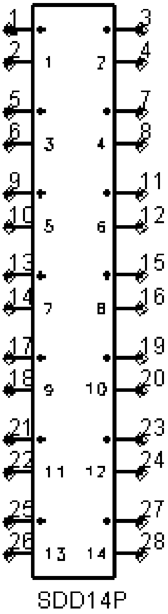
   If $V_2 = 5$, then Coeff = list(5,0)

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

I[i, j]] = explicit equation that describes port current in terms of voltage. *i* refers to the port number. *j* refers to the weighting function (0,1, or user defined).

F[i,j]] = implicit equation defining a nonlinear relationship of port voltages and port currents (or the currents of certain other devices) that is equal to 0. *i* refers to the port number. *j* refers to the weighting function (0, 1, or user defined).

H[k] = user-defined weighting function

C[l] = controlling current device name

Cport[l] = port number on controlling current device to use (default: 1)

In[i,j] = equation that specifies the noise current squared. *i* refers to the port number. *j* refers to the weighting function (0, 1, or user-defined)

Nc[i,j] = complex noise correlation coefficient between ports *i* and *j*.

_M = number of devices in parallel (default: 1)

Range of Usage

$0 \le i \le 10$
$0 \le j$
$2 \le k$
$1 \le l$

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 error to place the components.
3. The port index *i* can go from 1 to 14, not 0 to 10, and not 13.
4. Port variables, *_in* and *_vn*, contain the current and voltage values of a port, respectively. n specifies the port number, for example, the current and voltage variables for port one 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:

   $$i_k = f(v_1, v_2, \ldots v_n)$$

   The *implicit* representation uses an implicit relationship between any of the port currents and any of the port voltages:

   $$f_k(v_1, v_2, \ldots v_n, i_1, i_2, \ldots i_n) = 0$$

   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[k] 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 *jw* and is used when a time derivative is desired. Other weighting functions can be defined, starting with 2.

   H[k] 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[k] 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[l]. These currents can then be referred to using the variable *_ck* for the *kth* referenced current. The variables *_ck* can be used in the SDD equations along with the SDD port voltages *_vn* and port currents *_in*.

8. In[] and Nc[] are used to specify the noise behavior of the SDD. In[*i*,*j*] specifies

   (i_i, i_i*)

   the short-circuit noise current squared, in units of amperes squared at port *i*, with weighting function *j*.

   Nc[*i*,*j*] specifies the complex noise correlation coefficient between ports *i* and *j*. It should be a complex number with a magnitude less than or equal to one, Nc[i,j] and Nc[j,i] should be complex conjugates of each other.

$$Nc\lceil i,\ j\rceil = \frac{(i_i, i_j*)}{\sqrt{(i_i, i_i*)(i_i, i_j*)}}$$

9. For more information on how to use these devices and application examples, refer to Chapter 5 *Custom Modeling with Symbolically-Defined Devices* in the *Analog/RF User-Defined Models* manual.