AIM SPICE CIRCUIT SIMULATION GUIDE

SPICE is the standard circuit simulator in the industry. You can code in your circuit schematic and SPICE will compute a number of variables, such as DC node voltages, transfer curves, frequency response curves, and transient analysis showing timing response of the circuit to pulsed or otherwise time varying input. It is an invaluable tool in design and will also allow a student to probe the mysteries of electronics by giving you the answers. We will download a SPICE version that is suitable for PCs (sorry Mac lovers like me).

There is a readme.txt file to help you, and there is a help icon within SPICE. Searching google for AIM SPICE returns many sources of information.

There are three steps in this learning:

1. Download AIM SPICE from a web site. You can find this site by typing “aim spice” on the google search engine. Or you can go to http://www.aimspice.com/. Click on ‘download software’. Click on the install file. If you are installing on the computers in Room ECE 211, install to this directory “C\documents and settings (your profile)\Aimspice” You are ready to learn SPICE.

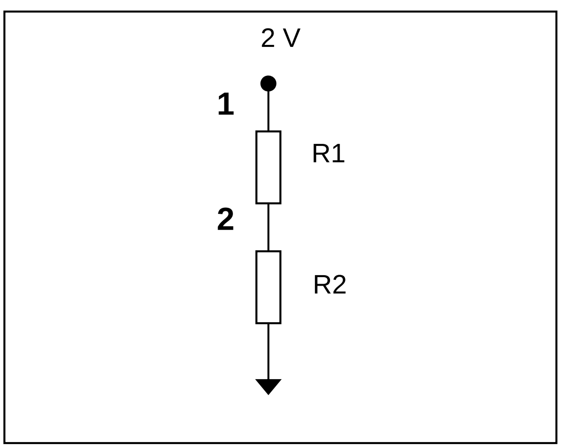
2. Creating a SPICE program of the circuit called a netlist. We will learn by example.

3. Running the simulator and asking for appropriate output information.

We will go to SPICE examples. Running one example successfully gets you 90% to the final goal. A bit of practice setting up and running SPICE programs will make you an expert in a short time. Daily practice is a good idea even if you’re just doing simple things.

Example-1

This is the simplest of circuits using a power supply and two series resistors. The schematic is below, and the SPICE code is written below the circuit. SPICE requires that the first line be a title text. Each element in the circuit (vdd, R1, and R2) is identified by node numbers and a value. Ground is usually given a zero node number. You will type in the SPICE netlist inside the simulator program in a text editor similar to WORD. The netlist is shown next to the schematic.




```
Example1 using vdd and resistors
vdd 1 0 dc 2v
r1 1 2 5k
r2 2 0 10k
```

Getting into SPICE and Writing the Code:

Double click on the file 'aimspice.exe'. An untitled file will appear. Go to 'save as' in the file menu on top. Save it as any name you want to give it. You will then notice that the file picked up an extension of '.cir' A *.cir is required for running SPICE. Now type in the lines of code as shown above for the circuit. Save the file so you don't lose your work.

The 'OP' icon on the top stands for operation, or operating (DC) voltages The AIM-Spice Toolbars in the help section explain all of the icons. Click on the 'OP' icon. A dialog box showing the simulation statistics will pop up, followed by an EXCEL looking file showing the computed node voltages. Congratulations! You have just run your first SPICE circuit. Other icons give graphical outputs that can be used as is or copied to a WORD, PowerPoint, or EXCEL file for more presentation flexibility.

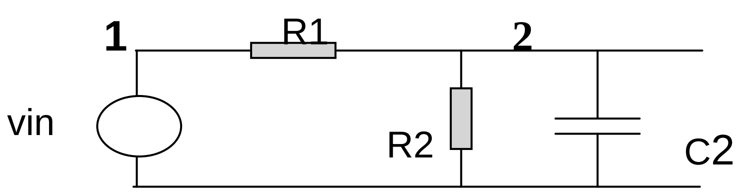
<u>OUTPUT</u>

Example1 using vdd and resistors

Variables in circuit	Values
v(1)	2 V
v(2)	1.33333 V
i(vdd)	-0.000133333 A

EXAMPLE –2

The SPICE code for the ac circuit below is given to the right of the circuit. Simulate a frequency response curve.




```
AC circuit
vin 1 0 1 ac
r1 1 2 10k
r2 2 0 50k
c2 2 0 1n
```

Click on the 'AC' icon. Several dialog boxes will pop up. For the "AC Analysis Parameters" box, enter the following parameters and click on "run":

LIN

Number of points=1000

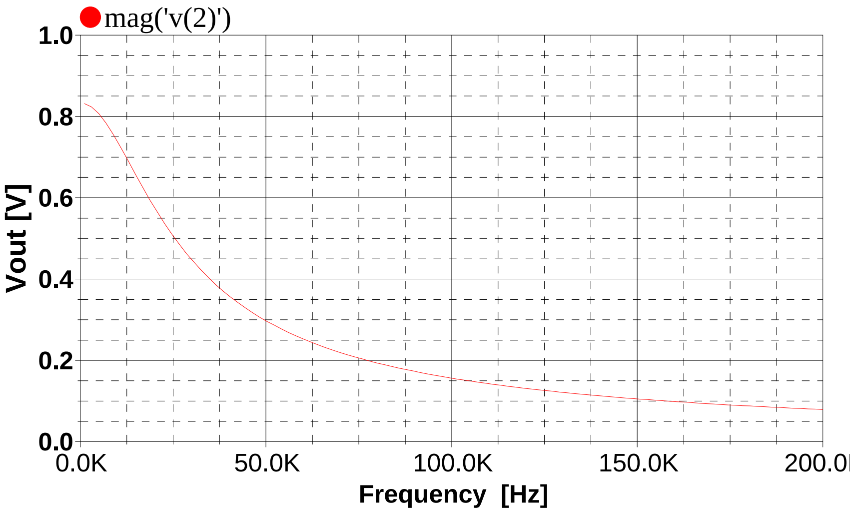
Start frequency=0

End Frequency=200k

Click on "OK." A second dialog box asks for the variables to plot. Look at your schematic and netlist and select "magnitude plot" and "v(2) voltage" for the variable. You will get an x-y plot with no data. You will get the plot in a moment. Now go under the "Control" menu at the top and click on "Start Simulation'. A popup box appears giving run "Simulation Statistics." Click on "OK" and the curve appears on the plot. The 'format' menu allows you to adjust the axis data marks or the legend. Auto-scale also does a good job.

You can plot the curve by double clicking inside the figure and it will expand to screen full scale. There are two ways to copy the curve: (1) go to the 'edit' menu, click 'copy' for the plot graphic, and paste into a WORD file, or (2) Go to the 'file' menu and click on 'export to spreadsheet' to put the data into an EXCEL type file. Copy the data in the file (using keyboard commands -control-a and control-c) and paste into an EXCEL file (control-v) for your further manipulation.

OUTPUT: The frequency response

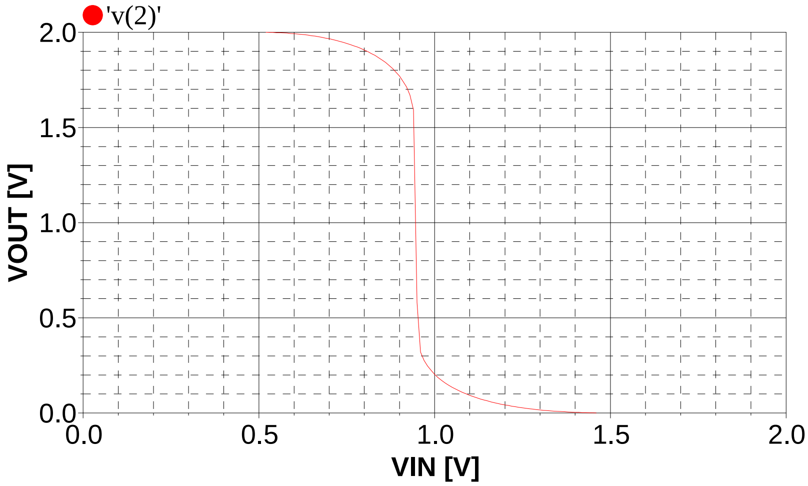


EXAMPLE-3

The simple CMOS inverter has two transistors, but great complexity. The voltage transfer curve plotting VOUT versus VIN is fundamental. Write the SPICE netlist below (and watch your "l"), click on "DC" icon, and plot the results.

```
CMOS Inverter Transfer Curve
vdd 3 0 dc 2
vin 1 0 dc 0.0 pulse(0 2 5ns 2ns 2ns 40ns)
m1 2 1 3 3 ptype l=2u w=8u
m2 2 1 0 0 ntype l=2u w=4u
.model ptype pmos(level=2 vto=-0.5 kp=8.5e-6 gamma=0.4 phi=0.65 lambda=0.05 xj=0.5e-6)
.model ntype nmos(level=2 vto=0.5 kp=24e-6 gamma=0.15 phi=0.65 lambda=0.015 xj=0.5e-6)
```

OUTPUT Voltage Transfer Curve (Double click on the plot. Make the plot “pretty”, and then go to ‘edit’ menu, and ‘copy’. Then paste into a report.



SPICE trick: Plot v(2) and vin and you will get the transfer curve and a 45^o line. The intersection defines the logic threshold voltage (V_{thr}).

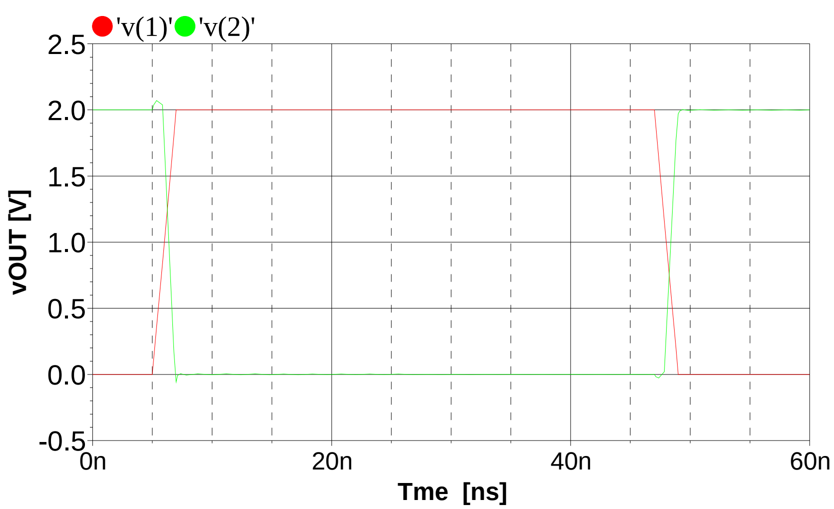
Now run a transient analysis using “TR” with these parameters

Step Size=0.1

Final Time=60ns

Plot with respect to variables v(1) and v(2)

OUTPUT Transient Analysis



Observe that no capacitors were inserted in the transistor model description so no real timing analysis occurred. Your delay in the curve is the increment defined in the plot. You will be emailed a model description for p- and n-MOS transistors that includes capacitance and other parameters that make the calculation more accurate.

Detailed Level=2 transistor parameters and CMOS inverter curve

CMOS Inverter Transfer Curve

vdd 3 0 dc 2

vin 1 0 dc 0.0 pulse(0 2 5ns 2ns 2ns 40ns)

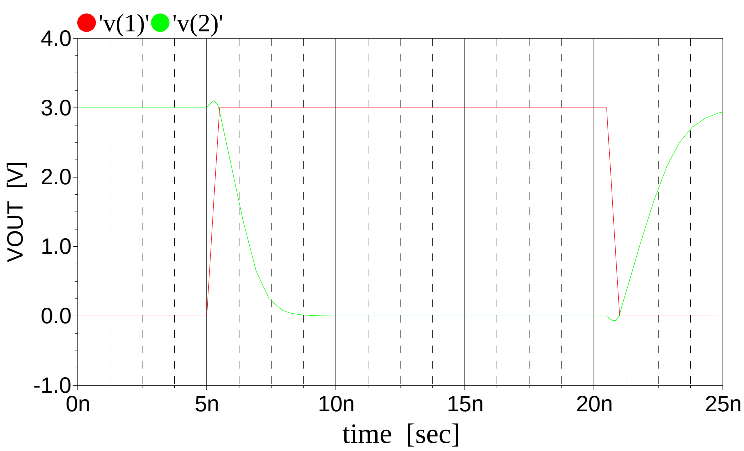
c1 2 0 100f

m1 2 1 3 3 ptype l=2u w=8u

m2 2 1 0 0 ntype l=2u w=4u

.MODEL CMOSN NMOS LEVEL=2 LD = 0.250000U TOX=417.000008E-10 NSUB=6.108619E+14 VTO=0.825008 KP=4.919000E-05 GAMMA=0.172 PHI=0.6 UO=594 UEXP=6.682275E-02 UCRIT=5000 DELTA=5.08308 VMAX=65547.3 XJ=0.250000U LAMBDA=6.636197E-03 NFS=1.98E+11 NEFF=1 NSS=1.000000E+10 TPG=1.000000 RSH=32.740000 CGDO=3.10534E-10 CGSO=3.105345E-10 CGBO=3.848530E-10 CJ=9.494900E-05 MJ=0.847099 CJSW=4.410100E-10 MJSW=0.334060 PB=0.800000

.MODEL CMOSP PMOS LEVEL=2 LD = 0.227236U TOX=417.000008E-10 NSUB=1.056124E+16 VTO=-0.937048 KP=1.731000E-05 GAMMA=0.715 PHI=0.6 UO=209 UEXP=0.23383 UCRIT=47509.9 DELTA=1.07179 VMAX=100000 XJ=0.250000U LAMBDA=4.391428E-02 NFS=3.27E+11 NEFF=1.001 NSS=1.000000E+10 TPG=-1.000000 RSH=72.960000 CGDO=2.822585E-10 CGSO=2.822585E-10 CGBO=5.292375E-10 CJ=3.224200E-04 MJ=0.584956 CJSW=2.979100E-10 MJSW=0.310807 PB=0.800000



AIM SPICE REFERENCE MANUAL

Title Line and Comments

Title Line

General form:

```
Any text
```

Example:

```
SIMPLE DIFFERENTIAL PAIR
MOS OPERATIONAL AMPLIFIER
```

The title line must be the first line in the circuit description.

Comment Lines

General form:

```
*(any text)
!(any text)
```

Example:

```
* MAIN CIRCUIT STARTS HERE
r1 drain vdd 10k ! load resistance
```

An asterisk in the first column indicates that this line is a comment line. If a comment follows an AIM-Spice command on the same line, it must be preceded by the '!' character.

Comment lines may be placed anywhere in the circuit description.

Comment Blocks

A set of comment lines can be grouped together into a block as shown below.

General form:

```
#com
(any text)
.
.
(any text)
#endcom
```

Example:

```
#com
this line is considered a comment
this line also
#endcom
```

Comment blocks may be placed anywhere in the netlist.

Simulator Commands

.ac

General form:
```
.ac [type] [nb] [fstart] [fstop]
```

Example:
```
.ac dec 50 1 1g
```

This command is used to request a small-signal AC analysis over a given frequency range. The parameter `type` can be either `dec`, `oct` or `lin`, which specifies logarithmic, octave, or linear distribution of frequencies, respectively. The parameter `nb` specifies the number of frequency points per decade, octave or total depending on the value of the `type` parameter. `fstart` and `fstop` are the start and stop frequencies in Hertz, respectively.

The AC analysis is typically used to calculate the frequency response of a circuit over a range of frequencies.

Note that in order for this analysis to be meaningful, at least one independent source must be specified with an ac value.

If the circuit has only one ac input, it is convenient to set that input to unity and zero phase. Then the output variable will be the transfer function of the output variable with respect to the input.

.connect

General form:
```
.connect [node name 1] [node name 2]
```

Example:
```
.connect vss 0
```

This command is used to directly connect two nodes.

.dc

General form:
```
.dc [sn] [start] [stop] [incr] <[sn2] [start2] [stop2] [incr2]>
```
or
```
.dc temp [tstart] [tstop] [tincr]
```

Examples:
```
.dc vin 0 1 0.1
.dc vds 0 1 0.01 vgs 0.4 1 0.2
```

This command is used to request a DC analysis sweeping one or two independent sources (voltage and/or current). The parameter `sn` is the name of an independent voltage or current source defined in the circuit. The parameters `start`, `stop` and `incr`, are the starting, final and incrementing values, respectively. An optional specification of a second sweep source can be specified. In the second form of the command, a temperature sweep is requested, where `tstart`, `tstop` and `tincr` are the starting, final and increment temperatures in degrees centigrade, respectively.

The DC operating point of the circuit is calculated for every value of the source(s) or, in case of the second form, temperature.

If a second source is specified with associated sweep parameters, the first source is swept over its range for each value of the second source. This option is useful for obtaining semiconductor device output characteristics.

.defwave

General form:

```
.defwave wave_name = wave_expression
```

Examples:

```
.defwave vo = v(vop)-v(von)
.defwave rout = 1/gds(m1)
```

This command is used to define a new wave which can be a function of previously defined waves, circuit variables (node voltages/branch currents) and device variables. For a list of operators and mathematical functions see the description of the Non-linear Dependent Source.

.ends

General form:

```
.ends <subcircuit name>
```

Example:

```
.ends opamp
```

Each subcircuit definition must end with the `.ends` command. A subcircuit name after `.ends` indicates ending of the corresponding subcircuit. Otherwise all definitions are ended.

.extract

General form:

```
.extract <analysis> <label=name> <file=filename> function
```

Example:

```
.extract phmrgn(v(vo))
```

This command extracts waveform information using a set of predefined functions. The optional parameter `analysis` can be one of the following: `ac`, `dc`, `noise` or `tran`. The parameter `label` can be used to label the results of an extract command. The optional parameter `file` if specified directs AIM-Spice to save the results of the extract command in the file `filename`. The parameter `function` is one of the following:

Function	Description
`max(wave<,min,max>)`	Finds the maximum value of the waveform `wave` in the x-axis range `min` to `max`.
`min(wave<,min,max>)`	Finds the minimum value of the waveform `wave` in the x-axis range `min` to `max`.
`phmrgn(wave)`	Finds the phase margin of the specified complex waveform `wave`.
`xdown(wave,vth<,min,max>,n)`	Returns the x-axis value of the waveform `wave` at the `n`th occurrence of it falling below a y-axis value `vth` in the x-axis range `min` to `max`.
`xup(wave,vth<,min,max>,n)`	Returns the x-axis value of the waveform `wave` at the `n`th occurrence of it rising above a y-axis value `vth` in the x-axis range `min` to `max`.

.global

General form:

```
.global [node name 1] < node name 2> ...
```

Example:

```
.global vdd vss
```

This command is used to specify nodes to be global throughout your circuit.

.ic

General form:

```
.ic v(nodename)=value v(nodename)=value ...
```

Example:

```
.ic v(11)=5 v(1)=2.3
```

This command is used for specifying initial values of a transient analysis. It is interpreted in two ways, depending on whether UIC is specified or not.

> If UIC is specified, the node voltages in the .IC command will be used to compute initial values for capacitors, diodes, and transistors. This is equivalent to specify IC=... for each element, only more convenient. IC=... can still be specified and will override the .IC values. AIM-Spice will not perform any operating point analysis when this command is used, and therefore, the command should be used with care.
>
> AIM-Spice will perform an operating point analysis before a transient analysis if UIC is not specified. Then the .IC command has no effect.

.include

General form:

```
.include [filename]
```

Example:
```
.include d:\aimspice\cmos.mod
```

`filename` is the name of the file with path extension if needed, that will be included in the circuit netlist.

.lib

General form:
```
.lib [filename] [libtype]
```

Examples:
```
.lib d:\libraries\model_definitions.lib
.lib transistors.lib worst_case_speed
```

This command is used to specify a library file for AIM-Spice to search for model and subcircuit definitions that are not found in the netlist. Nesting of .lib is allowed.

The `libtype` parameter is used to specify library variants for process variations.

.nodeset

General form:
```
.nodeset v(node name)=value v(node name)=value ...
```

Example:
```
.nodeset v(12)=4.5 v(4)=2.23
```

This command helps AIM-Spice locating the dc operating point. Specified node voltages are used as a first guess of the dc operating point. This command is useful when analyzing bistable circuits. Normally, `.nodeset` is not needed.

.noise

General form:
```
.noise [v(output<,ref>)] [src] [type] [nb] [fstart] [fstop]
+ <pts_per_summary>
```

Example:
```
.noise v(outp,outn) vin dec 50 1 1g 1
```

This command is used to request a small-signal noise analysis over a given frequency range. The parameter `output` specifies the node for which the total output noise is calculated. If `ref` is given, the noise voltage v(output)-v(ref) is calculated. By default, `ref` is assumed to be ground. The parameter `src` is the name of an independent source to which input noise is referred to. The parameter `type` can be either `dec`, `oct` or `lin`, which specifies logarithmic, octave, or linear distribution of frequencies, respectively. The parameter `nb` specifies the number of frequency points per decade, octove or total depending on the value of the `type` parameter. `fstart` and `fstop` are the start and stop frequencies in Hertz, respectively. `pts_per_summary` is an optional integer, if specified, the noise contributions of each noise generator is produced every `pts_per_summary` frequency points.

This analysis produces two plots. One for the Noise Spectral Density curves and one for the total Integrated Noise over the specified frequency range. All noise voltages/currents are in squared units (V^2/Hz and A^2/Hz for spectral density, V^2 and A^2 for integrated noise).

.op

General form:

```
.op
```

This command requests a DC operating point analysis of a circuit. It has no parameters.

.option

General form:

```
.option [option=val] < option=val>
```

Example:

```
.option vntol=1nV method=gear
```

A set of options that controls different aspects of a simulation is available through the option command. The options can be divided into the following four logical groups:

- General
- Analysis specific
- Device specific
- Numeric specific

The options are listed below.

General Options:

Name	Description	Default
GMIN	Minimum allowed conductance	1.0E-12
RELTOL	Relative error tolerance	0.001
ABSTOL	Absolute current error tolerance	1nA
VNTOL	Absolute voltage error tolerance	1μV
CHGTOL	Charge tolerance	1.0E-14
TNOM	Nominal temperature. The value can be overridden by a temperature specification on any temperature dependent device model.	27
TEMP	Operating temperature of the circuit. The value can be overridden by a temperature specification on any temperature dependent instance.	27

TRYTOCOMPACT	Applicable only to the LTRA model. When specified, the simulator tries to condense LTRA transmission lines past history of input voltages and currents	Not Set

Analysis Specific Options:

Name	**Description**	**Default**
TRTOL	Transient analysis error tolerance	7.0
ITL1	Maximum number of iterations in computing the dc operating point	100
ITL2	Maximum number of iterations in dc transfer curve analysis	50
ITL4	Transient analysis time point iteration limit	10

Device Specific Options:

Name	**Description**	**Default**
DEFL	Default channel length for a MOS-transistor	100µm
DEFW	Default channel width for a MOS-transistor	100µm
DEFAD	Default drain diffusion area for a MOS-transistor	0.0
DEFAS	Default source diffusion area for a MOS-transistor	0.0

Numerical Options:

Name	**Description**	**Default**
PIVTOL	Minimum value for an element to be accepted as a pivot element.	1.0E-13
PIVREL	The minimum relative ratio between the largest element in the column and a accepted pivot element	1.0E-13
METHOD	Sets the numerical integration method used by AIM-Spice. Possible methods are Gear or Trapezoidal.	Trap

.param

General forms:

```
.param [parameter name 1] = [value 1] ...
.param [parameter name 1] = [{expression 1}] ...
```

Examples:

```
.param vdd=5V length=0.1u
.param pd = {2*(W+LDIFF)}
```

This command is used to assign values to parameters used in model and device instantiations. Parameters and expressions may be used in all of the following cases:

- Device and model values
- Values of independent voltage and current sources
- Coefficients of dependent sources

Expressions can be used in the netlist with certain restrictions. Expressions must be inserted between curly brackets as shown above. Constants and parameters may be used in expressions together with built-in functions and operators. For a list of built-in functions and operators, see non-linear dependent sources.

Note: Parameters and expressions are not allowed in device and node names, Only one definition per parameter is allowed.

.plot

General form:

```
.plot [analysis] variable
```

Examples:

```
.plot ac vdb(vo)
.plot tran w(vo)
.plot dc gm(m1)
```

This command requests output of any number of variables in a form suitable for plotting, When using the interactive version of AIM-Spice this command is also used to specify which variables to plot during simulation. The optional parameter `analysis` can be one of the following: `ac`, `dc`, `noise` or `tran`. The parameter `variable` can be a defined wave, a circuit variable (node voltage/branch current) or a device variable.

.pz

General form:

```
.pz [node1] [node2] [node3] [tftype] [polezero]
```

Example:

```
.pz inp inn outp outn vol pz
```

This command is used to locate poles and/or zeros of the AC small-signal transfer function specified by the node parameters. The parameters `node1` and `node2` specifies the input nodes, and `node3` and `node4`, specifies the output nodes. The value of the parameter `tftype` can be either `vol` or `cur`, where `vol` specifies a transfer function of type (output voltage)/(input voltage) and `cur` specifies a transfer function of type (output voltage)/(input current). The parameter `polezero` can take one of the following three values: `pz` (find both poles and zeros), `pol` (find only poles), `zer` (find only zeros).

.subckt

General form:

```
.subckt [subcircuit name] n1 n2 n3 ... <PARAM: PAR=VAL ...>
```

Example:

```
.subckt opamp 1 2 3 4 5
```

A subcircuit definition starts with the `.subckt` command. `subcircuit name` is the name of the subcircuit used when referencing the subcircuit. `n1`, `n2`, ... are external nodes, excluding "0". `PARAM` is a keyword indicating parameter allocation within the subcircuit definition. `PAR=VAL` specifies that the parameter `PAR` is assigned the value `VAL` inside the subcircuit, unless another value is assigned to the parameter when the subcircuit is instantiated.

The group of elements that follows directly after the `.subckt` command defines the topology of the subcircuit. The definition must end with the `.ends` command. A subcircuit definition can contain other subcircuit definitions, device models, and call to other subcircuits. Note that device models and subcircuit definitions within a subcircuit definition are local to that subcircuit and are not available outside. Nodes used in a subcircuit are also local, except "0" (ground) which is always global.

.tf

General form:

```
.tf [outvar] [insrc]
```

Example:

```
.tf v(outp,outn) vin
.tf i(vload) vin
```

This command is used to request a calculation of small-signal quantities at zero frequency: the input resistance seen at `insrc`, the output resistance seen at `outvar`, and the gain from `insrc` to `outvar`. `outvar` must be specified as either a voltage or a current through a voltage source. `insrc` must be the name of an independent voltage source.

.tran

General form:

```
.tran [tstep] [tstop] <tstart> <tmax> <uic>
```

Example:

```
.tran 10n 1u
.tran 1n 10n uic
```

If this command is specified, AIM-Spice will calculate the large-signal time-domain transient response of the circuit from time zero to `tstop`. The parameter `tstep` is used as an initial guess for the time step used by AIM-Spice. The transient analysis always begins at time zero. The optional parameter `tstart` is used to delay the start of plotting until time equal `tstart` (default value of `tstart` is zero). To force a smaller time step than the one AIM-Spice internally chooses, specify a value for `tmax`. The optional flag `uic`, when specified, forces AIM-Spice to skip the solution of the quiescent operating point before starting the transient analysis. Initial transient conditions can then be specified in the circuit description using an IC= control command. Alternatively, an .IC command can be entered, specifying node voltages used to compute the initial conditions for the devices. (When `uic` is not specified, the .IC command and the IC= statement have no effect.)

Device Models

Models for the most important electrical and electronic devices are included in AIM-Spice. The following sections describe each of the models in detail.

A Heterostructure Field Effect Transistors (HFETs)

General form:

```
AXXXXXXX ND NG NS MNAME <L=VALUE> <W=VALUE> <TEMP=VALUE> <OFF>
+ <IC=VDS,VGS>
```

Example:

```
a1 7 2 3 hfeta l=1u w=10u
```

`ND`, `NG` and `NS` are the drain, gate and source nodes, respectively. `MNAME` is the model name, `L` is the channel length, `W` is the channel width, and `OFF` indicates an optional initial value for the element in a dc analysis. The optional `TEMP` value is the device operating temperature in degrees centigrade and overrides the temperature specified in the option value. The optional initial value `IC=VDS,VGS` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. If length and/or width is not specified, AIM-Spice will use default values, L=1µm and W=20µm.

HFET Model

```
.MODEL [model name] NHFET <model parameters>
.MODEL [model name] PHFET <model parameters>
```

AIM-Spice supports two HFET models. The parameter LEVEL selects which model to use. The default is LEVEL=1.

HFET Level 1 Model

The HFET level 1 model is a unified extrinsic model as described in section 4.6 in [1]. The model parameters are listed below. Note that the default values used correspond to the device used as an example in section 4.6 in [1].

Name	Parameter	Units	Default
Drain Current Parameters			
D1	Distance to buffer layer charge	m	0.03E-6
D2	Distance from gate to second channel	m	0.2E-6
DELTA	Transition width parameter	-	3
DELTAD	Thickness correction	m	4.5E-9
DI	Thickness of interface layer	m	0.04E-6
EPSI	Dielectric constant for interface layer	F/m	1.0841E-10
ETA	Subthreshold ideality factor	-	1.28 (NHFET) 1.4 (PHFET)

Name	Parameter	Units	Default
ETA1	Ideality factor of buffer layer charge	-	2.0
ETA2	Ideality factor of second channel conduction	-	2.0
KLAMBDA	Temperature coefficient of LAMBDA	1/(V°C)	0
KMU	Temperature coefficient of MU	m^2/(Vs°C)	0
KVTO	Temperature coefficient of VTO	V/°C	0
LAMBDA	Output conductance parameter	1/V	0.15
M	Knee shape parameter	-	3
MU	Low field mobility	m^2/vs	0.4 (NHFET) 0.03 (PHFET)
NMAX	Maximum sheet charge density in the channel	m^{-2}	2E16
RD	Drain ohmic resistance	Ω	0
RDI	Internal drain ohmic resistance	Ω	0
RS	Source ohmic resistance	Ω	0
RSI	Internal source ohmic resistance	Ω	0
SIGMA0	DIBL parameter	-	0.057
VS	Saturation velocity	m/s	1.5E5 (NHFET) 0.8E5 (PHFET)
VSIGMA	DIBL parameter	V	0.1
VSIGMAT	DIBL parameter	V	0.3
VT1	Threshold voltage of interface layer conduction	V	Calculated
VT2	Threshold voltage of second channel	V	VTO
VTO	Threshold voltage	V	0.15 (NHFET) -0.15 (PHFET)
Gate Current Parameters			
A1	First correction current coefficient	-	0
A2	Second correction current coefficient	-	0
ALPHAT	Drain temperature coefficient	K/V^2	0
ASTAR	Effective Richardson constant	A/(m^2K^2)	4.0E4
CK1	First drain temperature coefficient	-	1
CK2	Second drain temperature coefficient	V	0
CM1	Third drain temperature coefficient	-	3
CM2	Fourth drain temperature coefficient	V	0
CM3	Third correction current coefficient	-	0.17

Name	Parameter	Units	Default
DEL	Reverse junction conductance inverse ideality factor	-	0.04
GATEMOD	Gate leakage current model selector	-	0
GGR	Junction conductance at reverse bias	$1/(\Omega m^2)$	40
JS1D	Forward gate-drain diode saturation current density	A/m^2	1.0
JS1S	Forward gate-source diode saturation current density	A/m^2	1.0
JS2D	Reverse gate-drain diode saturation current density	A/m^2	1.15E6
JS2S	Reverse gate-source diode saturation current density	A/m^2	1.15E6
M1D	Forward gate-drain diode ideality factor	-	1.32
M1S	Forward gate-source diode ideality factor	-	1.32
M2D	Reverse gate-drain diode ideality factor	-	6.9
M2S	Reverse gate-source diode ideality factor	-	6.9
MT1	First drain temperature exponent	-	3.5
MT2	Second drain temperature exponent	-	9.9
MV1	Correction current exponent	-	3
PHIB	Effective heterojunction barrier height	eV	0.5
RG	Gate ohmic resistance	Ω	0
RGD	Gate-drain ohmic resistance	Ω	90
RGS	Gate-source ohmic resistance	Ω	90
AC Parameters			
CDS	Drain-source capacitance	F	0
DELF	g_{ds} transition width	Hz	0.0
FGDS	Transition frequency for g_{ds}	Hz	0.0
GAMMA	Capacitance parameter	-	3
KAPPA	Determines the relative increase in g_{ds} at high frequencies	-	0.0
MC	Capacitance transition parameter	-	3
P	Charge partitioning parameter	-	1.0
RF	Resistance in series with C_{gd}	Ω	0
RI	Resistance in series with C_{gs}	Ω	0
TF	Characteristic temperature for the frequency dependence of g_{ds}	°C	TEMP

Either intrinsic or extrinsic models can be selected by proper use of the parameters RD, RS, RDI, and RSI. If values for RD and RS are specified, the intrinsic model is selected with parasitic resistances applied externally. The extrinsic model is selected by specifying values for RDI and RSI.

Supported Analyses

Noise and Pole-Zero Analysis not supported.

Temperature effects

The temperature appears explicitly in the several exponential terms. In addition, the temperature dependence of several key parameters are modeled as shown below (in terms of absolute temperatures).

The dependence of the threshold voltage on temperature is modeled by the equation

$$V_T = \mathrm{VT0} - \mathrm{KVTO(TEMP - TNOM)}$$

where TNOM is the nominal temperature specified as an option.

The mobility and output conductance are adjusted according to:

$$\mu = \mathrm{MU} - \mathrm{KMU(TEMP - TNOM)}$$

$$\lambda = \mathrm{LAMBDA} + \mathrm{KLAMBDA(TEMP - TNOM)}$$

Frequency dependent output conductance

The output conductance g_{ds} depends on the frequency. In a small-signal ac analysis, g_{ds} is modified according to the following equations:

$$g_{ds} = g_{ds0}\left(1 + \frac{\mathrm{KAPPA}}{2}\left[1 + \tanh\left(\frac{f - f_{gds}}{\Delta f}\right)\right]\right)$$

$$\Delta f = \mathrm{DELF} \cdot \exp\left(\frac{\mathrm{TEMP}}{\mathrm{TF}}\right)$$

$$f_{gds} = \mathrm{FGDS} \cdot \exp\left(\frac{\mathrm{TEMP}}{\mathrm{TF}}\right)$$

Equivalent circuit (GATEMOD = 0)

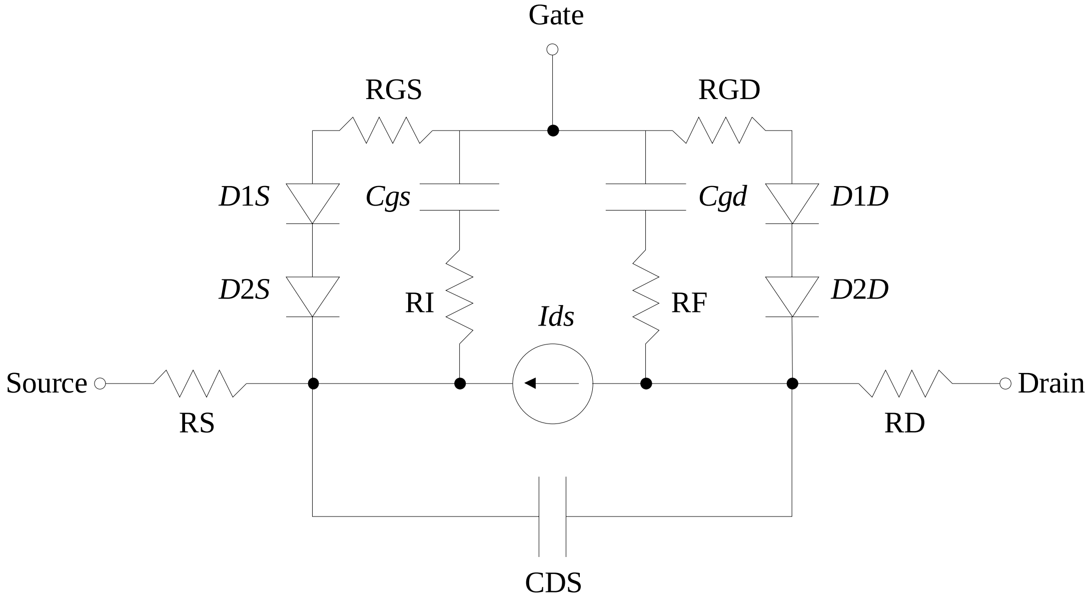


Figure A1

Equivalent circuit (GATEMOD = 1)

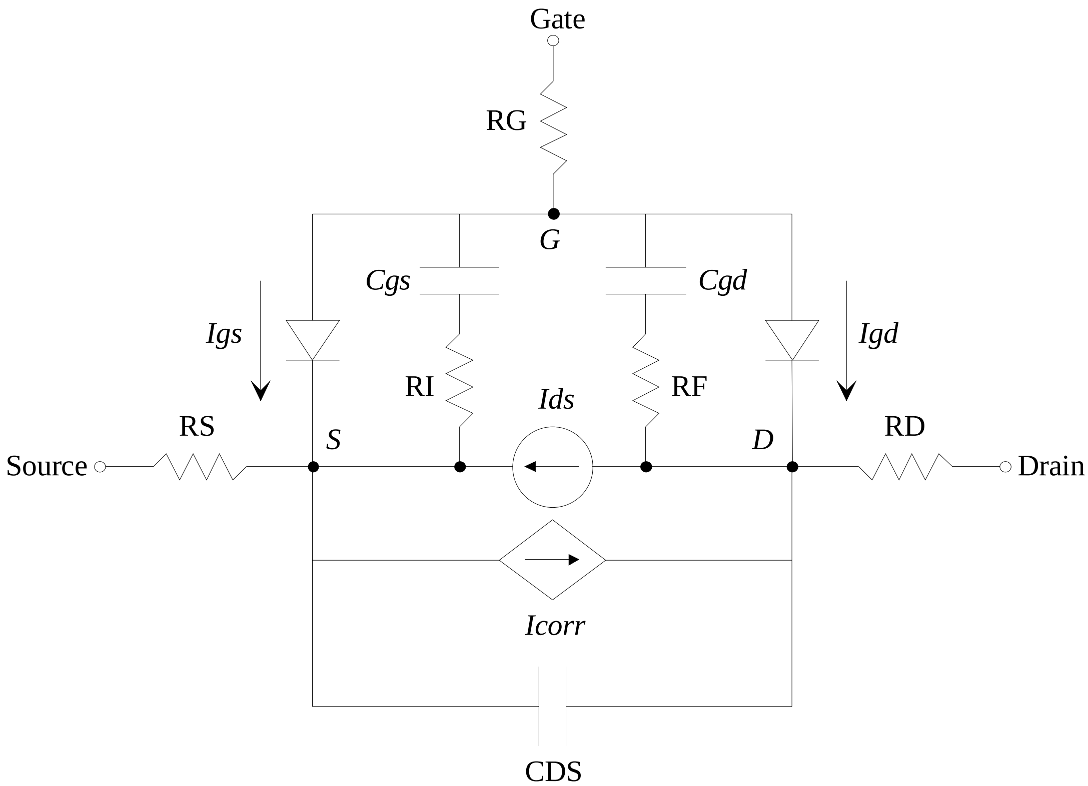


Figure A2

Drain current equations

$$I_{ds} = \frac{g_{ch} V_{ds} (1 + \lambda V_{ds})}{\left[1 + \left(V_{ds} / V_{sate}\right)^{\mathrm{M}}\right]^{1/\mathrm{M}}}$$

$$V_{sate} = \frac{I_{sat}}{g_{ch}}$$

$$g_{ch} = \frac{g_{chi}}{1 + g_{chi} (\mathrm{RSI} + \mathrm{RDI})}$$

$$g_{chi} = q n_{stot} \mathrm{W} \cdot \mu / \mathrm{L}$$

$$I_{sat} = \frac{I'_{sat}}{\left[1 + \left(I'_{sat} / I_{\max}\right)^{\mathrm{GAMMA}}\right]^{1/\mathrm{GAMMA}}}$$

$$I'_{sat} = \frac{g'_{chi} V_{gte}}{1 + g'_{chi}\ \mathrm{RSI} + \sqrt{1 + 2 g'_{chi}\ \mathrm{RSI} + (V_{gte} / V_L)^2}}$$

$$g'_{chi} = q n'_s\ \mathrm{W} \cdot \mu / \mathrm{L}$$

$$I_{\max} = q \cdot \mathrm{NMAX} \cdot \mathrm{VS} \cdot \mathrm{W}$$

$$V_L = \mathrm{VS} \cdot \mathrm{L} / \mu$$

$$V_{gte} = V_{th} \left[1 + \frac{V_{gt}}{2 V_{th}} + \sqrt{\delta^2 + \left(\frac{V_{gt}}{2 V_{th}} - 1 \right)^2} \right]$$

$$V_{gt} = V_{gs} - V_T + \sigma V_{ds}$$

$$\sigma = \frac{\mathrm{SIGMA0}}{1 + \exp\left(\frac{V_{gs} - V_T - \mathrm{VSIGMAT}}{\mathrm{VSIGMA}} \right)}$$

Calculation of total inversion charge

$$n_s = \frac{n'_s}{\left[1 + \left(n'_s / \mathrm{NMAX}\right)^{\mathrm{GAMMA}}\right]^{1/\mathrm{GAMMA}}}$$

$$n'_s = 2n_0 \ln\left[1 + \frac{1}{2}\exp\left(\frac{V_{gt}}{\eta V_{th}}\right)\right]$$

$$n_0 = \frac{\mathrm{EPSI} \cdot \mathrm{ETA} \cdot V_{th}}{2q(\mathrm{DI} + \mathrm{DELTAD})}$$

If second channel parameters (ETA2 and D2) are not given:

$$n_{stot} = n_s$$

else

$$n_{stot} = \frac{n'_{stot}}{\left[1 + \left(n'_{stot} / \mathrm{NMAX}\right)^{\mathrm{GAMMA}}\right]^{1/\mathrm{GAMMA}}}$$

where

$$n'_{stot} = \frac{n'_s \, n_{s2}}{n'_s + n_{s2}}$$

$$n_{s2} = 2n_{02} \ln\left[1 + \frac{1}{2}\exp\left(\frac{V_{gs} - \mathrm{VT2} + \sigma V_{ds}}{\mathrm{ETA2} \cdot V_{th}}\right)\right]$$

$$n_{02} = \frac{\mathrm{EPSI} \cdot \mathrm{ETA2} \cdot V_{th}}{2q \cdot \mathrm{D2}}$$

Gate current equations (GATEMOD = 0)

When specifying GATEMOD = 0, the gate leakage current is modeled as two diode paths from gate to drain and from gate to source as shown in Figure A1. Each diode path contains a series combination of a parasitic resistance and two ideal diodes. The four diodes are labeled *D*1*D*, *D*2*D*, *D*1*S* and *D*2*S*. The table below shows the ideal diode model parameters for each diode.

Diode	Ideality factor	Reverse saturation current density
*D*1*D*	M1D	JS1D
*D*2*D*	M2D	JS2D
*D*1*S*	M1S	JS1S
*D*2*S*	M2S	JS2S

The current through an ideal diode is given by

$$I_d = I_s\left[\exp\left(V / mV_{th}\right) - 1\right]$$

where I_s is the reverse saturation current and m is the ideality factor.

Gate current equations (GATEMOD = 1)

When GATEMOD = 1 is specified, the effects of hot-electrons near the drain side of the channel is accounted. The equivalent circuit is shown in Figure A2. Note that it contains only the diodes which represent the heterojunction, and hence, it may not describe the gate current at low current levels for some devices.

$$I_{gd} = \frac{\mathrm{L}\cdot\mathrm{W}}{2}\mathrm{ASTAR}\cdot T_d^{\,2}\exp\left(-\frac{q\cdot\mathrm{PHIB}}{k_B T_d}\right)\exp\left(\frac{q(V_{GS} - V_{DSE})}{\mathrm{M2D}\cdot k_B T_d}\right) - \frac{\mathrm{L}\cdot\mathrm{W}}{2}\mathrm{ASTAR}\cdot\mathrm{TEMP}^2\exp\left(-\frac{q\cdot\mathrm{PHIB}}{k_B\mathrm{TEMP}}\right)$$

$$I_{gs} = \frac{\mathrm{L}\cdot\mathrm{W}}{2}\mathrm{ASTAR}\cdot\mathrm{TEMP}^2\cdot\exp\left(-\frac{q\cdot\mathrm{PHIB}}{k_B\cdot\mathrm{TEMP}}\right)\left[\exp\left(\frac{qV_{GS}}{\mathrm{M2S}\cdot k_B\cdot\mathrm{TEMP}}\right) - 1\right]$$

$$T_d = \mathrm{TEMP} + \mathrm{ALPHAT}\frac{V_{DSE}^2}{\left[1 + (V_{DSE} / V_{kneet})^{\mathrm{MT1}}\right]^{1/\mathrm{MT1}}}$$

$$V_{DSE} = \frac{V_{DS}}{\left[1 + (V_{DS} / V_{\max})^{\mathrm{MT2}}\right]^{1/\mathrm{MT2}}}$$

$$V_{kneet} = \mathrm{CK1}\cdot V_{sate} + \mathrm{CK2}$$

$$V_{\max} = \mathrm{CM1}\cdot V_{sate} + \mathrm{CM2}$$

Gate current at reverse gate bias

$$I_g = \frac{\mathrm{LW}}{2}\mathrm{GGR}\cdot V_{gs}\exp\left(-\frac{qV_{gs}\mathrm{DEL}}{k_B\mathrm{TEMP}}\right)+\frac{\mathrm{LW}}{2}\mathrm{GGR}\cdot V_{gd}\exp\left(-\frac{qV_{gd}\mathrm{DEL}}{k_B\mathrm{TEMP}}\right)$$

Correction current

If GATEMOD = 0, the correction current is zero. If GATEMOD = 1 is specified, the correction current is given by the following equations:

$$I_{corr} = \mathrm{A1}\cdot I_{gs} - \mathrm{A1}\cdot(1+\mathrm{A2}\cdot V_{gte}V'_{DSE})I_{gd}$$

$$V'_{DSE} = \frac{V_{DS}}{\left[1+(V_{DS}/V_{\max 1})^{\mathrm{MV1}}\right]^{1/\mathrm{MV1}}}$$

$$V_{\max 1} = \mathrm{CM3}\cdot V_{sate}$$

Capacitance equations

$$C_{gs} = C_f + \frac{2}{1+p}\left\{\frac{2}{3}C_{gc}\left[1-\left(\frac{V_{sate}-V_{dse}}{2V_{sate}-V_{dse}}\right)^2\right]\right\}$$

$$C_{gd} = C_f + \frac{2p}{1+p}\left\{\frac{2}{3}C_{gc}\left[1-\left(\frac{V_{sate}}{2V_{sate}-V_{dse}}\right)^2\right]\right\}$$

$$C_f = 0.5\cdot\mathrm{EPSI}\cdot\mathrm{W}$$

$$V_{dse} = V_{ds}\left[1+\left(\frac{V_{ds}}{V_{sate}}\right)^{\mathrm{MC}}\right]^{-1/\mathrm{MC}}$$

$$p = \mathrm{P} + (1-\mathrm{P})\exp\left(-\frac{V_{ds}}{V_{sate}}\right)$$

$$C_{gc} = \mathrm{L} \cdot \mathrm{W}\left(c_{gc} + c_{g1}\right)$$

$$c_{gc} = q\frac{dn_{stot}}{dV_{gs}}$$

$$c_{g1} = \left[\frac{\mathrm{D1}}{\mathrm{EPSI}} + \frac{\mathrm{ETA1} \cdot V_{th}}{qn_{01}}\exp\left(-\frac{V_{gt1}}{\mathrm{ETA1} \cdot V_{th}}\right)\right]^{-1}$$

$$n_{01} = \frac{\mathrm{EPSI} \cdot \mathrm{ETA1} \cdot V_{th}}{2q \cdot \mathrm{D1}}$$

$$V_{gt1} = V_{gs} - V_{T1}$$

If VT1 is not specified, V_{T1} is calculated using the following expression:

$$V_{T1} = \mathrm{VTO} + \frac{q \cdot \mathrm{NMAX} \cdot \mathrm{DI}}{\mathrm{EPSI}}$$

HFET Level 2 Model

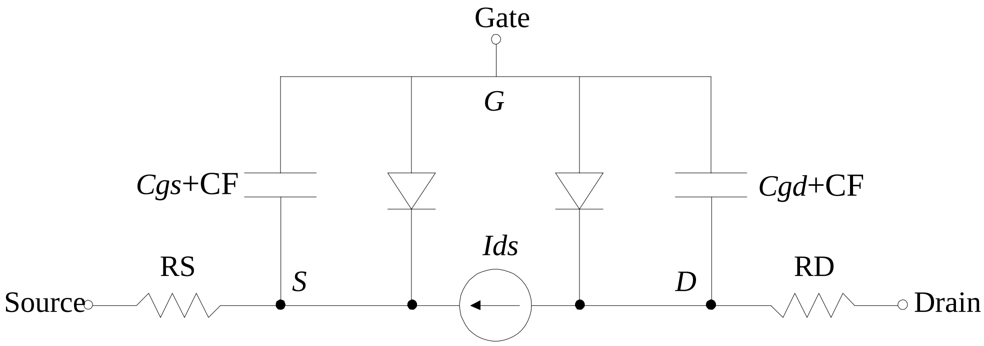
The HFET level 2 model is a simplified version of the level 1 model. The model is optimized for speed and is suitable for simulation of digital circuits. To increase the speed, some of the features included in the level 1 model is not implemented for the level 2 model. The model parameters are listed below.

Name	Parameter	Units	Default
	Drain Current Parameters		
	Same as for level 1		
	Gate Current Parameters		
DEL	Reverse junction conductance inverse ideality factor	-	0.04
GGR	Junction conductance at reverse bias	$1/\Omega m^2$	0
JS	Forward bias saturation current	A/m^2	0
N	Forward bias ideality factor	–	1
	AC Parameters		
CF	Fringing capacitance	F	0
GAMMA	Capacitance parameter	-	3
MC	Capacitance transition parameter	-	3

P	Charge partitioning parameter	-	1.0

Either intrinsic or extrinsic models can be selected by proper use of the parameters RD, RS, RDI, and RSI. If values for RD and RS are specified, the intrinsic model is selected with parasitic resistances applied externally. The extrinsic model is selected by specifying values for RDI and RSI.

Equivalent circuit



Drain current equations

Same as for level 1.

Gate current equations

$$I_g = \mathrm{JS}\frac{\mathrm{LW}}{2}\left[\exp\left(\frac{V_{gs}}{\mathrm{N}\cdot V_{th}}\right)-1\right]+\frac{\mathrm{LW}}{2}\mathrm{GGR}\cdot V_{gs}\exp\left(-\frac{qV_{gs}\mathrm{DEL}}{k_B\mathrm{TEMP}}\right)+$$

$$\mathrm{JS}\frac{\mathrm{LW}}{2}\left[\exp\left(\frac{V_{gd}}{\mathrm{N}\cdot V_{th}}\right)-1\right]+\frac{\mathrm{LW}}{2}\mathrm{GGR}\cdot V_{gd}\exp\left(-\frac{qV_{gd}\mathrm{DEL}}{k_B\mathrm{TEMP}}\right)$$

Capacitance equations

Same as for level 1 except for that the fringing capacitance is specified as a model parameter and is not calculated.

Supported Analyses

Noise and Pole-Zero Analysis not supported.

References

[1] K. Lee, M. Shur, T. A. Fjeldly and T. Ytterdal, *Semiconductor Device Modeling for VLSI*, 1993, Prentice Hall, New Jersey.

B Non-linear Dependent Sources

General form:

```
BXXXXXXX N+ N- <I=EXPR> <V=EXPR>
```

Example:

```
b1 0 1 i=cos(v(1))+sin(v(2))
b1 0 1 v=ln(cos(log(v(1,2)^2)))-v(3)^4+v(2)^v(1)
b1 3 4 i=17
b1 3 4 v=exp(pi^i(vdd))
```

`N+` and `N-` are the positive and negative nodes respectively. The values of the `V` and `I` parameters determine the voltages and currents across and through the device respectively. If `I` is given then the device is a current source, and if `V` is given the device is a voltage source. One and only one of these parameters must be given.

During an ac analysis, the source acts as a linear dependent source with a proportionality constant equal to the derivative of the source at the dc operating point.

The expressions given for `V` and `I` may be any function of node voltages and/or currents through voltage sources in the system. The following are allowed functions of real variables:

abs	asinh	cosh	sin	u
acos	atan	exp	sinh	uramp
acosh	atanh	ln	sqrt	
asin	cos	log	tan	

Note that all functions have only one argument.

The following operations are defined:

`+` `-` `*` `/` `^` unary `-`

If the argument of `log`, `ln`, or `sqrt` becomes less than zero, the absolute value of the argument is used. If a divisor becomes zero or the argument of `log` or `ln` becomes zero, an error will result. Other problems may occur when the argument of a function in a partial derivative enters a region where that function is undefined.

The functions `u` and `uramp` are the unit step and unit ramp, respectively.

To introduce time into an expression, you can integrate the current from a constant current source with a capacitor and use the resulting voltage. For a correct result, you have to set the initial voltage across the capacitor.

Non-constant capacitors, resistors, and inductors may be synthesized using non-linear dependent sources. Here is an example on how to implement a non-constant capacitor (C(V)==a*V+b):

```
* Bx: define the capacitance function C(V)=a*V+b
Bx 1 0 v=(a*v(pos,neg)+b)*v(pos,neg)
```

```
* Cx: linear capacitance
Cx 2 0 1
* Vx: Ammeter to measure current into the capacitor
Vx 2 1 DC 0 Volts
* Drive the current through Cx back into the circuit
Fx pos neg Vx 1
```

Supported Analyses

All.

C Capacitors

General form:

```
CXXXXXXX N+ N- VALUE <IC=Initial values>
```

Examples:

```
cl 66 0 70pf
CBYP 17 23 10U IC=3V
```

`N+` and `N-` are the positive and negative element nodes respectively. `VALUE` is the capacitance in Farads.

The optional initial value is the initial time zero value of the capacitor voltage in Volts. Note that the value is used only when the option UIC is specified in a transient analysis.

Semiconductor Capacitors

General form:

```
CXXXXXXX N1 N2 <VALUE> <MNAME> <L=LENGTH> <W=WIDTH>
+ <IC=VALUE>
```

Examples:

```
CMOD 3 7 CMODEL L=10U W=1U
```

This is a more general model for the capacitor than the one presented above. It gives you the possibility of modeling temperature effects and calculating capacitance values based on geometric and process information. `VALUE` if given, defines the capacitance, and information on geometry and process will be ignored. If `MNAME` is specified, the capacitance value is calculated based on information on process and geometry. If `VALUE` is not given, then `MNAME` and `LENGTH` must be specified. If `WIDTH` is not given, then the model default width will be used.

Capacitor Model

```
.MODEL [model name] C <model parameters>
.MODEL [model name] CAP <model parameters>
```

The model allows calculation of the capacitance based on information on geometry and process by the expression:

$$C = \mathrm{CJ} \cdot (\mathrm{L} - \mathrm{NARROW}) \cdot (\mathrm{W} - \mathrm{NARROW}) + 2 \cdot \mathrm{CJSW} \cdot (\mathrm{L} + \mathrm{W} - 2 \cdot \mathrm{NARROW})$$

where the parameters are defined below.

Name	Parameter	Unit	Default
CJ	Junction bottom capacitance	F/m^2	-
CJSW	Junction sidewall capacitance	F/m	-
DEFW	Default width	m	1e-6
NARROW	Narrowing due to side etching	m	0.0

Supported Analyses
All.

D Diodes

General form:

```
DXXXXXXX N+ N- MNAME <AREA> <OFF> <IC=VD> <TEMP=T>
```

Examples:

```
DBRIDGE 2 10 DIODE1
DCLMP 3 7 DMOD 3.0 IC=0.2
```

`N+` and `N-` are the positive and negative nodes, respectively. `MNAME` is the model name, `AREA` is the area factor, and `OFF` indicates an optional initial value during a dc analysis. If the area factor is not given, 1 is assumed. The optional initial value `IC=VD` is meant to be used together with an UIC in a transient analysis. The optional `TEMP` value is the temperature at which this device is to operate. It overrides the temperature specified as an option.

Diode Model

```
.MODEL [model name] D <model parameters>
```

AIM-Spice has 2 diode models. Level 1, the default model, is an expanded version of the standard diode model supplied from Berkeley (extended to include high-level injection and generation/ recombination current). Level 2 is a GaAs/AlGaAs heterostructure diode model described in section 1.10 in [1]. To select the heterostructure diode model specify LEVEL=2 on the model line.

Level 1 model parameters are:

Name	Parameter	Units	Default
IS	Saturation current (level 1 only)	A	1.0e-14
RS	Ohmic resistance	Ω	0
N	Emission coefficient	-	1
TT	Transit time	s	0
CJO	Zero bias junction capacitance	F	0
VJ	Junction potential	V	1
M	Grading coefficient	-	0.5
EG	Activation energy	eV	1.11
IKF	Corner for high injection current roll-off	A	infinite
ISR	Recombination saturation current	A	0
NR	Recombination emission coefficient	-	2
XTI	Saturation current temperature exponent	-	3.0
KF	Flicker noise coefficient	-	0
AF	Flicker noise exponent	-	1
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5

Name	Parameter	Units	Default
BV	Reverse breakdown voltage	V	infinite
IBV	Current at breakdown voltage	A	1.0e-3
TNOM	Parameter measurement temperature	°C	27

Level 2 model parameters are (in addition to those for level 1):

Name	Parameter	Units	Default
DN	Diffusion constant for electrons	m^2/s	0.02
DP	Diffusion constant for holes	m^2/s	0.000942
LN	Diffusion length for electrons	m	7.21e-5
LP	Diffusion length for holes	m	8.681e-7
ND	Donor doping density	m^{-3}	7.0e24
NA	Acceptor doping density	m^{-3}	3e22
DELTAEC	Conduction band discontinuity	eV	0.6
XP	p-region width	m	1μm
XN	n-region width	m	1μm
EPSP	Dielectric constant on p-side	F/m	1.0593e-10
EPSN	Dielectric constant on n-side	F/m	1.1594e-10

Temperature Effects

Temperature appears explicitly in the exponential terms.

Temperature dependence of the saturation current in the junction diode model is determined by:

$$I_S(T_1) = I_S(T_0)\left(\frac{T_1}{T_0}\right)^{\frac{\mathrm{XTI}}{\mathrm{N}}} \exp\left(\frac{E_g q(T_1 - T_0)}{\mathrm{N}kT_1 T_0}\right)$$

where k is Boltzmann's constant, q is the electronic charge, EG is the energy gap (in eV), XTI is the saturation current temperature exponent, and N is the emission coefficient. The last three quantities are model parameters.

For Schottky barrier diodes, the value for XTI is usually 2.

Supported Analyses

All.

E Linear Voltage-Controlled Voltage Sources

General forms:

```
Exx N+ N- NC+ NC- VALUE
Exx N+ N- POLY(ORDER) PNC+ PNC- <PNC+ PNC-> CP <CP>
```

Parameters:

`xx`	Name of the source
`N+`	Name of positive node
`N-`	Name of negative node
`NC+`	Name of positive controlling node
`NC-`	Name of negative controlling node
`VALUE`	Voltage gain
`POLY`	Keyword indicating that the source has a non-linear polynomial description
`ORDER`	Order of the polynomial
`PNC+`	Name of positive controlling node producing the voltage difference for the function arguments of the polynomial. Number is equal to the order of the polynomial
`PNC-`	Name of negative controlling node producing the voltage difference for the function arguments of the polynomial. Number is equal to the order of the polynomial
`CP`	Coefficients of the polynomial

Examples:

```
e1 2 3 14 1 2.0
```

Specifies that the voltage applied between nodes 14 and 1 is twice the potential difference between nodes 2 and 3

```
e2 99  0 poly(2) (3,0) (4,0) 0 0.5 0.5 1.0 2.3
```

Specifies a second order non-linear voltage controlled voltage source connected between node 99 and ground. The two controlling voltages appear between node 3 and ground, and between node 4 and ground. Polynomial coefficients are 0, 0.5, 0.5, 1.0 and 2.3. The resulting non-linear voltage function has the following form:

$$v(99,0) = 0 + 0.5\cdot v(3,0) + 0.5\cdot v(4,0) + 1.0\cdot v(3,0)^2 + 2.3\cdot v(3,0)\cdot v(4,0)$$

Polynomial Source

Non-linear polynomial sources with multi-dimensional arguments are supported, defined by the keyword POLY.

The polynomials are specified by the coefficients $p_0\ldots p_n$. The significance of the coefficients depends upon the order of the polynomial, as shown below:

<u>First order polynomial</u>

$$\mathrm{v(N+, N-)} = \mathrm{CP0} + \mathrm{CP1}\,f_\mathrm{a} + \mathrm{CP2}\,f_a^2 + \mathrm{CP3}\,f_a^3 \ldots$$

where f_a is v(PNC+,PNC-).

Second order polynomial

$$\text{v(N+, N-)} = \text{CP0} + \text{CP1}\,f_a + \text{CP2}\,f_b + \text{CP3}\,f_a^2 + \text{CP4}\,f_a f_b + \text{CP5}\,f_b^2 + \\ \text{CP6}\,f_a^3 + \text{CP7}\,f_a^2 f_b + \text{CP8}\,f_a f_b^2 \ldots$$

where f_a is v(PNC1+,PNC1-) and f_b is v(PNC2+,PNC2-).

Third order polynomial

$$\text{v(N+, N-)} = \text{CP0} + \text{CP1}\,f_a + \text{CP2}\,f_b + \text{CP3}\,f_c + \text{CP4}\,f_a^2 + \text{CP5}\,f_a f_b + \text{CP6}\,f_a f_c + \\ \text{CP7}\,f_b^2 + \text{CP8}\,f_b f_c + \text{CP9}\,f_c^2 + \text{CP10}\,f_a^3 \ldots$$

where f_a is v(PNC1+,PNC1-), f_b is v(PNC2+,PNC2-) and f_c is v(PNC3+,PNC3-).

Supported Analyses
All.

F Linear Current-Controlled Current Sources

General forms:

```
Fxx N+ N- VNAME VALUE
Exx N+ N- POLY(ORDER) PVNAME <PVNAME> CP <CP>
```

Parameters:

`xx`	Name of the source
`N+`	Name of positive node
`N-`	Name of negative node. Current flows from the positive node through the source to the negative node
`VNAME`	Name of the voltage source where the controlling current flows. The direction of positive control current is from positive node through the source to the negative node of `VNAME`
`VALUE`	Current gain
`POLY`	Keyword indicating that the source has a non-linear polynomial description
`ORDER`	Order of the polynomial
`PVNAME`	Name of the voltage source measuring the current for the function arguments of the polynomial. Number is equal to the order of the polynomial
`CP`	Coefficients of the polynomial

Example:

```
f1 14 7 vin 5
```

Specifies that the current through f1 flowing from node 14 to node 7 is five times the current through the voltage source vin.

```
f1 voi vss poly(2) vin1 vin2 1 1 2 4 0.5
```

Specifies a second order non-linear current controlled current source connected between node voi and vss. The two controlling currents are through the two voltage sources vin1 and vin2. Polynomial coefficients are 1, 1, 1, 4 and 0.5. The resulting non-linear current function has the following form:

$$\mathrm{i(voi,vss)} = 1 + 1\cdot\mathrm{i(vin1)} + 2\cdot\mathrm{i(vin2)} + 4\cdot\mathrm{i(vin1)}^2 + 0.5\cdot\mathrm{i(vin1)}\cdot\mathrm{i(vin2)}$$

Polynomial Source

Non-linear polynomial sources with multi-dimensional arguments are supported, defined by the keyword POLY.

The polynomials are specified by the coefficients $p_0\ldots p_n$. The significance of the coefficients depends upon the order of the polynomial, as shown below:

<u>First order polynomial</u>

$$\mathrm{i(N+, N-)} = \mathrm{CP0} + \mathrm{CP1}\,f_{\mathrm{a}} + \mathrm{CP2}\,f_a^2 + \mathrm{CP3}\,f_a^3 \ldots$$

where f_a is i(PVNAME1).

Second order polynomial

$$\text{i(N+, N-)} = \text{CP0} + \text{CP1}\, f_a + \text{CP2}\, f_b + \text{CP3}\, f_a^2 + \text{CP4}\, f_a f_b + \text{CP5}\, f_b^2 + \text{CP6}\, f_a^3 + \text{CP7}\, f_a^2 f_b + \text{CP8}\, f_a f_b^2 \ldots$$

where f_a is i(PVNAME1) and f_b is i(PVNAME2).

Third order polynomial

$$\text{i(N+, N-)} = \text{CP0} + \text{CP1}\, f_a + \text{CP2}\, f_b + \text{CP3}\, f_c + \text{CP4}\, f_a^2 + \text{CP5}\, f_a f_b + \text{CP6}\, f_a f_c + \text{CP7}\, f_b^2 + \text{CP8}\, f_b f_c + \text{CP9}\, f_c^2 + \text{CP10}\, f_a^3 \ldots$$

where f_a is i(PVNAME1), f_b is i(PVNAME2) and f_c is i(PVNAME3).

Supported Analyses
All.

G Linear Voltage-Controlled Current Sources

General forms:

```
Gxx N+ N- NC+ NC- VALUE
Gxx N+ N- POLY(ORDER) PNC+ PNC- <PNC+ PNC-> CP <CP>
```

Parameters:

`xx`	Name of the source
`N+`	Name of positive node
`N-`	Name of negative node
`NC+`	Name of positive controlling node
`NC-`	Name of negative controlling node
`VALUE`	Transconductance in mhos (1/Ω)
`POLY`	Keyword indicating that the source has a non-linear polynomial description
`ORDER`	Order of the polynomial
`PNC+`	Name of positive controlling node producing the voltage difference for the function arguments of the polynomial. Number is equal to the order of the polynomial
`PNC-`	Name of negative controlling node producing the voltage difference for the function arguments of the polynomial. Number is equal to the order of the polynomial
`CP`	Coefficients of the polynomial

Examples:

```
g1 2 0 5 0 0.1m
```

Specifies that the current through g1 flowing from node 2 to ground is 0.1m times the potential difference between node 5 and ground.

```
g2 vout vss poly(2) vin1 vss vin2 vss 0.2 0.5 0.3 0.1
```

Specifies a second order non-linear voltage controlled current source connected between nodes vout and vss. The two controlling voltages appear between node vin1 and vss, and between node vin2 and vss. Polynomial coefficients are 0.2, 0.5, 0.3, 0.2 and 0.1. The resulting non-linear current function has the following form:

$$i(vout,vss) = 0.2 + 0.5 \cdot v(vin1,vss) + 0.3 \cdot v(vin2,vss) + 0.1 \cdot v(vin1,vss)^2$$

Polynomial Source

Non-linear polynomial sources with multi-dimensional arguments are supported, defined by the keyword POLY.

The polynomials are specified by the coefficients $p_0 \ldots p_n$. The significance of the coefficients depends upon the order of the polynomial, as shown below:

First order polynomial

$$i(N+, N-) = CP0 + CP1 f_a + CP2 f_a^2 + CP3 f_a^3 \ldots$$

where f_a is v(PNC+,PNC-).

Second order polynomial

$$\text{i(N+, N-)} = \text{CP0} + \text{CP1}\,f_a + \text{CP2}\,f_b + \text{CP3}\,f_a^2 + \text{CP4}\,f_a\,f_b + \text{CP5}\,f_b^2 + \\ \text{CP6}\,f_a^3 + \text{CP7}\,f_a^2\,f_b + \text{CP8}\,f_a\,f_b^2 \ldots$$

where f_a is v(PNC1+,PNC1-) and f_b is v(PNC2+,PNC2-).

Third order polynomial

$$\text{i(N+, N-)} = \text{CP0} + \text{CP1}\,f_a + \text{CP2}\,f_b + \text{CP3}\,f_c + \text{CP4}\,f_a^2 + \text{CP5}\,f_a\,f_b + \text{CP6}\,f_a\,f_c + \\ \text{CP7}\,f_b^2 + \text{CP8}\,f_b\,f_c + \text{CP9}\,f_c^2 + \text{CP10}\,f_a^3 \ldots$$

where f_a is v(PNC1+,PNC1-), f_b is v(PNC2+,PNC2-) and f_c is v(PNC3+,PNC3-).

Supported Analyses
All.

H Linear Current-Controlled Voltage Sources

General forms:

```
Hxx N+ N- VNAME VALUE
Hxx N+ N- POLY(ORDER) PVNAME <PVNAME> CP <CP>
```

Parameters:

`xx`	Name of the source
`N+`	Name of positive node
`N-`	Name of negative node
`VNAME`	Name of the voltage source where the controlling current flows. The direction of positive control current is from positive node through the source to the negative node of `VNAME`
`VALUE`	Transresistance in Ohm
`POLY`	Keyword indicating that the source has a non-linear polynomial description
`ORDER`	Order of the polynomial
`PVNAME`	Name of the voltage source measuring the current for the function arguments of the polynomial. Number is equal to the order of the polynomial
`CP`	Coefficients of the polynomial

Example:

```
hx1 6 2 vz 0.5k
```

Specifies that the voltage applied between nodes 6 and 2 is 500 times the current through the voltage source vz.

```
h1 6 2 poly(1) vin 1 0.2 0.2 0.03
```

Specifies a first order non-linear current controlled voltage source connected between node 6 and 2. The controlling current are through the voltage source vin. Polynomial coefficients are 1, 0.2, 0.2 and 0.03. The resulting non-linear voltage function has the following form:

$$v(6,2) = 1 + 0.2 \cdot i(vin) + 0.2 \cdot i(vin)^2 + 0.03 \cdot i(vin)^3$$

Polynomial Source

Non-linear polynomial sources with multi-dimensional arguments are supported, defined by the keyword POLY.

The polynomials are specified by the coefficients $p_0 \ldots p_n$. The significance of the coefficients depends upon the order of the polynomial, as shown below:

First order polynomial

$$v(N+, N-) = CP0 + CP1 f_a + CP2 f_a^2 + CP3 f_a^3 \ldots$$

where f_a is i(PVNAME1).

Second order polynomial

$$\text{v(N+, N-)} = \text{CP0} + \text{CP1}\, f_a + \text{CP2}\, f_b + \text{CP3}\, f_a^2 + \text{CP4}\, f_a\, f_b + \text{CP5}\, f_b^2 + \text{CP6}\, f_a^3 + \text{CP7}\, f_a^2\, f_b + \text{CP8}\, f_a\, f_b^2 \ldots$$

where f_a is i(PVNAME1) and f_b is i(PVNAME2).

Third order polynomial

$$\text{v(N+, N-)} = \text{CP0} + \text{CP1}\, f_a + \text{CP2}\, f_b + \text{CP3}\, f_c + \text{CP4}\, f_a^2 + \text{CP5}\, f_a\, f_b + \text{CP6}\, f_a\, f_c + \text{CP7}\, f_b^2 + \text{CP8}\, f_b\, f_c + \text{CP9}\, f_c^2 + \text{CP10}\, f_a^3 \ldots$$

where f_a is i(PVNAME1), f_b is i(PVNAME2) and f_c is i(PVNAME3).

Supported Analyses

All.

I Independent Current Sources

General form:

```
IYYYYYYY N+ N- <<DC> DC/TRAN VALUE> <AC <ACMAG <ACPHASE>>>
+ <DISTOF1 <F1MAG <F1PHASE>>> <DISTOF2 <F2MAG <F2PHASE>>>
```

Examples:

```
isrc 23 21 ac 0.333 45.0 sffm(0 1 10k 5 1k)
```

`N+` and `N-` are the positive and negative nodes, respectively. Positive current flows from the positive node through the source to the negative node.

`DC/TRAN` is the source value during a dc or a transient analysis. The value can be omitted if it is zero for both the dc and transient analysis. If the source is time invariant, its value can be prefixed with `DC`.

`ACMAG` is amplitude value and `ACPHASE` is the phase value of the source during an ac analysis. If `ACMAG` is omitted after the keyword `AC`, 1 is assumed. If `ACPHASE` is omitted, 0 is assumed.

`DISTOF1` and `DISTOF2` are the keywords that specify that the independent source has distortion inputs at the frequencies `F1` and `F2` respectively (see the description of the distortion analysis parameters). The keywords may be followed by an optional magnitude and phase. The default values of the magnitude and phase are 1.0 and 0.0 respectively.

All independent sources can be assigned time varying values during a transient analysis. If a source is assigned a time varying value, its value at t=0 is used during a dc analysis. There are 5 predefined functions for time varying sources: pulse, exponent, sinusoidal, piece-wise linear, and single frequency FM. If parameters are omitted, the default values shown in the tables below will be assumed. DT and T2 are the increment time and final time in a transient analysis, respectively (see Transient Analysis).

Pulse

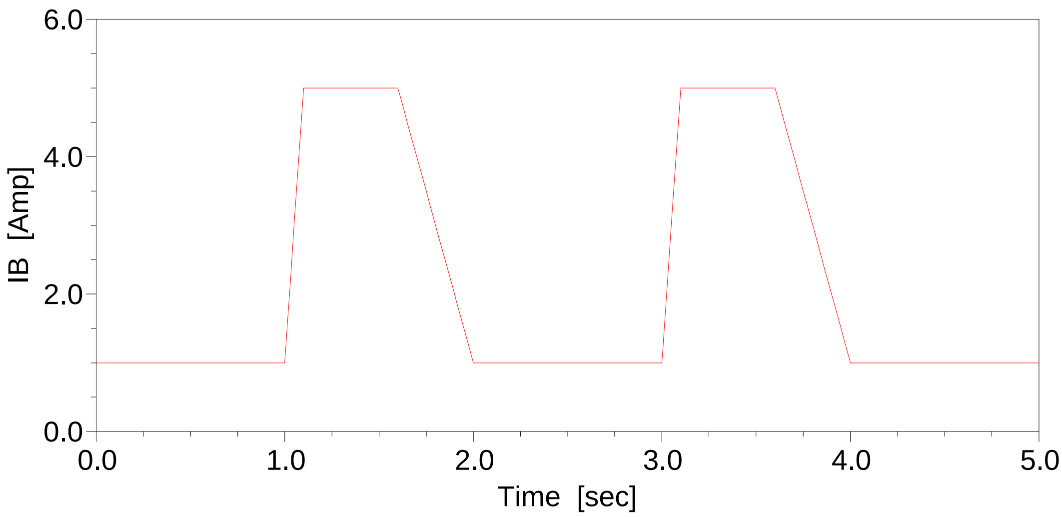
General form:

```
PULSE(I1 I2 TD TR TF PW PER)
```

Parameters	**Default values**	**Units**
I1 (initial value)	None	A
I2 (pulsed value)	None	A
TD (delay time)	0.0	s
TR (rise time)	DT	s
TF (fall time)	DT	s
PW (pulse width)	T2	s
PER (period)	T2	s

Example:

```
IB 3 0 PULSE(1 5 1S 0.1S 0.4S 0.5S 2S)
```



Sinus

General form:

```
SIN(I0 IA FREQ TD THETA)
```

Parameters	Default values	Units
I0 (offset)	None	A
IA (amplitude)	None	A
FREQ (frequency)	1/T2	Hz
TD (delay)	0.0	s
THETA(damping factor)	0.0	1/s

The shape of the waveform is:

<u>0 < *time* < TD</u>

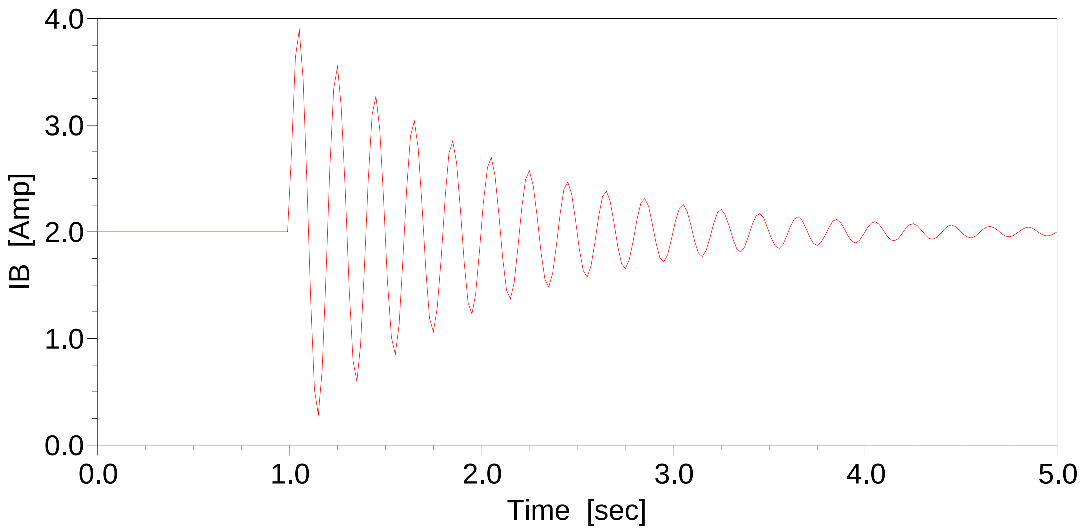
$$I = \mathrm{I0}$$

<u>TD < *time* < T2</u>

$$I = \mathrm{I0} + \mathrm{IA} \cdot \sin\left(2\pi \cdot \mathrm{FREQ} \cdot \left(time + \mathrm{TD}\right)\right) \cdot \exp\left(-\left(time - \mathrm{TD}\right) \cdot \mathrm{THETA}\right)$$

Example:

```
IB 3 0 SIN(2 2 5 1S 1)
```



Exponent

General form:

```
EXP(I1 I2 TD1 TAU1 TD2 TAU2)
```

Parameters	Default values	Units
I1 (initial value)	None	A
IA (pulsed value)	None	A
TD1(rise delay time)	0.0	s
TAU1(rise time constant)	DT	s
TD2 (delay fall time)	TD1+DT	s
TAU2 (fall time constant)	DT	s

The shape of the waveform is:

<u>$0 < time < \mathrm{TD1}$</u>

$$I = \mathrm{I1}$$

<u>$\mathrm{TD1} < time < \mathrm{TD2}$</u>

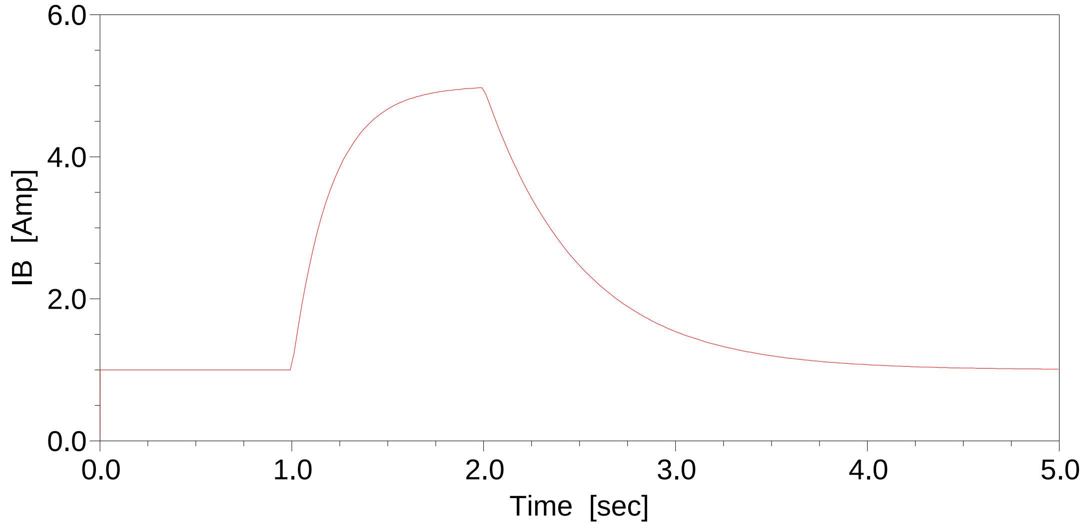
$$I = \mathrm{I1} + (\mathrm{I2} - \mathrm{I1}) \cdot (1 - \exp(-(time - \mathrm{TD1}) / \mathrm{TAU1}))$$

<u>$\mathrm{TD2} < time < \mathrm{T2}$</u>

$$I = \mathrm{I1} + (\mathrm{I2} - \mathrm{I1}) \cdot (1 - \exp(-(time - \mathrm{TD1}) / \mathrm{TAU1})) + (\mathrm{I1} - \mathrm{I2}) \cdot (1 - \exp(-(time - \mathrm{TD2}) / \mathrm{TAU2}))$$

Example:

```
IB 3 0 EXP(1 5 1S 0.2S 2S 0.5S)
```



Piece-wise Linear

General form:

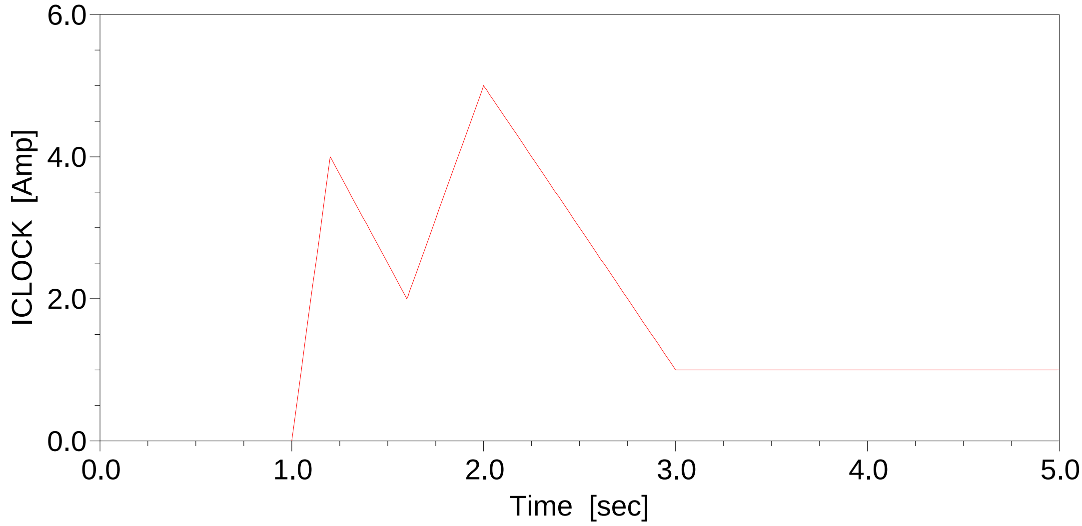
```
PWL(T1 I1 <T2 I2 T3 I3 T4 I4 T5 I5 ....>)
```

Parameters and default values:

Every pair of values (T_i, I_i) specifies that the value of the source is I_i at T_i. The value of the source between these values is calculated using a linear interpolation.

Example:

```
ICLOCK 7 5 PWL(0 0 1 0 1.2 4 1.6 2.0 2.0 5.0 3.0 1.0)
```



Single frequency FM

General form:

```
SFFM(I0 IA FC MDI FS)
```

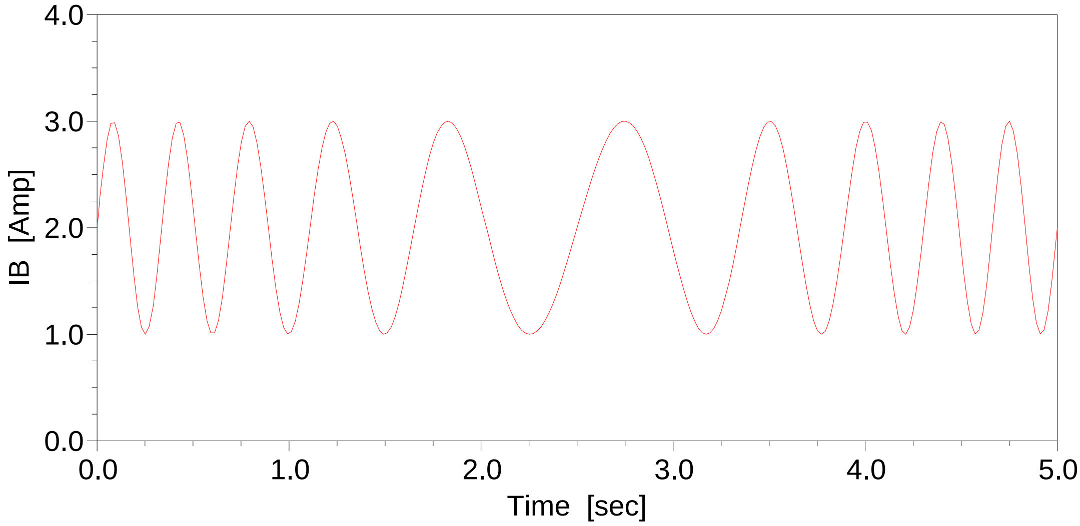
Parameters	Default values	Units
I0 (offset)	None	A
IA (amplitude)	None	A
FC (carrier frequency)	1/T2	Hz
MDI (modulation index)	None	-
FS (signal frequency)	1/T2	Hz

The shape of the waveform is:

$$I = \mathrm{I0} + \mathrm{IA} \cdot \sin\left(\left(2\pi \cdot \mathrm{FC} \cdot time\right) + \mathrm{MDI} \cdot \sin\left(2\pi \cdot \mathrm{FS} \cdot time\right)\right)$$

Example:

```
IB 12 0 SFFM(2 1 2 5 0.2)
```



Supported Analyses

All

J Junction Field-Effect Transistors (JFETs)

General form:

```
JXXXXXXX ND NG NS MNAME <AREA> <OFF> <IC=VDS,VGS> <TEMP=T>
```

Example:

```
J1 7 2 3 JM1 OFF
```

`ND`, `NG` and `NS` are the drain, gate and source nodes, respectively. `MNAME` is the model name, `AREA` is the area factor, and `OFF` indicates a optional initial value for the element in a dc analysis. If the area factor is omitted, 1.0 is assumed. The optional initial value `IC=VDS,VGS` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. The optional `TEMP` value is the temperature at which this device operates. It overrides the temperature specified in the option value.

JFET Model

```
.MODEL [model name] NJF <model parameters>
.MODEL [model name] PJF <model parameters>
```

Name	Parameter	Units	Default
VTO	Threshold voltage	V	-2.0
BETA	Transconductance parameter	A / V^2	1.0e-4
LAMBDA	Channel length modulation parameter	1/V	0
RD	Drain resistance	Ω	0
RS	Source resistance	Ω	0
CGS	Zero-bias G-S junction capacitance	F	0
CGD	Zero-bias G-D junction capacitance	F	0
PB	Gate junction potential	V	1
IS	Gate junction saturation current	A	1.0E-14
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
TNOM	Parameter measurement temperature	°C	27

Temperature Effects

Temperature appears explicitly in the exponential terms.

Temperature dependence of the saturation current in the two gate junctions of the model is determined by:

$$I_S(T_1) = I_S(T_0)\exp\left[1.11\left(\frac{T_1}{T_0} - 1\right) / V_{th}\right]$$

where V_{th} is the thermal voltage.

Supported Analyses
All.

K Coupled Inductors (transformers)

General form:

```
KXXXXXXX LYYYYYYY LZZZZZZZ VALUE
```

Examples:

```
k43 laa lbb 0.9999
kxfrmr l1 l2 0.82
```

`LYYYYYYY` and `LZZZZZZZ` are the names of the two coupled inductors, and `VALUE` is the coupling coefficient K which must be greater than 0 and less than or equal to 1. Using the dot convention, place a dot on the first node of each inductor.

The relation between the coupling coefficient K and the mutual inductance is given by

$$K = \frac{M_{ij}}{\sqrt{L_i L_j}},$$

where L_i and L_j are the coupled pair of inductors, and M_{ij} is the mutual inductance between L_i and L_j.

Supported Analyses

All.

L Inductors

General form:

```
LYYYYYYY N+ N- VALUE <IC=Initial values>
```

Examples:

```
llink 42 69 1uh
lshunt 23 51 10u ic=15.7ma
```

N+ and N- are the positive and negative element nodes respectively. VALUE is the inductance in Henries. The optional initial value is the initial time zero value of the inductor current in amps that flows from N+ through the inductor to N-. Notice that the value is used only when the option UIC is specified in a transient analysis.

Supported Analyses

All.

M Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

General form:

```
MXXXXXXX ND NG NS NB MNAME <L=VALUE> <W=VALUE> <AD=VALUE>
+ <AS=VALUE> <PD=VALUE> <PS=VALUE> <NRD=VALUE>
+ <NRS=VALUE> <OFF> <IC=VDS,VGS,VBS> <TEMP=T>
```

Example:

```
M1 24 2 0 20 TYPE1
m15 15 15 12 32 m w=12.7u  l=207.8u
M1 2 9 3 0 MOD1 L=10U W=5U AD=100P AS=100P PD=40U PS=40U
```

`ND`, `NG`, `NS` and `NB` are the drain, gate, source and bulk (substrate) nodes, respectively. `MNAME` is the model name, `L` and `W` are the channel length and width in meters, respectively. `AD` and `AS` are the drain and source diffusion areas in square meters. If any of `L`, `W`, `AD` or `AS` are not specified, default values are used. `PD` and `PS` are the perimeters of the drain and source diffusion areas. `NRD` and `NRS` are the relative resistivities of the drain and source in number of squares, respectively. Default values of `PD` and `PS` are 0.0, while default values of `NRD` and `NRS` are 1.0. `OFF` indicates an optional initial value for the element in a dc analysis. The optional initial value `IC=VDS,VGS,VBS` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. The optional `TEMP` value is the temperature at which this device operates. It overrides the temperature specified in the option value.

Note! The parameters `AD`, `AS`, `PD`, `PS`, `NRD`, `NRS`, the substrate node and the `VBS` initial voltage are ignored in Levels 11, 12, 15 and 16.

MOSFET Model

```
.MODEL [model name] NMOS <model parameters>
.MODEL [model name] PMOS <model parameters>
```

AIM-Spice supports 26 MOSFET models. The parameter LEVEL selects which model to use. The default is LEVEL=1.

LEVEL=1	Shichman-Hodges
LEVEL=2	Geometric based analytical model
LEVEL=3	Semi-empirical short channel model
LEVEL=4	BSIM1 (Berkeley Short Channel Igfet Model)
LEVEL=5	BSIM2 (as described in [2])
LEVEL=6	MOS6 (as described in [3])
LEVEL=7	A universal extrinsic short channel MOS model (as described in Section 3.9 in [1])
LEVEL=8	A unified long channel MOS model (as described in Section 3.10 and 3.11 in [1])
LEVEL=9	A short channel MOS model (as described in Section 3.10 and 3.11 in [1])

LEVEL=10	A unified intrinsic short channel model (as described in Section 3.10 and 3.11 in [1])
LEVEL=11	A unified extrinsic amorphous silicon thin film transistor model (as described in Section 5.2 in [1])
LEVEL=12	A model for polysilicon thin film transistors (as described in Section 5.3 in [1])
LEVEL=13	BSIM3 version 2.0 [5]
LEVEL=14	BSIM3 version 3.1 [6]
LEVEL=15	ASIA2, amorphous-Si TFT model
LEVEL=16	PSIA2, poly-Si TFT model
LEVEL=17	BSIM3 version 3.2
LEVEL=19	BSIM3SOI
LEVEL=20	BSIM4 version 1.0
LEVEL=21	BSIM4 version 2.0
LEVEL=22	BSIM3SOI version 2.2 PD
LEVEL=23	EKV MOS model version 2.6
LEVEL=24	BSIM4 version 2.1
LEVEL=25	BSIM4 version 3.0
LEVEL=26	BSIM4 version 4.0

Effects of charge storage based on the model by Meyer is implemented in Levels 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 15 and 16. In the universal MOSFET model (Level 7), a second, unified charge storage model based on the charge conserving Meyer-like approach proposed by Turchetti *et al*. [7] is implemented. The BSIM models (Levels 4, 5, 13 and 14) use charge based models owing to Ward and Dutton [8].

Effects of the thin-oxide capacitance is treated slightly different in Level 1. Voltage dependent capacitances are included only if TOX is specified.

A redundancy exists in specifying junction parameters. For example, the reverse current can be specified either with the IS parameter (in Amp) or with JS (in Amp/m^2). The first choice is an absolute value while the second choice is multiplied with AD and AS to give the reverse current at the drain and source junctions, respectively. The latter approach is preferred. The same is also true for the parameters CBD, CBS and CJ. Parasitic resistances can be given with RD and RS (in Ohm) or with RSH (in Ohm/square). RSH is multiplied with number of squares NRD and NRS.

References

[2] B. J. Sheu, D. L. Scharfetter, P. K. Ko, and M. C. Jeng, “BSIM: Berkeley Short-Channel IGFET Model for MOS Transistors,” *IEEE J. Solid-State Circuits*, vol. 22, no. 4, pp. 558-566, 1987.

[3] T. Sakurai and A. R. Newton, *A simple MOSFET Model for Circuit Analysis and its applications to CMOS gate delay analysis and series-connected MOSFET Structure*, ERL Memo No. ERL M90/19, Electronics Research Laboratory, University of California, Berkeley, March 1990.

[4] K. Lee, M. Shur, T. A. Fjeldly and T. Ytterdal, *Semiconductor Device Modeling for VLSI*, 1993, Prentice Hall, New Jersey.

[5] J. H. Huang, Z. H. Liu, M. C. Jeng, P. K. Ko, and C. Hu, "A Robust Physical and Predictive Model for Deep-Submicrometer MOS Circuit Simulation," in *Proc. IEEE 1993 Custom Integrated Circuits Conference*, p. 14.2.1, 1993.

[6] Y. Cheng, M. Jeng, Z. Liu, J. Huang, M. Chan, K. Chen, P. K. Ko, C. Hu, "A Physical and Scalable *I-V* Model in BSIM3v3 for Analog/Digital Circuit Simulation," *IEEE Trans. on Electron Devices*, vol. 44, no. 2, pp. 277-287, February 1997.

[7] C. Turchetti, P. Prioretti, G. Masetti, E. Profumo, and M. Vanzi, "A Meyer-like Approach for the Transient Analysis of Digital MOS IC's," *IEEE Trans. on Computer-Aided Design*, vol. 5, no. 10, pp. 499-507, Oct. 1986.

[8] D. E. Ward and R. W. Dutton, "A Charge-Oriented Model for MOS Transistor Capacitances," *IEEE J. of Solid-State Circuits*, vol. 13, no. 5, pp. 703-708, Oct. 1978.

Berkeley SPICE Models Levels 1, 2, 3 and 6

Name	Parameter	Units	Default
VTO	Zero-bias threshold voltage	V	0.0
KP	Transconductance parameter	A / V^2	2.0e-5
GAMMA	Bulk threshold parameter	$\sqrt{V}$	0.0
PHI	Surface potential	V	0.6
LAMBDA	Channel length modulation (only Levels 1 and 2)	1/V	0.0
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0
CBD	Zero-bias B-D junction capacitance	F	0.0
CBS	Zero-bias B-S junction capacitance	F	0.0
IS	Bulk junction saturation current	A	1.0e-14
PB	Bulk junction potential	V	0.8
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0
RSH	Drain and source diffusion sheet resistance	$\Omega / \square$	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 sidewall capacitance per meter of junction perimeter	F/m	0.0
MJSW	Bulk junction sidewall grading coefficient	-	0.50 (level 1) 0.33 (level 2)
JS	Bulk junction saturation current per m^2 of junction area	A / m^2	0
TOX	Gate oxide thickness	m	1.0e-7
NSUB	Substrate doping	$1 / cm^3$	0.0
NSS	Surface state density	$1 / cm^2$	0.0
NFS	Fast surface state density	$1 / cm^2$	0.0
TPG	Type of gate material: +1 : opposite of substrate -1 : same as substrate 0 : Al gate	-	1.0

Name	Parameter	Units	Default
XJ	Metallurgical junction depth	m	0.0
LD	Lateral diffusion	m	0.0
U0	Surface mobility	cm^2 / Vs	600
UCRIT	Critical field for mobility degradation (only Level 2)	V/cm	1.0e4
UEXP	Critical field exponent in mobility degradation (only Level 2)	-	0.0
UTRA	Transverse field coefficient (deleted for Level 2)	-	0.0
VMAX	Maximum drift velocity for carriers	m/s	0.0
NEFF	Total channel charge (fixed and mobile) coefficient (only Level 2)	-	1.0
KF	Flicker noise coefficient	-	0.0
AF	Flicker noise exponent	-	1.0
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
DELTA	Width effect on threshold voltage (only Levels 2 and 3)	-	0.0
THETA	Mobility modulation (only Level 3)	1/V	0.0
ETA	Static feedback (only Level 3)	-	0.0
KAPPA	Saturation field factor (only Level 3)	-	0.2
TNOM	Parameter measurement temperature	°C	27

Temperature Effects

Temperature appears explicitly in the exponential terms in the equations describing current across the bulk junctions.

Temperature appears explicitly in the value of junction potential, ϕ (in AIM-Spice PHI). The temperature dependence is given by:

$$\phi(T) = \frac{kT}{q} \ln\left(\frac{N_a N_d}{N_i (T)^2} \right)$$

where k is Boltzmann's constant, q is the electronic charge, N_a is the acceptor impurity density, N_d is the donor impurity density, and N_i is the intrinsic carrier concentration.

Temperature appears explicitly in the value of surface mobility μ_0 (or U0). The temperature dependence is given by:

$$\mu_0 (T) = \frac{\mu_0 (T_0)}{\left(T / T_0\right)^{1.5}}$$

Supported Analyses

Level 1-3: All.

Level 6: AC, Noise, and Pole-Zero analyses not supported.

Berkeley SPICE BSIM1 Model (Level 4)

Parameters for this model is obtained from process characterization. Parameters marked with an '*' in the l/w column in the tables below have length and width dependency. For example, for the flat band voltage, VFB, the dependence on the gate electrode geometry can be expressed in terms of the additional flat band parameters, LVFB and WVFB, measured in Volt·μm:

$$VFB = VFB0 + \frac{LVFB}{L_{effective}} + \frac{WVFB}{W_{effective}}$$

where

$$L_{effective} = L_{input} - \mathrm{DL}$$

$$W_{effective} = W_{input} - \mathrm{DW}$$

Note that the BSIM1 model is meant to be used together with a process characterization system. None of the parameters in these models have default values, and leaving one out is registered as an error.

Name	**Parameter**	**Units**	**l/w**
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	
CGSO	Gate-source overlap capacitance per meter channel width	F/m	
CJ	Source drain junction capacitance per unit area	F / m^2	
CJSW	Source drain junction side wall capacitance per unit length	F/m	
DELL	Source drain junction length reduction	m	
DL	Shortening of channel	μm	
DW	Narrowing of channel	μm	
ETA	Zero-bias drain-induced barrier lowering coefficient	-	*
JS	Source drain junction current density	A / m^2	
K1	Body effect coefficient	$V^{1/2}$	*
K2	Drain/source depletion charge sharing coefficient	-	*
MJ	Grading coefficient of source drain junction	-	
MJSW	Grading coefficient of source drain junction sidewall	-	
MUS	Mobility at zero substrate bias and at $V_{ds} = V_{dd}$	$cm^2 / V^2 s$	
MUZ	Zero-bias mobility	cm^2 / Vs	
N0	Zero-bias subthreshold slope coefficient	-	*
NB	Sensitivity of subthreshold slope to substrate bias	-	*

Name	Parameter	Units	l/w
ND	Sensitivity of subthreshold slope to drain bias	-	*
PB	Built in potential of source drain junction	V	
PBSW	Built in potential of source drain junction side wall	V	
PHI	Surface inversion potential	V	*
RSH	Drain and source diffusion sheet resistance	Ω/□	
TEMP	Temperature at which parameters were measured	C	
TOX	Gate oxide thickness	μm	
U0	Zero-bias transverse-field mobility degradation coefficient		*
U1	Zero-bias velocity saturation coefficient	μm/V	*
VDD	Measurement bias range	V	
VFB	Flat band voltage	V	
WDF	Source drain junction default width	m	
X2E	Sensitivity of drain-induced barrier lowering effect to substrate bias		*
X2MS	Sensitivity of mobility to substrate bias at $V_{ds}= V_{dd}$	cm^2 / V^2s	*
X2MZ	Sensitivity of mobility to substrate bias at $V_{ds}=0$	cm^2 / V^2s	*
X2U0	Sensitivity of transverse field mobility degradation effect to substrate bias	$1/V^2$	*
X2U1	Sensitivity of velocity saturation effect to substrate bias	μmV^{-2}	*
X3E	Sensitivity of drain-induced barrier lowering effect to drain bias at $V_{ds}= V_{dd}$		*
X3MS	Sensitivity of mobility to drain bias at $V_{ds}= V_{dd}$	μmV^{-2}	*
X3U1	Sensitivity of velocity saturation effect on drain bias at $V_{ds}= V_{dd}$	μmV^{-2}	*
XPART	Gate-oxide capacitance charge model flag	-	

XPART=0 selects a 40/60 drain/source partition of the gate charge in saturation, while XPART=1 selects a 0/100 drain/source charge partition.

Supported Analyses

Noise Analysis not supported.

Berkeley SPICE BSIM2 Model (Level 5)

Parameters for this model is obtained from process characterization. Parameters marked with an '*' in the l/w column in the tables below have length and width dependency. For example, for the flat band voltage, VFB, the dependence on the gate electrode geometry can be expressed in terms of the additional flat band parameters, LVFB and WVFB, measured in Volt·μm:

$$VFB = VFB0 + \frac{LVFB}{L_{effective}} + \frac{WVFB}{W_{effective}}$$

where

$$L_{effective} = L_{input} - \mathrm{DL}$$

$$W_{effective} = W_{input} - \mathrm{DW}$$

Note that the BSIM2 model is meant to be used together with a process characterization system. None of the parameters in these models have default values, and leaving one out is registered as an error.

Name	**Parameter**	**Units**	**l/w**
AI0	Pre-factor of hot-electron effect	–	*
AIB	V_{bs} dependence on AI	1/V	*
BI0	Exponential factor of hot-electron effect	V	*
BIB	V_{bs} dependence on BI	–	*
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	
CGSO	Gate-source overlap capacitance per meter channel width	F/m	
CJ	Source drain junction capacitance per unit area	F / m^2	
CJSW	Source drain junction sidewall capacitance per unit length	F/m	
DELL	Source drain junction length reduction	m	
DL	Shortening of channel	μm	
DW	Narrowing of channel	μm	
ETA0	V_{ds} dependence of threshold voltage at V_{ds} = 0 V	-	*
ETAB	V_{bs} dependence of ETA	1/V	*
JS	Source drain junction current density	A / m^2	
K1	Body effect coefficient	$V^{1/2}$	*
K2	Drain/source depletion charge sharing coefficient	-	*
MJ	Grading coefficient of source drain junction	-	
MJSW	Grading coefficient of source drain junction sidewall	-	

Name	Parameter	Units	l/w
MU0	Low-field mobility at V_{ds} = 0, $V_{gs} = V_{th}$	cm^2 / Vs	
MU0B	V_{bs} dependence of low-field mobility	cm^2 / V^2s	*
MU20	V_{ds} dependence of mobility in tanh term	–	*
MU2B	V_{bs} dependence of MU2	1/V	*
MU2G	V_{gs} dependence of MU2	1/V	*
MU30	V_{ds} dependence of mobility in linear term	cm^2 / V^2s	*
MU3B	V_{bs} dependence of MU3	cm^2 / V^3s	*
MU3G	V_{gs} dependence of MU3	cm^2 / V^3s	*
MU40	V_{ds} dependence of mobility in linear term	cm^2 / V^3s	*
MU4B	V_{bs} dependence of MU4	cm^2 / V^4s	*
MU4G	V_{gs} dependence of MU4	cm^2 / V^4s	*
MUS0	Mobility at $V_{ds} = V_{dd}$, $V_{gs} = V_{th}$	cm^2 / Vs	*
MUSB	Vbs dependence of MUS0	cm^2 / V^2s	*
N0	Zero-bias subthreshold slope coefficient	-	*
NB	Sensitivity of subthreshold slope to substrate bias	-	*
ND	Sensitivity of subthreshold slope to drain bias	-	*
PB	Built in potential of source drain junction	V	
PBSW	Built in potential of source drain junction sidewall	V	
PHI	Surface inversion potential	V	*
RSH	Drain and source diffusion sheet resistance	Ω/☐	
TEMP	Temperature at which parameters were measured	C	
TOX	Gate oxide thickness	μm	
U10	V_{ds} dependence on mobility	1/V	*
U1B	V_{bs} dependence on U1	V^{-2}	*
U1D	V_{ds} dependence on U1	V^{-2}	*
UA0	Linear V_{gs} dependence of mobility	1/V	*
UAB	V_{bs} dependence of UA	V^{-2}	*
UB0	Quadratic V_{gs} dependence on mobility	V^{-2}	*
UBB	Vbs dependence on UB	V^{-3}	*
VBB	Maximum V_{bs}	V	
VDD	Measurement bias range	V	
VFB	Flat band voltage	V	
VGG	Maximum V_{gs}	V	
VGHIGH	Upper bound of the cubic spline function	V	*
VGLOW	Lower bound of the cubic spline function	V	*
VOF0	Threshold voltage offset at V_{ds} = 0, V_{bs} = 0	–	*
VOFD	V_{ds} dependence on VOF	1/V	*
WDF	Source drain junction default width	m	
XPART	Gate-oxide capacitance charge model flag	-	

XPART=0 selects a 40/60 drain/source partition of the gate charge in saturation, while XPART=1 selects a 0/100 drain/source charge partition.

Supported Analyses

Noise Analysis not supported.

MOSFET Model MOSA1 (Level 7)

The following parameters are used for the threshold voltage model:

Name	Parameter	Units	Default
GAMMAS0	Body effect constant in front of square root term	$\sqrt{\mathrm{V}}$	0.0
LGAMMAS	Sensitivity of γ_S on device length	$\sqrt{\mathrm{V}}$	0.0
WGAMMAS	Sensitivity of γ_S on device width	$\sqrt{\mathrm{V}}$	0.0
GAMMAL0	Body effect constant in front of linear term	-	0.0
LGAMMAL	Sensitivity of γ_L on device length	-	0.0
WGAMMAL	Sensitivity of γ_L on device width	-	0.0
L0	Gate length of nominal device	m	2μm
W0	Gate width of nominal device	m	20μm

The following are the expressions for the threshold voltage:

$$V_T = V_{T00} + \gamma_S \sqrt{2\varphi_b - V_{bs}} - \gamma_L \left(2\varphi_b - V_{bs}\right),$$

where

$$\gamma_S = \mathrm{GAMMAS0} + \mathrm{LGAMMAS} \cdot \left(1 - \frac{L0}{L}\right) + \mathrm{WGAMMAS} \cdot \left(1 - \frac{W0}{W}\right),$$

$$\gamma_L = \mathrm{GAMMAL0} + \mathrm{LGAMMAL} \cdot \left(1 - \frac{L0}{L}\right) + \mathrm{WGAMMAL} \cdot \left(1 - \frac{W0}{W}\right).$$

The value of V_{T00} above is given by the model parameter VTO as

$$V_{T00} = \mathrm{VTO} - \gamma_S \sqrt{2\varphi_b} + \gamma_L \cdot 2\varphi_b .$$

These equations are valid for

$$V_{T00} - V_{bs} \le \left(\frac{\gamma_S}{2\gamma_L}\right)^2 .$$

Beyond this limit, we assume that the threshold voltage remains constant at

$$V_{TM} = V_{T00} + \gamma_L \left(\frac{\gamma_S}{2\gamma_L}\right)^2 .$$

Other parameters:

Name	Parameter	Units	Default
AF	Flicker noise exponent	-	1.0
ALPHA	Parameter accounting for the threshold dependence on the channel potential	–	1.05
CBD	Zero-bias B-D junction capacitance	F	0.0
CBS	Zero-bias B-S junction capacitance	F	0.0
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
CJ	Zero-bias bulk junction bottom capacitance per square-meter of junction area	F / m^2	0.0
CJSW	Zero-bias bulk junction sidewall capacitance per meter of junction perimeter	F/m	0.0
CV	Charge storage model selector	–	1
CVE	Meyer-like capacitor model selector	–	1
DELTA	Transition width parameter	-	5.0
ETA	Subthreshold ideality factor	-	1.32
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
FPE	Charge partitioning scheme selector	–	1
IS	Bulk junction saturation current	A	1.0e-14
JS	Bulk junction saturation current per m^2 of junction area	A / m^2	0
KF	Flicker noise coefficient	-	0.0
LAMBDA	Output conductance parameter	1/V	0.048
LD	Lateral diffusion	m	0.0
M	Knee shape parameter	-	4.0
MCV	Transition width parameter used by the charge partitioning scheme	–	10
MJ	Bulk junction bottom grading coefficient	-	0.5
MJSW	Bulk junction sidewall grading coefficient	-	0.33
NSS	Surface state density	$1 / cm^2$	0.0
NSUB	Substrate doping	$1 / cm^3$	0.0
PB	Bulk junction potential	V	0.8
PHI	Surface potential	V	0.6
RD	Drain resistance	Ω	0.0
RDI	Internal drain resistance	Ω	0
RS	Source resistance	Ω	0.0

Name	Parameter	Units	Default
RSH	Drain and source diffusion sheet resistance	Ω /☐	0.0
RSI	Internal source resistance	Ω	0
SIGMA0	DIBL parameter	-	0.048
THETA	Mobility degradation parameter	m/V	0
TNOM	Parameter measurement temperature	°C	27
TOX	Gate oxide thickness	m	1.0e-7
TPG	Type of gate material: +1 : opposite of substrate -1 : same as substrate 0 : Al gate	-	1.0
U0	Surface mobility	cm^2 / Vs	280
VFB	Flat band voltage	V	*
VMAX	Maximum drift velocity for carriers	m/s	4.0e4
VSIGMA	DIBL parameter	V	0.2
VSIGMAT	DIBL parameter	V	1.7
VTO	Zero-bias threshold voltage	V	0.0
XJ	Metallurgical junction depth	m	0.0
XQC	Charge partitioning factor	–	0.6

* Parameter is calculated if not specified

Modeling of charge storage for the Level 7 model is selected by specifying a value for the model parameter CV. CV = 1 selects the standard Meyer model and CV = 2 selects the charge conserving Meyer-like model.

Allowed values of the Meyer-like capacitor model selector CVE are 1 and 2. CVE = 1 selects the standard Meyer capacitors and CV = 2 selects the UCCM capacitors.

The model parameter FPE selects the charge partitioning scheme used by the Meyer-like charge storage model (CV = 2). FPE = 1 selects a constant partitioning factor, FPE = 2 selects an empirical partitioning scheme, and FPE=3 selects an analytical partitioning scheme.

Either intrinsic or extrinsic models can be selected by proper use of the parameters RD, RS, RDI, and RSI. If values for RD and RS are specified, the intrinsic model is selected with parasitic resistances applied externally. The extrinsic model is selected by specifying values for RDI and RSI.

Supported Analyses

Noise Analysis not supported

MOSFET Model NPMOSA1 (Level 8)

Name	Parameter	Units	Default
AF	Flicker noise exponent	-	1.0
ALPHA	Parameter accounting for the threshold dependence on the channel potential	-	1.164 (NMOS) 1.4 (PMOS)
CBD	Zero-bias B-D junction capacitance	F	0.0
CBS	Zero-bias B-S junction capacitance	F	0.0
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
CJ	Zero-bias bulk junction bottom capacitance per square-meter of junction area	F / m^2	0.0
CJSW	Zero-bias bulk junction side wall capacitance per meter of junction perimeter	F/m	0.0
DELTA	Width effect on threshold voltage	-	0.0
ETA	Subthreshold ideality factor	-	1.3 (NMOS) 1.2 (PMOS)
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
GAMMA	Bulk threshold parameter	$\sqrt{V}$	0.0
IS	Bulk junction saturation current	A	1.0e-14
JS	Bulk junction saturation current per m^2 of junction area	A / m^2	0
K1	Mobility parameter	$cm^2 / V^2 s$	28 (NMOS) 1510 (PMOS)
KF	Flicker noise coefficient	-	0.0
LD	Lateral diffusion	m	0.0
MJ	Bulk junction bottom grading coefficient	-	0.5
MJSW	Bulk junction side wall grading coefficient	-	0.33
NSS	Surface state density	$1 / cm^2$	0.0
NSUB	Substrate doping	$1 / cm^3$	0.0
PB	Bulk junction potential	V	0.8
PHI	Surface potential	V	0.6
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0
RSH	Drain and source diffusion sheet resistance	Ω /☐	0.0
TNOM	Parameter measurement temperature	°C	27
TOX	Gate oxide thickness	m	1.0e-7

Name	Parameter	Units	Default
TPG	Type of gate material: +1 : opposite of substrate -1 : same as substrate 0 : Al gate	-	1.0
U0	Surface mobility	cm^2 / Vs	625 (NMOS) 279 (PMOS)
VMAX	Maximum drift velocity for carriers	m/s	6.0e4
VTO	Zero-bias threshold voltage	V	0.0
XJ	Metallurgical junction depth	m	0.0

Supported Analyses

Noise Analysis not supported.

MOSFET Model NPMOSA2 (Level 9)

Name	**Parameter**	**Units**	**Default**
AF	Flicker noise exponent	-	1.0
ALPHA	Parameter accounting for the threshold dependence on the channel potential	-	1.2 (NMOS) 1.34 (PMOS)
CBD	Zero-bias B-D junction capacitance	F	0.0
CBS	Zero-bias B-S junction capacitance	F	0.0
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
CJ	Zero-bias bulk junction bottom capacitance per square-meter of junction area	F / m^2	0.0
CJSW	Zero-bias bulk junction side wall capacitance per meter of junction perimeter	F/m	0.0
DELTA	Width effect on threshold voltage	-	0.0
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
GAM	Saturation point parameter	-	3.0 (NMOS) 2.35 (PMOS)
GAMMA	Bulk threshold parameter	$\sqrt{V}$	0.0
IS	Bulk junction saturation current	A	1.0e-14
JS	Bulk junction saturation current per m^2 of junction area	A / m^2	0
K1	Mobility parameter	$cm^2 / V^2 s$	28 (NMOS) 1510 (PMOS)
KF	Flicker noise coefficient	-	0.0
LAMBDA	Characteristic length of the saturated region of the channel	m	994Å (NMOS) 1043Å (PMOS)
LD	Lateral diffusion	m	0.0
MJ	Bulk junction bottom grading coefficient	-	0.5
MJSW	Bulk junction side wall grading coefficient	-	0.33
NSS	Surface state density	$1 / cm^2$	0.0
NSUB	Substrate doping	$1 / cm^3$	0.0
PB	Bulk junction potential	V	0.8
PHI	Surface potential	V	0.6
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0

Name	Parameter	Units	Default
RSH	Drain and source diffusion sheet resistance	Ω /☐	0.0
TNOM	Parameter measurement temperature	°C	27
TOX	Gate oxide thickness	m	1.0e-7
TPG	Type of gate material: +1 : opposite of substrate -1 : same as substrate 0 : Al gate	-	1.0
U0	Surface mobility	cm^2 / Vs	625 (NMOS) 279 (PMOS)
VMAX	Maximum drift velocity for carriers	m/s	6.0e4
VTO	Zero-bias threshold voltage	V	0.0
XI	Saturation voltage parameter (NMOS only)	-	0.79
XJ	Metallurgical junction depth	m	0.0
ZETA	Velocity saturation factor (PMOS only)	-	0.34

Supported Analyses

Noise Analysis not supported.

MOSFET Model NPMOSA3 (Level 10)

Name	Parameter	Units	Default
AF	Flicker noise exponent	-	1.0
ALPHA	Parameter accounting for the threshold dependence on the channel potential	-	1.2 (NMOS) 1.34 (PMOS)
CBD	Zero-bias B-D junction capacitance	F	0.0
CBS	Zero-bias B-S junction capacitance	F	0.0
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
CJ	Zero-bias bulk junction bottom capacitance per square-meter of junction area	F/m^2	0.0
CJSW	Zero-bias bulk junction side wall capacitance per meter of junction perimeter	F/m	0.0
DELTA	Width effect on threshold voltage	-	0.0
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
GAM	Saturation point parameter	-	3.0 (NMOS) 2.35 (PMOS)
GAMMA	Bulk threshold parameter	$\sqrt{V}$	0.0
IS	Bulk junction saturation current	A	1.0e-14
JS	Bulk junction saturation current per m^2 of junction area	A/m^2	0
K1	Mobility parameter	cm^2/V^2s	28 (NMOS) 1510 (PMOS)
KF	Flicker noise coefficient	-	0.0
LAMBDA	Characteristic length of the saturated region of the channel	m	994Å (NMOS) 1043Å (PMOS)
LD	Lateral diffusion	m	0.0
MJ	Bulk junction bottom grading coefficient	-	0.5
MJSW	Bulk junction side wall grading coefficient	-	0.33
NSS	Surface state density	$1/cm^2$	0.0
NSUB	Substrate doping	$1/cm^3$	0.0
PB	Bulk junction potential	V	0.8
PHI	Surface potential	V	0.6
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0

Name	Parameter	Units	Default
RSH	Drain and source diffusion sheet resistance	Ω /☐	0.0
TNOM	Parameter measurement temperature	°C	27
TOX	Gate oxide thickness	m	1.0e-7
TPG	Type of gate material: +1 : opposite of substrate -1 : same as substrate 0 : Al gate	-	1.0
U0	Surface mobility	cm^2 / Vs	625 (NMOS) 279 (PMOS)
VMAX	Maximum drift velocity for carriers	m/s	6.0e4
VTO	Zero-bias threshold voltage	V	0.0
XI	Saturation voltage parameter (NMOS only)	-	0.79
XJ	Metallurgical junction depth	m	0.0
ZETA	Velocity saturation factor (PMOS only)	-	0.34

Supported Analyses

Noise Analysis not supported.

Amorphous-Si TFT Model ASIA1 (Level 11)

Name	Parameter	Units	Default
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
EPS	Relative dielectric constant of substrate	-	11.7
EPSI	Relative dielectric constant of gate insulator	-	3.9
ETA	Subthreshold slope	-	6.9
LAMBDA	Output conductance parameter	1/V	0.0048
M1	Knee shape parameter	-	2.5
M2	Exponent in mobility expressions	-	0.5
MC	Exponent in capacitance expressions	-	3.0
N0	Scaling factor	m^{-2}	1E16
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0
SIGMA0	Parameter accounting for DIBL effects	-	0.048
TNOM	Parameter measurement temperature	°C	27
TOX	Thin-oxide thickness	m	1.0e-7
U0	Surface mobility	cm^2 / Vs	1.0
V2	Characteristic voltage	V	0.086
VSIGMA	Parameter accounting for DIBL effects	V	0.2
VSIGMAT	Parameter accounting for DIBL effects	V	1.7
VTO	Zero-bias threshold voltage	V	0.0
XO	Fitting parameter	V/J	3.63E20

Supported Analyses

Noise and Pole-Zero analyses not supported

Poly-Si TFT Model PSIA1 (Level 12)

Name	Parameter	Units	Default
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
ETA	Subthreshold slope	-	6.9
GAMMA	Saturation voltage parameter	-	0.03
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0
RSH	Drain and source diffusion sheet resistance	Ω /☐	0.0
TNOM	Parameter measurement temperature	°C	27
TOX	Thin-oxide thickness	m	1.0e-7
U0	Surface mobility	cm^2 / Vs	100
V0	Scaling voltage	V	10.7
VTO	Zero-bias threshold voltage	V	0.0

Supported Analyses

Noise and Pole-Zero analyses not supported.

Berkeley SPICE BSIM3v2 Model (Level 13)

Name	Parameter	Units	Default
SUBTHMOD	Subthreshold model selector	-	2
SATMOD	Saturation model selector	-	2
BULKMOD	Bulk charge effect model selector	-	1 (NMOS) 2 (PMOS)
MOBMOD	Mobility model selector	-	1
TOX	Gate oxide thickness	m	150 Å
CDSC	Drain-source and channel coupling capacitance	F/m^2	2.4E-4
CDSCB	Body effect coefficient of CDSC	$F/(V \cdot m^2)$	0
CIT	Interface trapped charge capacitance	F/m^2	0
NFACTOR	Swing coefficient	-	1
XJ	Metallurgical junction depth	m	0.15 μm
VSAT	Saturation velocity at TNOM	cm/s	8.0E6
AT	Temperature coefficient of VSAT	m/s	3.3E4
A0	Bulk charge effect; default is 1 for BULKMOD=1, 2 for BULKMOD=2	-	
A1	First non-saturation effect coefficient	1/V	0 (NMOS) 0.23 (PMOS)
A2	Second non-saturation effect coefficient	-	1.0 (NMOS) 0.08 (PMOS)
KETA	Body bias coefficient of the bulk charge effect	1/V	-0.047
VGHIGH	High bound of transition region	V	0.12
VGLOW	Low bound of transition region	V	-0.12
NSUB	Doping concentration	cm^{-3}	6E16
NPEAK	Peak doping concentration	cm^{-3}	1.7E17
NGATE	Poly gate doping concentration	cm^{-3}	#
GAMMA1	Body effect coefficient near interface	$\sqrt{V}$	*
GAMMA2	Body effect coefficient in bulk	$\sqrt{V}$	*
VBX	Threshold voltage transition body voltage	V	*
VBI	Drain-substrate built-in voltage	V	*
VBM	Maximum substrate bias	V	-5
XT	Doping depth	m	1.55E-7
PHI	Strong inversion surface potential	V	*
LITL	Depth of current path	m	*
EM	Critical electric field in the channel	V/m	4.1E7
K3	Narrow width effect coefficient	-	80
KT1	First threshold voltage temperature coefficient	V	-0.11
KT2	Second threshold voltage temperature coefficient	-	0.022

Name	Parameter	Units	Default
KT1L	Threshold voltage temperature coefficient length sensitivity	V·m	0
K3B	Body effect coefficient of K3	-	0
W0	Narrow width effect reference width	m	2.5E-6
NLX	Vertical non-uniform width doping coefficient	m	1.74E-7
DVT0	Short channel effect coefficient 0	-	2.2
DVT1	Short channel effect coefficient 1	-	0.53
DVT2	Short Channel effect coefficient 2	1/V	-0.032
DROUT	Coefficient for DIBL effect on Rout	-	0.56
DSUB	Subthreshold DIBL coefficient exponent	-	DROUT
VTH0	Threshold voltage at zero substrate bias	V	0.7 (NMOS) -0.7 (PMOS)
U0	Low-field mobility at TNOM	cm^2/Vs	670 (NMOS) 250 (PMOS)
UA	First order mobility degradation coefficient	m/V	2.25E-9
UB	Second order mobility degradation coefficient	$(m/V)^2$	5.87E-19
UC	Body-bias sensitivity coefficient of mobility	1/V	0.0465
UA1	Temperature coefficient of UA	m/V	4.31E-9
UB1	Temperature coefficient of UB	$(m/V)^2$	-7.61E-18
UC1	Temperature coefficient of UC	1/V	-0.056
UTE	Temperature coefficient of mobility	-	-1.5
VOFF	Offset voltage of subthreshold region	V	-0.11
DL	Channel length reduction	m	0
DW	Channel width reduction	m	0
TNOM	Parameter measurment temperature	°C	27
RDS0	Source drain resistance	Ω	0
RDSW	Width sensitivity of RDS0	Ω·µm	0
LDD	Total source and drain LDD region length	m	0
ETA	Drain voltage reduction coefficient	-	0.3
ETA0	Subthreshold region DIBL coefficient	-	0.08
ETAB	Body bias coefficient for the subthreshold DIBL effect	1/V	-0.07
THETA	Drain Induced Barrier Lowering Effect Coefficient	-	0.02
PCLM	Channel length modulation effect coefficient	-	1.3
PDIBL1	Drain induced barrier lowering coefficient 1	-	0.39
PDIBL2	Drain induced barrier lowering coefficient 2	-	0.0086

Name	Parameter	Units	Default
PSCBE1	Substrate current body effect coefficient. 1	V/m	4.24E8
PSCBE2	Substrate current body effect coefficient. 2	m/V	1.0E-5
PVAG	Gate voltage dependence of Rout coefficient	-	0

Parameter is not used if not specified
* Parameter is calculated if not specified

Valid values of the subthreshold model selector SUBTHMOD are 0, 1 and 2 for this model. If SUBTHMOD = 0 is specified, the subthreshold current is zero. SUBTHMOD = 1 selects the BSIM1 subthreshold model and SUBTHMOD = 2 selects the BSIM3 subthreshold model.

Valid values of the saturation region model selector SATMOD are 1 and 2 for this model. SATMOD = 1 selects a semi-empirical model and SATMOD = 2 selects the fully physical model.

Supported Analyses

Noise Analysis not supported

Berkeley SPICE BSIM3v3.1 Model (Level 14)

Name	Parameter	Units	Default
Control Parameters			
CAPMOD	Flag for the short channel capacitance model	-	2
MOBMOD	Mobility model selector	-	1
NQSMOD	NQS model selector	-	0
NOIMOD	Noise model selector	-	1
DC Parameters			
VTH0	Threshold voltage at zero substrate bias	V	0.7 (NMOS) -0.7 (PMOS)
K1	First-order body effect coefficient	$V^{1/2}$	0.5
K2	Second-order body effect coefficient	-	-0.0186
K3	Narrow width effect coefficient	-	80
K3B	Body effect coefficient of K3	-	0
W0	Narrow width effect reference width	m	2.5E-6
NLX	Lateral non-uniform doping coefficient	m	1.74E-7
VBM	Maximum substrate bias	V	-3
DVT0	First coefficient of short-channel effect on Vth	-	2.2
DVT1	Second coefficient of short-channel effect on Vth	-	0.53
DVT2	Body-bias coefficient of short-channel effect on Vth	1/V	-0.032
DVT0W	First coefficient of narrow width effect on Vth at small L	1/m	0
DVT1W	Second coefficient of narrow width effect on Vth at small L	1/m	5.3E6
DVT2W	Body-bias coefficient of short-channel effect on Vth at small L	1/V	-0.032
U0	Low-field mobility at TNOM	cm^2 / Vs	670 (NMOS) 250 (PMOS)
UA	First-order mobility degradation coefficient	m/V	2.25E-9
UB	Second-order mobility degradation coefficient	$(m / V)^2$	5.87E-19
UC	Body-effect of mobility degradation coefficient	1/V	*
VSAT	Saturation velocity at TNOM	cm/s	8.0E6
A0	Bulk charge effect coefficient for channel length	-	1.0
AGS	Gate bias coefficient of the Abulk	1/V	0
B0	Bulk charge effect coefficient for	m	0

Name	Parameter	Units	Default
	channel width		
B1	Bulk charge effect width offset	m	0
KETA	Body bias coefficient of the bulk charge effect	1/V	-0.047
A1	First non-saturation effect coefficient	1/V	0
A2	Second non-saturation effect coefficient	-	1.0
RDSW	Width coefficient of parasitic resistance	$\Omega \cdot \mu m^{WR}$	0
PRWG	Gate bias effect coefficient of RDSW	1/V	0
PRWB	Body effect coefficient of RDSW	$V^{-1/2}$	0
WR	Width offset from Weff for Rds calculation	-	1
WINT	Width offset fitting parameter from I-V without bias	m	0
LINT	Length offset fitting parameter from I-V without bias	m	0
DWG	Coefficient of Weff's gate dependence	m/V	0
DWB	Coefficient of Weff's body bias dependence	$m / V^{1/2}$	0
VOFF	Offset voltage in the subthreshold region at large W and L	V	-0.11
NFACTOR	Subthreshold swing factor	-	1
ETA0	Subthreshold region DIBL coefficient	-	0.08
ETAB	Body bias coefficient for the subthreshold DIBL effect	1/V	-0.07
DSUB	Subthreshold DIBL coefficient exponent	-	DROUT
CIT	Interface trapped charge capacitance	F / m^2	0
CDSC	Drain/Source to channel coupling capacitance	F / m^2	2.4E-4
CDSCB	Body-bias sensitivity of CDSC	F / Vm^2	0
CDSCD	Drain-bias sensitivity of CDSC	F / Vm^2	0
PCLM	Channel length modulation parameter	-	1.3
PDIBLC1	First output resistance DIBL effect correction parameter	-	0.39
PDIBLC2	Second output resistance DIBL effect correction parameter	-	0.0086
PDIBLCB	Body effect coefficient of DIBL correction parameters	1/V	0
DROUT	L dependence coefficient of DIBL correction parameters	-	0.56
PSCBE1	First substrate current body-effect parameter	V/m	4.24E8
PSCBE2	Second substrate current body-effect	m/V	1.0E-5

Name	Parameter	Units	Default
	parameter		
PVAG	Gate voltage dependence of Rout coefficient	-	0
DELTA	Effective Vds parameter	V^2	0.01
NGATE	Poly gate doping concentration	cm^{-3}	0
ALPHA0	First impact ionization current parameter	m/V	0
BETA0	Second impact ionization current parameter	V	30
RSH	Source/Drain sheet resistance in Ohm per square	Ω/☐	0
JSSW	Side wall saturation current density	A/m	0
JS	Source/Drain junction saturation current density	A / m^2	1E-4
AC and Capacitance Parameters			
XPART	Charge partitioning rate flag	-	0
CGS0	Non-LDD region source-gate overlap capacitance per meter channel length	F/m	Calculated
CGD0	Non-LDD region drain-gate overlap capacitance per meter channel length	F/m	Calculated
CGB0	Gate-bulk overlap capacitance per meter channel length	F/m	2*DWC*Cox
CJ	Source and drain junction capacitance per unit area	F / m^2	5E4
MJ	Grading coefficient of source drain junction	-	0.5
MJSW	Grading coefficient of source drain junction sidewall	-	0.33
CJSW	Source drain junction sidewall capacitance per unit length	F/m	5E-10
CJSWG	Source/drain gate sidewall junction capacitance garding coefficient	F/m	CJSW
MJSWG	Source/drain gate sidewall junction capacitance coefficient	-	MJSW
PBSW	Source/drain side junction built-in potential	V	1.0
PB	Bottom built-in potential	V	1.0
PBSWG	Source/drain gate sidewall junction built-in potential	V	PBSW
CGS1	Overlap capacitance of lightly doped source-gate region	F/m	0
CGD1	Overlap capacitance of lightly doped drain-gate region	F/m	0
CKAPPA	Coefficient for lightly doped region overlap capacitance fringing field capacitance	F/m	0.6

Name	Parameter	Units	Default
CF	Fringing field capacitance	F/m	Calculated
CLC	Constant term for the short channel model	m	0.1E-6
CLE	Exponential term for the short channel model	-	0.6
DLC	Length offset fitting parameter from C-V	m	LINT
DWC	Width offset fitting parameter from C-V	m	WINT
VFB	Flat-band voltage parameter (for capmmod=0 only)	V	-1
Temperature Effect Parameters			
TNOM	Temperature at which parameters are extracted	°C	27
PRT	Temperature coefficient for RDSW	$\Omega \cdot \mu m/°C$	0
UTE	Temperature coefficient of mobility	-	-1.5
KT1	Threshold voltage temperature coefficient	V	-0.11
KT1L	Channel length sensitivity of temperature coefficient for threshold voltage	V·m	0
KT2	Body-bias coefficient of the Vth temperature effect	-	0.022
UA1	Temperature coefficient of UA	m/V	4.31E-9
UB1	Temperature coefficient of UB	$(m / V)^2$	-7.61E-18
UC1	Temperature coefficient of UC	1/V	-0.056
AT	Temperature coefficient of VSAT	m/s	3.3E4
NJ	Emission coefficient of junction	-	1
XTI	Junction current temperature exponent coefficient	-	3
NQS Model Parameters			
ELM	Elmore constant of the channel	-	5
dW and dL Parameters			
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

Name	Parameter	Units	Default
LL	Coefficient of length dependence for length offset	m^{LLN}	0.0
LLN	Power of length dependence for length offset	-	1.0
LW	Coefficient of width dependence for length offset	m^{LWN}	0.0
LWN	Power of width dependence for length offset	-	1.0
LWL	Coefficient of length and width cross term for length offset	$m^{LWN+LLN}$	0.0
Bin Description Parameters			
LMIN	Minimum channel length	m	0
LMAX	Maximum channel length	m	1
WMIN	Minimum channel width	m	0
WMAX	Maximum channel width	m	1
BINUNIT	Bin unit scale factor	-	1
Process Parameters			
TOX	Gate oxide thickness	m	150 Å
XJ	Metallurgical junction depth	m	0.15 μm
GAMMA1	Body effect coefficient near the interface	$\sqrt{V}$	Calculated
GAMMA2	Body effect coefficient in the bulk	$\sqrt{V}$	Calculated
NCH	Channel doping concentration	cm^{-3}	1.7E17
NSUB	Doping concentration	cm^{-3}	6E16
VBX	Vbs at which the depletion width equals XT	V	Calculated
XT	Doping depth	m	1.55E-7
Noise Model Parameters			
NOIA	Noise parameter A	-	1E20 (NMOS) 9.9E18 (PMOS)
NOIB	Noise parameter B	-	5E4 (NMOS) 2.4E3 (PMOS)
NOIC	Noise parameter C	-	-1.4E-12 (NMOS) 1.4E-12 (PMOS)
EM	Saturated field	V/m	4.1E7
AF	Frequency exponent	-	1
EF	Flicker exponent	-	1
KF	Flicker noise parameter	-	0

* If MOBMOD = 1 or 2: UC = -4.65E-11. If MOBMOD = 3: UC = -0.046

For a detailed BSIM3 model reference, download the BSIM3v3 manual. The URL address is: http://www-device.eecs.berkeley.edu/~bsim3.

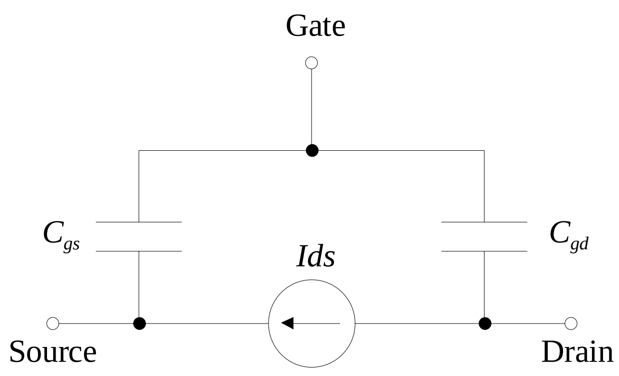
Supported Analyses

All

Amorphous-Si TFT Model ASIA2 (Level 15)

Name	Parameter	Units	Default
ALPHASAT	Saturation modulation parameter	-	0.6
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
DEF0	Dark Fermi level position	eV	0.6
DELTA	Transition width parameter	-	5
EL	Activation energy of the hole leakage current	eV	0.35
EMU	Field effect mobility activation energy	eV	0.06
EPS	Relative dielectric constant of substrate	-	11
EPSI	Relative dielectric constant of gate insulator	-	7.4
GAMMA	Power law mobility parameter	-	0.4
GMIN	Minimum density of deep states	$m^{-3}eV^{-1}$	1E23
IOL	Zero bias leakage current	A	3E-14
KASAT	Temperature coefficient of ALPHASAT	1/°C	0.006
KVT	Threshold voltage temperature coefficient	V/°C	-0.036
LAMBDA	Output conductance parameter	1/V	0.0008
M	Knee shape parameter	-	2.5
MUBAND	Conduction band mobility	m^2 / Vs	0.001
RD	Drain resistance	Ω	0.0
RS	Source resistance	Ω	0.0
SIGMA0	Minimum leakage current parameter	A	1E-14
TNOM	Parameter measurement temperature	°C	27
TOX	Thin-oxide thickness	m	1.0e-7
V0	Characteristic voltage for deep states	V	0.12
VAA	Characteristic voltage for field effect mobility (determined by tail states)	V	7.5E3
VDSL	Hole leakage current drain voltage parameter	V	7
VFB	Flat band voltage	V	-3
VGSL	Hole leakage current gate voltage parameter	V	7
VMIN	Convergence parameter	V	0.3
VTO	Zero-bias threshold voltage	V	0.0

Equivalent circuit



Drain current equations

$$I_{ds} = I_{leakage} + I_{ab}$$

$$I_{ab} = g_{ch} V_{dse} (1 + \mathrm{LAMBDA} \cdot V_{ds})$$

$$V_{dse} = \frac{V_{ds}}{\left[1 + (V_{ds} / V_{sate})^{\mathrm{M}}\right]^{1/\mathrm{M}}}$$

$$V_{sate} = \alpha_{sat} V_{gte}$$

$$g_{ch} = \frac{g_{chi}}{1 + g_{chi} (\mathrm{RS} + \mathrm{RD})}$$

$$g_{chi} = q n_s \mathrm{W} \cdot \mathrm{MUBAND} / \mathrm{L}$$

$$n_s = \frac{n_{sa} n_{sb}}{n_{sa} + n_{sb}}$$

$$n_{sa} = \frac{\mathrm{EPSI} \cdot V_{gte}}{q \cdot \mathrm{TOX}} \left(\frac{V_{gte}}{V_{aat}} \right)^{\mathrm{GAMMA}}$$

$$n_{sb} = n_{so}\left(\frac{t_m}{\mathrm{TOX}}\frac{V_{gfbe}}{\mathrm{V0}}\frac{\mathrm{EPSI}}{\mathrm{EPS}}\right)^{\frac{2\cdot\mathrm{V0}}{V_e}}$$

$$n_{so} = N_c t_m \frac{V_e}{\mathrm{V0}}\exp\left(-\frac{\mathrm{DEF0}}{V_{th}}\right)$$

$$N_c = 3.0\cdot 10^{25}\ \mathrm{m}^{-3}$$

$$V_e = \frac{2\cdot\mathrm{V0}\cdot V_{tho}}{2\cdot\mathrm{V0}-V_{th}}$$

$$t_m = \sqrt{\frac{\mathrm{EPS}}{2q\cdot\mathrm{GMIN}}}$$

$$V_{gte} = \frac{\mathrm{VMIN}}{2}\left[1+\frac{V_{gt}}{\mathrm{VMIN}}+\sqrt{\mathrm{DELTA}^2+\left(\frac{V_{gt}}{\mathrm{VMIN}}-1\right)^2}\right]$$

$$V_{gt} = V_{gs} - V_T$$

$$V_{gfbe} = \frac{\mathrm{VMIN}}{2}\left[1+\frac{V_{gfb}}{\mathrm{VMIN}}+\sqrt{\mathrm{DELTA}^2+\left(\frac{V_{gfb}}{\mathrm{VMIN}}-1\right)^2}\right]$$

$$V_{gfb} = V_{gs} - \mathrm{VFB}$$

$$I_{leakage} = I_{hl} + I_{\min}$$

$$I_{hl} = \mathrm{IOL}\left[\exp\left(\frac{V_{ds}}{\mathrm{VDSL}}\right)-1\right]\exp\left(-\frac{V_{gs}}{\mathrm{VGSL}}\right)\exp\left[\frac{\mathrm{EL}}{q}\left(\frac{1}{V_{tho}}-\frac{1}{V_{th}}\right)\right]$$

$$I_{\min} = \mathrm{SIGMA0}\cdot V_{ds}$$

Temperature dependence

$$V_{tho} = k_B \cdot \mathrm{TNOM} / q$$

$$V_{th} = k_B \cdot \mathrm{TEMP} / q$$

$$V_{aat} = \mathrm{VAA} \exp\left[\frac{\mathrm{EMU}}{q \cdot \mathrm{GAMMA}}\left(\frac{1}{V_{th}} - \frac{1}{V_{tho}}\right)\right]$$

$$V_T = \mathrm{VTO} + \mathrm{KVT}(\mathrm{TEMP} - \mathrm{TNOM})$$

$$\alpha_{sat} = \mathrm{ALPHASAT} + \mathrm{KASAT}(\mathrm{TEMP} - \mathrm{TNOM})$$

Capacitance equations

$$C_{gs} = C_f + \frac{2}{3} C_{gc}\left[1 - \left(\frac{V_{sate} - V_{dse}}{2V_{sate} - V_{dse}}\right)^2\right]$$

$$C_{gd} = C_f + \frac{2}{3} C_{gc}\left[1 - \left(\frac{V_{sate}}{2V_{sate} - V_{dse}}\right)^2\right]$$

$$C_f = 0.5 \cdot \mathrm{EPS} \cdot \mathrm{W}$$

$$C_{gc} = q \frac{dn_{sc}}{dV_{gs}}$$

$$n_{sc} = \frac{n_{sac} n_{sbc}}{n_{sac} + n_{sbc}}$$

$$n_{sac} = \frac{\mathrm{EPSI} \cdot V_{gte}}{q \cdot \mathrm{TOX}}$$

$$n_{sbc} = n_{sb}$$

Supported Analyses

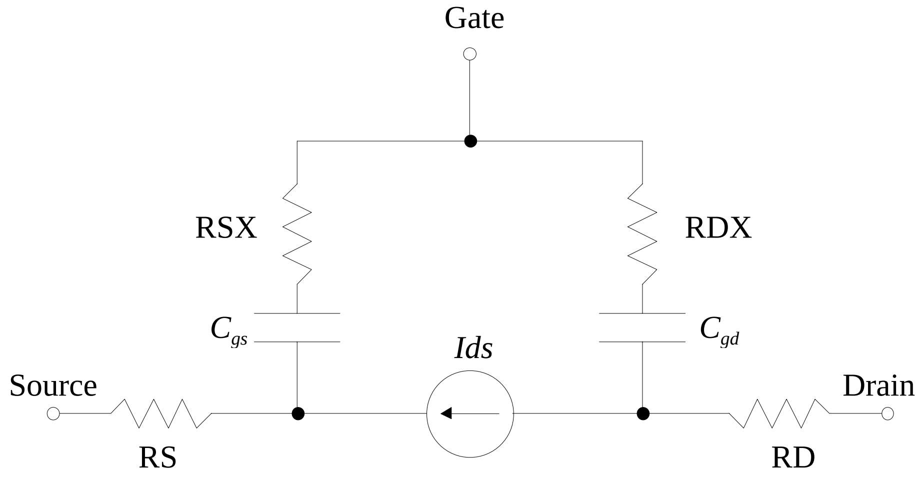
Noise and Pole-Zero analyses not supported

Poly-Si TFT Model PSIA2 (Level 16)

Name	Parameter	Units	Default
ASAT	Proportionality constant of Vsat	-	1
AT	DIBL parameter 1	m/V	3E-8
BLK	Leakage barrier lowering constant	-	0.001
BT	DIBL parameter 2	m·V	1.9E-6
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0
DASAT	Temperature coefficient of ASAT	1/°C	0
DD	Vds field constant	m	1400 Å
DELTA	Transition width parameter	-	4.0
DG	Vgs field constant	m	2000 Å
DMU1	Temperature coefficient of MU1	cm^2 / Vs°C	0
DVT	The difference between VON and the threshold voltage	V	0
DVTO	Temperature coefficient of VTO	V/°C	0
EB	Barrier height of diode	EV	0.68
ETA	Subthreshold ideality factor	-	7
ETAC0	Capacitance subthreshold ideality factor at zero drain bias	-	ETA
ETAC00	Capacitance subthreshold coefficient of drain bias	1/V	0
I0	Leakage scaling constant	A/m	6.0
I00	Reverse diode saturation current	A/m	150
LASAT	Coefficient for length dependence of ASAT	M	0
LKINK	Kink effect constant	M	19E-6
MC	Capacitance knee shape parameter	-	3.0
MK	Kink effect exponent	-	1.3
MMU	Low field mobility exponent	-	3.0
MU0	High field mobility	cm^2 / Vs	100
MU1	Low field mobility parameter	cm^2 / Vs	0.0022
MUS	Subthreshold mobility	cm^2 / Vs	1.0
RD	Drain resistance	Ω	0.0
RDX	Resistance in series with C_{gd}	Ω	0
RS	Source resistance	Ω	0.0
RSX	Resistance in series with C_{gs}	Ω	0
TNOM	Parameter measurement temperature	°C	27
TOX	Thin-oxide thickness	m	1.0e-7
VFB	Flat band voltage	V	-0.1
VKINK	Kink effect voltage	V	9.1

Name	Parameter	Units	Default
VON	*On*-voltage	V	0
VTO	Zero-bias threshold voltage	V	0.0

Equivalent circuit



Drain current equations

The expression for the subthreshold current is given by:

$$I_{sub} = \mathrm{MUS} \cdot C_{ox} \frac{\mathrm{W}}{\mathrm{L}} V_{sth}^{2} \exp\left(\frac{V_{GT}}{V_{sth}}\right)\left[1 - \exp\left(-\frac{V_{DS}}{V_{sth}}\right)\right]$$

$$V_{sth} = \mathrm{ETA} \cdot V_{th}, \quad V_{th} = k_B \cdot \mathrm{TEMP} / q$$

$$C_{ox} = \varepsilon_i \cdot \mathrm{L} \cdot \mathrm{W} / \mathrm{TOX}$$

$$V_{GT} = V_{GS} - V_T$$

$$V_T = V_{TX} - \frac{\mathrm{AT} \cdot V_{DS}^2 + \mathrm{BT}}{\mathrm{L}}$$

where ε_i is the dielectric constant of the oxide and k_B is the Boltzmann's constant.

Above threshold ($V_{GT} > 0$), the conduction current is given by:

$$I_a = \begin{cases} \mu_{FET} C_{ox} \dfrac{W}{L}\left(V_{GT} V_{DS} - \dfrac{V_{DS}^2}{2\alpha_{sat}} \right) & \text{for } V_{DS} < \alpha_{sat} V_{GT} \\ \mu_{FET} C_{ox} \dfrac{W}{L} \dfrac{V_{GT}^2 \alpha_{sat}}{2} & \text{for } V_{DS} \geq \alpha_{sat} V_{GT} \end{cases}$$

$$\frac{1}{\mu_{FET}} = \frac{1}{\mathrm{MUO}} + \frac{1}{\mu_1 (2V_{GT} / V_{sth})^{\mathrm{MMU}}}$$

Subthreshold leakage current is the result of thermionic field emission of carriers through the grain boundary trap states and is described by:

$$I_{leak} = \mathrm{I0} \cdot \mathrm{W} \left[\exp\left(\frac{q \cdot \mathrm{BLK} \cdot V_{DS}}{kT} \right) - 1 \right] \left[X_{TFE} + X_{TE} \right] + I_{diode}$$

$$X_{TFE} = \frac{X_{TFE,lo} X_{TFE,hi}}{X_{TFE,lo} + X_{TFE,hi}}$$

$$X_{TE} = \exp(-W_C)$$

$$W_C = (E_c - E_t) / kT = 0.55 \text{ eV} / kT$$

$$X_{TEF,lo} = \begin{cases} \dfrac{4\sqrt{\pi}}{3} f \exp\left(\dfrac{4}{27} f^2 - W_C \right) & \text{for } f \leq f_{lo} \\ X_{TFE,lo}(f_{lo}) \exp\left[\left(\dfrac{1}{f_{lo}} + \dfrac{8}{27} f_{lo} \right) (f - f_{lo}) \right] & \text{for } f > f_{lo} \end{cases}$$

$$f = F / F_0$$

$$F = \left[\frac{V_{DS}}{\mathrm{DD}} - \frac{V_{GS} - \mathrm{VFB}}{\mathrm{DG}} \right]$$

$$F_0 = (kT)^{3/2} \frac{4}{3} \frac{2\pi\sqrt{2m^*}}{qh}$$

$$m^* = 0.27 m_0$$

$$f_{lo} = \frac{3}{2}\left(\sqrt{W_C + 1} - 1\right)$$

$$X_{TEF,hi} = \begin{cases} \dfrac{2W_C}{3}\exp\left(1 - \dfrac{2W_C}{3}\right) & \text{for } f < f_{hi} \\ \left(1 - \dfrac{3\sqrt{W_C}}{2f}\right)^{-1}\exp\left(\dfrac{-W_C^{3/2}}{f}\right) & \text{for } f \geq f_{hi} \end{cases}$$

$$f_{hi} = 3\left(\frac{W_C^{3/2}}{2W_C - 3}\right)$$

$$I_{diode} = \mathrm{I00} \cdot W \exp\left(-\frac{\mathrm{EB}}{k_B T}\right)\left[1 - \exp\left(-\frac{qV_{DS}}{k_B T}\right)\right]$$

Finally, for very large drain biases, the kink effect is observed. It is modeled as impact ionization in a narrow region near the drain. The expression can be written as:

$$I_{kink} = A_{kink} I_a (V_{DS} - V_{DSAT}) \exp\left(-\frac{\mathrm{VKINK}}{V_{DS} - V_{DSAT}}\right)$$

$$A_{kink} = \frac{1}{\mathrm{VKINK}}\left(\frac{\mathrm{LKINK}}{\mathrm{L}}\right)^{\mathrm{MK}}, \; V_{DSAT} = \alpha_{sat} V_{GT}$$

The impact ionization current, I_{kink}, is added to the drain current.

Threshold voltage

If VTO is not specified

$$V_T = \mathrm{VON} - \mathrm{DVT}$$

else

$$V_T = \mathrm{VTO}$$

Temperature dependence

$$V_{TX} = V_T - \mathrm{DVTO}(\mathrm{TEMP} - \mathrm{TNOM})$$

$$\mu_1 = \mathrm{MU1} - \mathrm{DMU1}(\mathrm{TEMP} - \mathrm{TNOM})$$

$$\alpha_{sat} = \mathrm{ASAT} - \frac{\mathrm{LASAT}}{\mathrm{L}} - \mathrm{DASAT}(\mathrm{TEMP} - \mathrm{TNOM})$$

Capacitance equations

$$C_{gs} = C_f + \frac{2}{3}C_{gcd}\left[1 - \left(\frac{V_{DSAT} - V_{DSE}}{2V_{DSAT} - V_{DSE}}\right)^2\right]$$

$$C_{gd} = C_f + \frac{2}{3}C_{gcs}\left[1 - \left(\frac{V_{DSAT}}{2V_{DSAT} - V_{DSE}}\right)^2\right]$$

$$C_f = 0.5 \cdot \mathrm{EPS} \cdot \mathrm{W}$$

$$C_{gcd} = \frac{C_{ox}}{1 + \eta_{cd}\exp\left(-\frac{V_{GT}}{\eta_{cd}V_{th}}\right)}$$

$$C_{gcs} = \frac{C_{ox}}{1 + \mathrm{ETAC0} \cdot \exp\left(-\frac{V_{GT}}{\mathrm{ETAC0} \cdot V_{th}}\right)}$$

$$C_{ox} = \mathrm{W} \cdot \mathrm{L} \cdot \varepsilon_i / \mathrm{TOX}, \quad \eta_{cd} = \mathrm{ETAC0} + \mathrm{ETAC00} \cdot V_{DSE}$$

$$V_{DSE} = \frac{V_{DS}}{\left[1 + (V_{DS} / V_{DSAT})^{\mathrm{MC}}\right]^{1/\mathrm{MC}}}$$

Supported Analyses

Noise and Pole-Zero analyses not supported.

Berkeley SPICE BSIM3v3.2 Model (Level 17)

Name	Parameter	Units	Default
Control Parameters			
CAPMOD	Flag for the short channel capacitance model	-	2
MOBMOD	Mobility model selector	-	1
NQSMOD	NQS model selector	-	0
NOIMOD	Noise model selector	-	1
DC Parameters			
VTH0	Threshold voltage at zero substrate bias	V	0.7 (NMOS) -0.7 (PMOS)
VFB	DC flat-band voltage	V	calculated
K1	First-order body effect coefficient	$V^{1/2}$	0.5
K2	Second-order body effect coefficient	-	-0.0186
K3	Narrow width effect coefficient	-	80
K3B	Body effect coefficient of K3	-	0
W0	Narrow width effect reference width	m	2.5E-6
NLX	Lateral non-uniform doping coefficient	m	1.74E-7
VBM	Maximum substrate bias	V	-3
DVT0	First coefficient of short-channel effect on Vth	-	2.2
DVT1	Second coefficient of short-channel effect on Vth	-	0.53
DVT2	Body-bias coefficient of short-channel effect on Vth	1/V	-0.032
DVT0W	First coefficient of narrow width effect on Vth at small L	1/m	0
DVT1W	Second coefficient of narrow width effect on Vth at small L	1/m	5.3E6
DVT2W	Body-bias coefficient of short-channel effect on Vth at small L	1/V	-0.032
U0	Low-field mobility at TNOM	cm^2 / Vs	670 (NMOS) 250 (PMOS)
UA	First-order mobility degradation coefficient	m/V	2.25E-9
UB	Second-order mobility degradation coefficient	$(m / V)^2$	5.87E-19
UC	Body-effect of mobility degradation coefficient	1/V	*
VSAT	Saturation velocity at TNOM	cm/s	8.0E6
A0	Bulk charge effect coefficient for channel length	-	1.0
AGS	Gate bias coefficient of the Abulk	1/V	0

Name	Parameter	Units	Default
B0	Bulk charge effect coefficient for channel width	m	0
B1	Bulk charge effect width offset	m	0
KETA	Body bias coefficient of the bulk charge effect	1/V	-0.047
A1	First non-saturation effect coefficient	1/V	0
A2	Second non-saturation effect coefficient	-	1.0
RDSW	Width coefficient of parasitic resistance	$\Omega \cdot \mu m^{WR}$	0
PRWG	Gate bias effect coefficient of RDSW	1/V	0
PRWB	Body effect coefficient of RDSW	$V^{-1/2}$	0
WR	Width offset from Weff for Rds calculation	-	1
WINT	Width offset fitting parameter from I-V without bias	m	0
LINT	Length offset fitting parameter from I-V without bias	m	0
DWG	Coefficient of Weff’s gate dependence	m/V	0
DWB	Coefficient of Weff’s body bias dependence	$m / V^{1/2}$	0
VOFF	Offset voltage in the subthreshold region at large W and L	V	-0.11
NFACTOR	Subthreshold swing factor	-	1
ETA0	Subthreshold region DIBL coefficient	-	0.08
ETAB	Body bias coefficient for the subthreshold DIBL effect	1/V	-0.07
DSUB	Subthreshold DIBL coefficient exponent	-	DROUT
CIT	Interface trapped charge capacitance	F / m^2	0
CDSC	Drain/Source to channel coupling capacitance	F / m^2	2.4E-4
CDSCB	Body-bias sensitivity of CDSC	F / Vm^2	0
CDSCD	Drain-bias sensitivity of CDSC	F / Vm^2	0
PCLM	Channel length modulation parameter	-	1.3
PDIBLC1	First output resistance DIBL effect correction parameter	-	0.39
PDIBLC2	Second output resistance DIBL effect correction parameter	-	0.0086
PDIBLCB	Body effect coefficient of DIBL correction parameters	1/V	0
DROUT	L dependence coefficient of DIBL correction parameters	-	0.56
PSCBE1	First substrate current body-effect parameter	V/m	4.24E8

Name	Parameter	Units	Default
PSCBE2	Second substrate current body-effect parameter	m/V	1.0E-5
PVAG	Gate voltage dependence of Rout coefficient	-	0
DELTA	Effective Vds parameter	V^2	0.01
NGATE	Poly gate doping concentration	cm^{-3}	0
ALPHA0	First impact ionization current parameter	m/V	0
BETA0	Second impact ionization current parameter	V	30
RSH	Source/Drain sheet resistance in Ohm per square	Ω/□	0
JSSW	Side wall saturation current density	A/m	0
JS	Source/Drain junction saturation current density	A / m^2	1E-4
IJTH	Diode limiting current	A	0.1
ALPHA1	Substrate current parameter	1/V	0
ACDE	Exponential coefficient for charge thickness in the accumulation and depletion regions	m/V	1.0
MOIN	Coefficient for the gate-bias dependent surface potential	$V^{1/2}$	15.0
AC and Capacitance Parameters			
XPART	Charge partitioning rate flag	-	0
CGS0	Non-LDD region source-gate overlap capacitance per meter channel length	F/m	Calculated
CGD0	Non-LDD region drain-gate overlap capacitance per meter channel length	F/m	Calculated
CGB0	Gate-bulk overlap capacitance per meter channel length	F/m	2*DWC*Cox
CJ	Source and drain junction capacitance per unit area	F / m^2	5E4
MJ	Grading coefficient of source drain junction	-	0.5
MJSW	Grading coefficient of source drain junction sidewall	-	0.33
CJSW	Source drain junction sidewall capacitance per unit length	F/m	5E-10
CJSWG	Source/drain gate sidewall junction capacitance grading coefficient	F/m	CJSW
MJSWG	Source/drain gate sidewall junction capacitance coefficient	-	MJSW
PBSW	Source/drain side junction built-in potential	V	1.0
PB	Bottom built-in potential	V	1.0
PBSWG	Source/drain gate sidewall junction	V	PBSW

Name	Parameter	Units	Default
	built-in potential		
CGS1	Overlap capacitance of lightly doped source-gate region	F/m	0
CGD1	Overlap capacitance of lightly doped drain-gate region	F/m	0
CKAPPA	Coefficient for lightly doped region overlap capacitance fringing field capacitance	F/m	0.6
CF	Fringing field capacitance	F/m	Calculated
CLC	Constant term for the short channel model	m	0.1E-6
CLE	Exponential term for the short channel model	-	0.6
DLC	Length offset fitting parameter from C-V	m	LINT
DWC	Width offset fitting parameter from C-V	m	WINT
VOFFCV	C-V parameter for VgsteffCV for weak to strong inversion region	-	0.0
NOFF	C-V parameter for VgsteffCV for weak to strong inversion region	-	1.0
Temperature Effect Parameters			
TNOM	Temperature at which parameters are extracted	°C	27
PRT	Temperature coefficient for RDSW	$\Omega \cdot \mu m/°C$	0
UTE	Temperature coefficient of mobility	-	-1.5
KT1	Threshold voltage temperature coefficient	V	-0.11
KT1L	Channel length sensitivity of temperature coefficient for threshold voltage	V·m	0
KT2	Body-bias coefficient of the Vth temperature effect	-	0.022
UA1	Temperature coefficient of UA	m/V	4.31E-9
UB1	Temperature coefficient of UB	$(m / V)^2$	-7.61E-18
UC1	Temperature coefficient of UC	1/V	-0.056
AT	Temperature coefficient of VSAT	m/s	3.3E4
NJ	Emission coefficient of junction	-	1
XTI	Junction current temperature exponent coefficient	-	3
TPB	Temperature coefficient of PB	V/K	0
TPBSW	Temperature coefficient of PBSW	V/K	0
TPBSWG	Temperature coefficient of PBSWG	V/K	0
TCJ	Temperature coefficient of CJ	1/K	0
TCJSW	Temperature coefficient of CJSW	1/K	0

Name	Parameter	Units	Default
TCJSWG	Temperature coefficient of CJSW	1/K	0
NQS Model Parameters			
ELM	Elmore constant of the channel	-	5
dW and dL Parameters			
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
LL	Coefficient of length dependence for length offset	m^{LLN}	0.0
LLN	Power of length dependence for length offset	-	1.0
LW	Coefficient of width dependence for length offset	m^{LWN}	0.0
LWN	Power of width dependence for length offset	-	1.0
LWL	Coefficient of length and width cross term for length offset	$m^{LWN+LLN}$	0.0
LLC	Coefficient of length dependence for C-V channel length offset	m^{LLN}	LL
LWC	Coefficient of width dependence for C-V channel length offset	m^{LWN}	LW
LWLC	Coefficient of length and width cross term for C-V channel length offset	$m^{LWN+LLN}$	LWL
WLC	Coefficient of length dependence for C-V channel width offset	m^{WLN}	WL
WWC	Coefficient of width dependence for C-V channel width offset	m^{WWN}	WWN
WWLC	Coefficient of length and width cross-term for C-V channel width offset	$m^{WWN+WLN}$	WWL
Bin Description Parameters			
LMIN	Minimum channel length	m	0
LMAX	Maximum channel length	m	1
WMIN	Minimum channel width	m	0
WMAX	Maximum channel width	m	1
BINUNIT	Bin unit scale factor	-	1

Name	Parameter	Units	Default
Process Parameters			
TOX	Gate oxide thickness	m	150 Å
TOXM	Gate oxide thickness at which parameters are extracted	m	TOX
XJ	Metallurgical junction depth	m	0.15 μm
GAMMA1	Body effect coefficient near the interface	$\sqrt{V}$	Calculated
GAMMA2	Body effect coefficient in the bulk	$\sqrt{V}$	Calculated
NCH	Channel doping concentration	cm^{-3}	1.7E17
NSUB	Doping concentration	cm^{-3}	6E16
VBX	Vbs at which the depletion width equals XT	V	Calculated
XT	Doping depth	m	1.55E-7
Noise Model Parameters			
NOIA	Noise parameter A	-	1E20 (NMOS) 9.9E18 (PMOS)
NOIB	Noise parameter B	-	5E4 (NMOS) 2.4E3 (PMOS)
NOIC	Noise parameter C	-	-1.4E-12 (NMOS) 1.4E-12 (PMOS)
EM	Saturated field	V/m	4.1E7
AF	Frequency exponent	-	1
EF	Flicker exponent	-	1
KF	Flicker noise parameter	-	0

* If MOBMOD = 1 or 2: UC = -4.65E-11. If MOBMOD = 3: UC = -0.046

Parameter names in blue are new parameters in BSIM3v3.2.

For a detailed BSIM3 model reference, download the BSIM3v3 manual. The URL is:

http://www-device.eecs.berkeley.edu/~bsim3

Supported Analyses

All

Berkeley SPICE BSIM3SOI Model (Level 19)

Name	Parameter	Units	Default
Control Parameters			
DDMOD	Flag for dynamic depletion (DD) mode 0: No DD calculation 1: DD without back gate effect 2: DD with back gate effect 3: Ideal FD mode, no floating body	-	2
MOBMOD	Mobility model selector	-	1
NQSMOD	NQS model selector	-	0
NOIMOD	Noise model selector	-	1
SHMOD	Self-heating flag 0: No self-heating 0: Self-heating		
DC Parameters			
VTH0	Threshold voltage at zero substrate bias for long and wide device	V	0.7[1]
K1	First-order body effect coefficient	$V^{1/2}$	0.6
K2	Second-order body effect coefficient	-	0
K3	Narrow width coefficient	-	0
K3B	Body effect coefficient of K3	1/V	0
VBSA	Transition body voltage offset	V	0
DELP	Constant for limiting Vbseff to ϕs	V	0.02
KB1	Coefficient of Vbs0 dependency on Ves	-	1
KB3	Coefficient of Vbs0 dependency on Vgs in subthreshold region	-	1
DVBD0	First coefficient of Vbs0 dependency on Leff	V	0
DVBD0	Second coefficient of Vbs0 dependency on Leff	V	0
W0	Narrow width parameter	m	0
NLX	Lateral non-uniform doping parameter	m	1.74E-7
DVT0	First coefficient of short-channel effect on Vth	-	2.2
DVT1	Second coefficient of short-channel effect on Vth	-	0.53
DVT2	Body-bias coefficient of short-channel effect on Vth	1/V	-0.032
DVT0W	First coefficient of narrow width effect on Vth at small L	-	0
DVT1W	Second coefficient of narrow width	-	5.3E6

Name	Parameter	Units	Default
	effect on Vth at small L		
DVT2W	Body-bias coefficient of short-channel effect on Vth at small L	1/V	-0.032
U0	Low-field mobility at TNOM	cm^2 / Vs	670 (NMOS) 250 (PMOS)
UA	First-order mobility degradation coefficient	m/V	2.25E-9
UB	Second-order mobility degradation coefficient	$(m/V)^2$	5.9E-19
UC	Body-effect of mobility degradation coefficient	1/V	-0.0465
VSAT	Saturation velocity at TNOM	m/s	8.0E4
A0	Bulk charge effect coefficient for channel length	-	1.0
AGS	Gate bias coefficient of the Abulk	1/V	0
B0	Bulk charge effect coefficient for channel width	m	0
B1	Bulk charge effect width offset	m	0
KETA	Body bias coefficient of the bulk charge effect	1/V	-0.6
ABP	Coefficient of Abeff dependency on Vgst	-	1.0
MXC	Fitting parameter for Abeff calculation	-	-0.9
ADICE0	DICE bulk charge factor	-	1
A1	First non-saturation effect coefficient	1/V	0
A2	Second non-saturation effect coefficient	-	1.0
RDSW	Width coefficient of parasitic resistance	$\Omega \cdot \mu m^{WR}$	100
PRWG	Gate bias effect coefficient of RDSW	1/V	0
PRWB	Body effect coefficient of RDSW	$V^{-1/2}$	0
WR	Width offset from Weff for Rds calculation	-	1
WINT	Width offset fitting parameter from I-V without bias	m	0
LINT	Length offset fitting parameter from I-V without bias	m	0
DWG	Coefficient of Weff's gate dependence	m/V	0
DWB	Coefficient of Weff's body bias dependence	$m / V^{1/2}$	0
VOFF	Offset voltage in the subthreshold region at large W and L	V	-0.08
NFACTOR	Subthreshold swing factor	-	1
ETA0	Subthreshold region DIBL coefficient	-	0.08

Name	Parameter	Units	Default
ETAB	Body bias coefficient for the subthreshold DIBL effect	1/V	-0.07
DSUB	Subthreshold DIBL coefficient exponent	-	0.56
CIT	Interface trapped charge capacitance	F / m^2	0
CDSC	Drain/Source to channel coupling capacitance	F / m^2	2.4E-4
CDSCB	Body-bias sensitivity of CDSC	F / Vm^2	0
CDSCD	Drain-bias sensitivity of CDSC	F / Vm^2	0
PCLM	Channel length modulation parameter	-	1.3
PDIBL1	First output resistance DIBL effect correction parameter	-	0.39
PDIBL2	Second output resistance DIBL effect correction parameter	-	0.0086
DROUT	L dependence coefficient of DIBL correction parameters	-	0.56
PVAG	Gate dependence of Early voltage	-	0
DELTA	Effective Vds parameter	-	0.01
AII	First Leff dependence on Vdsatii parameter	1/V	0
BII	Second Leff dependence on Vdsatii parameter	m/V	0
CII	First Vds dependence on Vdsatii parameter	-	0
DII	Second Vds dependence on Vdsatii parameter	V	-1
ALPHA0	First impact ionization current parameter	m/V	0
ALPHA1	Second impact ionization current parameter	1/V	1
BETA0	Third impact ionization current parameter	V	30
AGIDL	GIDL constant	Ω^{-1}	0
BGIDL	GIDL exponential coefficient	V/m	0
NGIDL	GIDL Vds enhancement coefficient	V	1.2
NTUN	Reverse tunneling non-ideality factor	-	10
NDIODE	Diode non-ideality factor	-	1
ISBJT	BJT injection saturation current	A/m^2	1E-6
ISDIF	Body to source/drain injection saturation current	A/m^2	0
ISREC	Recombination in depletion saturation current	A/m^2	1E-5
ISTUN	Reverse tunneling saturation current	A/m^2	0
EDL	Electron diffusion length	m	2E-6
KBJT1	Parasitic bipolar Eraly effect	m/V	0

Name	Parameter	Units	Default
	coefficient		
RBODY	Intrinsic body contact sheet resistance	Ω/m^2	0
RBSH	Extrinsic body contact sheet resistance	Ω/m^2	0
RSH	Source/Drain sheet resistance in Ohm per square	Ω/□	0
AC and Capacitance Parameters			
XPART	Charge partitioning rate flag	-	0
CGS0	Non-LDD region source-gate overlap capacitance per meter channel length	F/m	calculated[2]
CGD0	Non-LDD region drain-gate overlap capacitance per meter channel length	F/m	calculated[2]
CGE0	Gate-substrate overlap capacitance per unit channel length	F/m	0
CJSWG	Source/drain gate sidewall junction capacitance per unit width	F/m^2	1E-10
PBSWG	Source/drain gate sidewall junction capacitance built-in potential	V	0.7
MJSWG	Source/drain gate sidewall junction capacitance grading coefficient	V	0.5
TT	Diffusion capacitance transit time	s	1p
VSDFB	Source/drain bottom diffusion capacitance flatband voltage	V	calculated
VSDTH	Source/drain bottom diffusion capacitance threshold voltage	V	calculated
CDSMIN	Source/drain bottom diffusion minimum capacitance	V	calculated
ASD	Source/drain bottom diffusion smoothing parameter	-	0.3
CSDESW	Source/drain sidewall fringing capacitance per unit length	F/m	0
CGS1	Overlap capacitance of lightly doped source-gate region	F/m	0
CGD1	Overlap capacitance of lightly doped drain-gate region	F/m	0
CKAPPA	Coefficient for lightly doped region overlap capacitance fringing field capacitance	F/m	0.6
CF	Gate to source/drain fringing field capacitance	F/m	calculated
CLC	Constant term for the short channel model	m	0.1E-7
CLE	Exponential term for the short channel model	-	0
DLC	Length offset fitting parameter from	m	LINT

Name	Parameter	Units	Default
	C-V		
DWC	Width offset fitting parameter from C-V	m	WINT
Temperature Effect Parameters			
TNOM	Temperature at which parameters are extracted	°C	27
UTE	Temperature coefficient of mobility	-	-1.5
KT1	Threshold voltage temperature coefficient	V	-0.11
KT1L	Channel length dependence of the temperature coefficient for threshold voltage	V·m	0
KT2	Body-bias coefficient of the Vth temperature effect	-	0.022
UA1	Temperature coefficient of UA	m/V	4.31E-9
UB1	Temperature coefficient of UB	$(m / V)^2$	-7.61E-18
UC1	Temperature coefficient of UC	1/V	-0.056[3]
AT	Temperature coefficient of VSAT	m/s	3.3E4
CTH0	Normailized thermal capacity	m°C/(W·s)	0
PRT	Temperature coefficient for RDSW	$\Omega \cdot \mu m$	0
RTH0	Normailized thermal resistance	m°C/W	0
XBJT	Power dependence of Jbjt on temperature	-	2
XDIF	Power dependence of Jdif on temperature	-	2
XREC	Power dependence of Jrec on temperature	-	20
XTUN	Power dependence of Jtun on temperature	-	0
Process Parameters			
NCH	Channel doping concentration	cm^{-3}	1.7E17
NGATE	Poly gate doping concentration	cm^{-3}	0
NSUB	Substrate doping concentration	cm^{-3}	6E16
TBOX	Buried oxide thickness	m	3E-7
TOX	Gate oxide thickness	m	100 Å
TSI	Silicon film thickness	m	10E-7
XJ	Metallurgical junction depth	m	see comment[4]

For a detailed BSIM3SOI model reference, download the BSIM3SOI manual. The URL is:

http://www-device.eecs.berkeley.edu/~bsim3soi/intro.html

Supported Analyses

All

[1] For FD devices, VTH0 is not equal to the measured long and wide device threshold voltage because Vbs0 is higher than zero.

[2] If CGX0 (X is S or D) is not given it is calculated using:

```
if(DLC is given and is grater than 0) then
     CGX0 = DLC*COX-CGX1
else if(the previously calculated CGX0 < 0) then
     CGX0 = 0
else
     CGX0 = 0.6*TSI*COX
```

[3] For MOBMOD=1 and 2, the unit is m/V^2. Default is -5.6E-11. For MOBMOD=3, the unit is 1/V and the default value is -0.056.

[4] In Modern SOI technology, source/drain extension or LDD are commonly used. As a result, the source/drain junction depth (XJ) can be different from the silicon film thickness (TSI). By default, if XJ is not given, it is set to TSI. XJ is not allowed to be greater than TSI.

Berkeley SPICE BSIM4 v1.0, v2.0, v2.1, v3.0 and v4.0 Model Parameters (Levels 20, 21, 24, 25 and 26)

For a detailed BSIM4 model reference, download the BSIM4 manual. The URL is:

http://www-device.eecs.berkeley.edu/~bsim3/bsim4.html

In addition to the standard MOSFET device parameters, BSIM4 devices can be specified with the following additional parameters:

Name	Description	Default Value
ACNQSMOD	AC NQS model selector	Corresponding model parameter
NF	Number of fingers	1
GEOMOD	Geometry dependent parasitics model selector	Corresponding model parameter
MIN	Minimize either D or S	0
NONOISE	If set to 1, device is noiseless	0
RBDB	Body resistance	Corresponding model parameter
RBODYMOD	Distributed body R model selector	Corresponding model parameter
RBPB	Body resistance	Corresponding model parameter
RBPS	Body resistance	Corresponding model parameter
RBSB	Body resistance	Corresponding model parameter
RGATEMOD	Gate resistance model selector	Corresponding model parameter
RGEOMOD	S/D resistance and contact model selector	Corresponding model parameter
SA	Distance between OD edge to poly of one side (version 3.0 and later)	0
SB	Distance between OD edge to poly of the other side (version 3.0 and later)	0
SD	Distance between neighbor fingers (version 3.0 and later)	0
TRNQSMOD	Transient NQS model selector	

Model parameters are listed below.

Name	Description	Default Value	Binnable	Note
Model Selectors/Controllers				
VERSION	Model version number	4.1.0	NA	-

Name	Description	Default Value	Binnable	Note
BINUNIT	Binning unit selector	1	NA	-
PARAMCHK	Switch for parameter value check	1	NA	Parameters checked
MOBMOD	Mobility model selector	1	NA	-
RDSMOD	Bias-dependent source/ drain resistance model selector	0	NA	*Rds* (*V*) modeled internally through IV equation
IGCMOD	Gate-to-channel tunneling current model selector	0	NA	OFF
IGBMOD	Gate-to-substrate tunneling current model selector	0	NA	OFF
CAPMOD	Capacitance model selector	2	NA	-
RGATEMOD (Also an instance parameter)	Gate resistance model selector	0 (no gate resistance)		-
RBODYMOD (Also an instance parameter)	Substrate resistance network model selector	0 (network off)	NA	-
TRNQSMOD (Also an instance parameter)	Transient NQS model selector	0	NA	OFF
ACNQSMOD (Also an instance parameter)	AC small-signal NQS model selector	0	NA	OFF
FNOIMOD	Flicker noise model selector	1	NA	-
TNOIMOD	Thermal noise model selector	0	NA	-
DIOMOD	Source/drain junction diode IV model selector	1	NA	-
PERMOD	Whether PS/PD (when given) includes the gate-edge perimeter	1 (including the gate-edge perimeter)	NA	-
GEOMOD (Also an instance parameter)	Geometry-dependent parasitics model selector - specifying how the end S/D diffusions are connected	0 (isolated)	NA	-
RGEOMOD (Instance	Source/drain diffusion resistance and contact	0 (no S/D	NA	-

Name	Description	Default Value	Binn able	Note
parameter only)	model selector - specifying the end S/D contact type: point, wide or merged, and how S/D parasitics resistance is computed	diffusion resistance)		
Process Parameters				
EPSROX	Gate dielectric constant relative to vacuum	3.9 (SiO_2)	No	Typically greater than or equal to 3.9
TOXE	Electrical gate equivalent oxide thickness	3.0e-9m	No	Fatal error if not positive
TOXP	Physical gate equivalent oxide thickness	TOXE	No	Fatal error if not positive
TOXM	*Tox* at which parameters are extracted	TOXE	No	Fatal error if not positive
DTOX	Defined as (TOXE-TOXP)	0.0m	No	-
XJ	S/D junction depth	1.5e-7m	Yes	-
GAMMA1	Body-effect coefficient near the surface	Calculated	$V^{1/2}$	Note-1
GAMMA2	Body-effect coefficient in the bulk	Calculated	$V^{1/2}$	Note-1
NDEP	Channel doping concentration at depletion edge for zero body bias	1.7e17cm-3	Yes	Note-2
NSUB	Substrate doping concentration	6.0e16cm-3	Yes	-
NGATE	Poly Si gate doping concentration	0.0cm-3	Yes	-
NSD	Source/drain doping concentration. Fatal error if not positive	1.0e20cm-3	Yes	-
VBX	*Vbs* at which the depletion region width equals XT	Calculated (V)	No	Note-3
XT	Doping depth	1.55e-7m	Yes	-
RSH	Source/drain sheet resistance	0.0ohm/ square	No	Should not be negative
RSHG	Gate electrode sheet resistance	0.1ohm/ square	No	Should not be negative
Basic Model Parameters				
VTH0 (or VTHO)	Long channel threshold voltage at *Vbs* = 0V	0.7 (nmos) -0.7 (pmos)	Yes	Note-4
VFB	Flat-band voltage	-1.0 V	Yes	Note-4

Name	Description	Default Value	Binnable	Note
PHIN	Non-uniform vertical dopinf effect on surface potential	0.0 V	Yes	-
K1	First-order body bias coefficient	0.5 $V^{1/2}$	Yes	Note-5
K2	Second-order body bias coefficient	0.0	Yes	Note-5
K3	Narrow width coefficient	80.0	Yes	-
K3B	Body effect coefficient of K3	0.0 V^{-1}	Yes	-
W0	Narrow width parameter	2.5e-6 m	Yes	-
LPE0	Lateral non-uniform doping parameter at *Vbs* = 0	1.74e-7 m	Yes	-
LPEB	Lateral non-uniform doping effect on K1	0.0 m	Yes	-
VBM	Maximum applied body bias in VTH0 calculation	-3.0 V	Yes	-
DVT0	First coefficient of short-channel effect on *Vth*	2.2	Yes	-
DVT1	Second coefficient of short-channel effect on *Vth*	0.53	Yes	-
DVT2	Body-bias coefficient of short-channel effect on *Vth*	-0.032 V^{-1}	Yes	-
DVTP0	First coefficient of drain-induced *Vth* shift due to for long-channel pocket devices	0.0 m	Yes	Not modeled if binned DVTP0 <= 0
DVTP1	Second coefficient of drain-induced *Vth* shift due to for long-channel pocket devices	0.0 V^{-1}	Yes	-
DVT0W	First coefficient of narrow width effect on *Vth* for small channel length	0.0	Yes	-
DVT1W	Second coefficient of narrow width effect on *Vth* for small channel length	5.3e6 m^{-1}	Yes	-
DVT2W	Body-bias coefficient of narrow width effect for small channel length	-0.032 V^{-1}	Yes	-
U0	Low-field mobility	0.067 m^2/Vs (NMOS) 0.025 m^2/Vs (PMOS)	Yes	-
UA	Coefficient of first-order	1.0e-9 m/V for	Yes	-

Name	Description	Default Value	Binn able	Note
	mobility degradation due to vertical field	MOBMOD=0 and 1 1.0e-15 m/V for MOBMOD=2		
UB	Coefficient of second-order mobility degradation due to vertical field	1.0e-19 m^2/V^2	Yes	-
UC	Coefficient of mobility degradation due to body-bias effect	-0.0465 V^{-1} for MOBMOD=1 -0.0465e-9 m/V^2 for MOBMOD= 0 and 2	Yes	-
EU	Exponent for mobility degradation of MOBMOD=2	1.67 (NMOS) 1.0 (PMOS)		-
VSAT	Saturation velocity	8.0e4 m/s	Yes	-
A0	Coefficient of channel length dependence of bulk charge effect	1.0	Yes	-
AGS	Coefficient of *Vgs* dependence of bulk charge effect	0.0 V^{-1}	Yes	-
B0	Bulk charge effect coefficient for channel width	0.0 m	Yes	-
B1	Bulk charge effect width offset	0.0 m	Yes	-
KETA	Body-bias coefficient of bulk charge effect	-0.047 V^{-1}	Yes	-
A1	First non-saturation effect parameter	0.0 V^{-1}	Yes	-
A2	Second non-saturation parameter	1.0	Yes	-
WINT	Channel-width offset parameter	0.0 m	No	-
LINT	Channel-length offset parameter	0.0 m	No	-
DWG	Coefficient of gate bias dependence of *Weff*	0.0 m/V	Yes	-
DWB	Coefficient of body bias dependence of *Weff* bias dependence	0.0 $m/V^{1/2}$	Yes	-
VOFF	Offset voltage in subthreshold region for	-0.08 V	Yes	-

Name	Description	Default Value	Binn able	Note
	large W and L			
VOFFL	Channel-length dependence of VOFF	0.0 m	No	-
MINV	*Vgsteff* fitting parameter for moderate inversion condition	0.0	Yes	-
NFACTOR	Subthreshold swing factor	1.0	Yes	-
ETA0	DIBL coefficient in subthreshold region	0.08	Yes	-
ETAB	Body-bias coefficient for the sub-threshold DIBL effect	-0.07 V^{-1}	Yes	-
DSUB	DIBL coefficient exponent in sub-threshold region	DROUT	Yes	-
CIT	Interface trap capacitance	0.0 F/m^2	Yes	-
CDSC	Coupling capacitance between source/drain and channel	2.4e-4 F/m^2	Yes	-
CDSCB	Body-bias sensitivity of *Cdsc*	0.0 $F/(Vm^2)$	Yes	-
CDSCD	Drain-bias sensitivity of CDSC	0.0 F/(Vm2)	Yes	-
PCLM	Channel length modulation parameter	1.3	Yes	-
PDIBLC1	Parameter for DIBL effect on *Rout*	0.39	Yes	-
PDIBLC2	Parameter for DIBL effect on *Rout*	0.0086	Yes	-
PDIBLCB	Body bias coefficient of DIBL effect on *Rout*	0.0 V^{-1}	Yes	-
DROUT	Channel-length dependence of DIBL effect on *Rout*	0.56	Yes	-
PSCBE1	First substrate current induced body-effect parameter	4.24e8 V/m	Yes	-
PSCBE1	Second substrate current induced body-effect parameter	1.0e-5 m/V	Yes	-
PVAG	Gate-bias dependence of Early voltage	0.0	Yes	-
DELTA	Parameter for DC *Vdseff*	0.01 V	Yes	-
FPROUT	Effect of pocket implant on Rout degradation	0.0 $V/m^{1/2}$	Yes	Not modeled if binned FPROUT not positive

Name	Description	Default Value	Binnable	Note
PDITS	Impact of drain-induced *Vth* shift on *Rout*	0.0 V^{-1}	Yes	Not modeled if binned PDITS=0; Fatal error if binned PDITS negative
PDITSL	Channel-length dependence of drain-induced *Vth* shift for *Rout*	0.0 m^{-1}	No	Fatal error if PDITSL negative
Parameters for Asymmetric and Bias-Dependent *Rds* Model				
RDSW	Zero bias LDD resistance per unit width for RDSMOD = 0	200 $\Omega\mu m^{WR}$	Yes	Reset to 0.0 if negative
RDSWMIN	LDD resistance per unit width at high *Vgs* and zero *Vbs* for RDSMOD = 0	0.0 $\Omega\mu m^{WR}$	No	-
RDW	Zero bias lightly-doped drain resistance Rd(V) per unit width for RDSMOD = 1	100 $\Omega\mu m$	Yes	-
RDWMIN	Lightly-doped drain resistance per unit width at high *Vgs* and zero *Vbs* for RDSMOD = 1	0.0 $\Omega\mu m^{WR}$	No	-
RSW	Zero bias lightly-doped source resistance Rd(V) per unit width for RDSMOD = 1	100 $\Omega\mu m$	Yes	-
RSWMIN	Lightly-doped source resistance per unit width at high *Vgs* and zero *Vbs* for RDSMOD = 1	0.0 $\Omega\mu m^{WR}$	No	-
PRWG	Gate-bias dependence of LDD resistance	1.0 V^{-1}	Yes	-
PRWB	Body-bias dependence of LDD resistance	0.0 $V^{-0.5}$	Yes	-
WR	Channel-width dependence parameter of LDD resistance	1.0	Yes	-
NRD (instance parameter only)	Number of drain diffusion squares	1.0	No	-
NRS (instance parameter only)	Number of source diffusion squares	1.0	No	-

Name	Description	Default Value	Binnable	Note
Impact Ionization Current Model Parameters				
ALPHA0	First parameter of impact ionization current	0.0 Am/V	Yes	-
ALPHA1	*Isub* parameter for length scaling	0.0 A/V	Yes	-
BETA0	The second parameter of impact ionization current	30.0 V	Yes	-
Gate-Induced Drain Leakage Model Parameters				
AGIDL	Pre-exponential coefficient for GIDL	0.0 mho	Yes	*Igidl* = 0.0 if binned AGIDL=0.0
BGIDL	Exponential coefficient for GIDL	2.3e9 V/m	Yes	*Igidl* = 0.0 if Binned BGIDL=0.0
CGIDL	Parameter for body-bias effect on GIDL	0.5 V^3	Yes	-
DGIDL	Fitting parameter for band bending for GIDL	0.8 V	Yes	-
Gate Dielectric Tunneling Current Model Parameters				
AIGBACC	Parameter for *Igb* in accumulation	0.43 $(Fs^2/g)^{1/2}m^{-1}$	Yes	-
BIGBACC	Parameter for *Igb* in accumulation	0.054 $(Fs^2/g)^{1/2}(mV)^{-1}$	Yes	-
CIGBACC	Parameter for *Igb* in accumulation	0.075 V^{-1}	Yes	-
NIGBACC	Parameter for *Igb* in accumulation	1.0	Yes	Fatal error if binned value not positive
AIGBINV	Parameter for *Igb* in inversion	0.35 $(Fs^2/g)^{1/2}m^{-1}$	Yes	-
BIGBINV	Parameter for *Igb* in inversion	0.03 $(Fs^2/g)^{1/2}(mV)^{-1}$	Yes	-
CIGBINV	Parameter for *Igb* in inversion	0.006 V^{-1}	Yes	-
EIGBINV	Parameter for *Igb* in inversion	1.1 V	Yes	-
NIGBINV	Parameter for *Igb* in inversion	3.0	Yes	Fatal error if binned value not positive
AIGC	Parameter for *Igcs* and *Igcd*	0.054 (NMOS) and 0.31 (PMOS) $(Fs^2/g)^{1/2}m^{-1}$	Yes	-

Name	Description	Default Value	Binnable	Note
BIGC	Parameter for *Igcs* and *Igcd*	0.054 (NMOS) and 0.024 (PMOS) $(Fs^2/g)^{1/2}(mV)^{-1}$	Yes	-
CIGC	Parameter for *Igcs* and *Igcd*	0.075 (NMOS) and 0.03 (PMOS) V^{-1}	Yes	-
AIGSD	Parameter for *Igs* and *Igd*	0.43 (NMOS) and 0.31 (PMOS) $(Fs^2/g)^{1/2}m^{-1}$	Yes	-
BIGSD	Parameter for *Igs* and *Igd*	0.054 (NMOS) and 0.024 (PMOS) $(Fs^2/g)^{1/2}(mV)^{-1}$	Yes	-
CIGSD	Parameter for *Igs* and *Igd*	0.075 (NMOS) and 0.03 (PMOS) V^{-1}	Yes	-
DLCIG	Source/drain overlap length for *Igs* abd *Igd*	LINT	Yes	-
NIGC	Parameter for *Igcs*, *Igcd*, *Igs* and *Igd*	1.0	Yes	Fatal error if binned value not positive
POXEDGE	Factor for the gate oxide thickness in source/drain overlap regions	1.0	Yes	Fatal error if binned value not positive
PIGCD	*Vds* dependence of *Igcs* and *Igcd*	1.0	Yes	Fatal error if binned value not positive
NTOX	Exponent for the gate oxide ratio	1.0	Yes	-
TOXREF	Nominal gate oxide thickness for gate dielectric tunneling current model only	3.0e-9 m	No	Fatal error if binned value not positive
Charge and Capacitance Model Parameters				
XPART	Charge partition parameter	0.0	No	-
CGSO	Non LDD region source-gate overlap capacitance per unit channel width	calculated (F/m)	No	Note-6
CGDO	Non LDD region drain-gate overlap capacitance per unit channel width	calculated (F/m)	No	Note-6

Name	Description	Default Value	Binnable	Note
CGBO	Gate-bulk overlap capacitance per unit channel length	calculated (F/m)	No	Note-6
CGSL	Overlap capacitance between gate and lightly-doped source region	0.0 F/m	Yes	-
CGDL	Overlap capacitance between gate and lightly-doped drain region	0.0 F/m	Yes	-
CLKAPPAS	Coefficient of bias-dependent overlap capacitance for the source side	0.6 V	Yes	-
CKAPPAD	Coefficient of bias-dependent overlap capacitance for the drain side	CKAPPAS	Yes	-
CF	Fringing field capacitance	calculated (F/m)	Yes	Note-7
CLC	Constant term for the short channel model	1.0e-7 m	Yes	-
CLE	Exponential term for the short channel model	0.6	Yes	-
DLC	Channel-length offset parameter for CV model	LINT (m)	No	-
DWC	Channel-width offset parameter for CV model	WINT (m)	No	-
VFBCV	Flat-band voltage parameter (for CAPMOD=0 only)	-1.0 V	Yes	-
NOFF	CV parameter in *Vgsteff,CV* for weak to strong inversion	1.0	Yes	-
VOFFCV	CV parameter in *Vgsteff,CV* for weak to strong inversion	0.0 V	Yes	-
ACDE	Exponential coefficient for charge thickness in CAPMOD=2 for accumulation and depletion regions	1.0 m/V	Yes	-
MOIN	Coefficient for the gate-bias dependent surface potential	15.0	Yes	-

Name	Description	Default Value	Binnable	Note
High-Speed/RF Model Parameters				
XRCRG1	Parameter for distributed channel-resistance effect for both intrinsic-input resistance and charge-deficit NQS models	12.0	Yes	Warning message issued if binned XRCRG1 <= 0.0
XRCRG2	Parameter to account for the excess channel diffusion resistance for both intrinsic input resistance and charge-deficit NQS models	1.0	Yes	-
RBPB (Also an instance parameter)	Resistance connected between bNodePrime and bNode	50.0 Ohm	No	If less than 1.0e-3ohm, reset to 1.0e-3ohm
RBPD (Also an instance parameter)	Resistance connected between bNodePrime and dbNode	50.0 Ohm	No	If less than 1.0e-3ohm, reset to 1.0e-3ohm
RBPS (Also an instance parameter)	Resistance connected between bNodePrime and sbNode	50.0 Ohm	No	If less than 1.0e-3ohm, reset to 1.0e-3ohm
RBDB (Also an instance parameter)	Resistance connected between dbNode and bNode	50.0 Ohm	No	If less than 1.0e-3ohm, reset to 1.0e-3ohm
RBSB (Also an instance parameter)	Resistance connected between sbNode and bNode	50.0 Ohm	No	If less than 1.0e-3ohm, reset to 1.0e-3ohm
GBMIN	Conductance in parallel with each of the five substrate resistances to avoid potential numerical instability due to unreasonably too large a substrate resistance	1.0e-12mho	No	Warning message issued if less than 1.0e-20
Flicker and Thermal Noise Model Parameters				
NOIA	Flicker noise parameter A	6.25e41 (NMOS) 6.188e40 (PMOS)	No	-

Name	Description	Default Value	Binnable	Note
		$(eV)^{-1}s^{1-EF}m^{-3}$		
NOIB	Flicker noise parameter B	3.125e26 (NMOS) 1.5e25 (PMOS) $(eV)^{-1}s^{1-EF}m^{-1}$	No	-
NOIC	Flicker noise parameter C	8.75 $(eV)^{-1}s^{1-EF}m$	No	-
EM	Saturation field	4.1e7 V/m	No	-
AF	Flicker noise exponent	1.0	No	-
EF	Flicker noise frequency exponent	1.0	No	-
KF	Flicker noise coefficient	0.0 $A^{2-EF}\ s^{1-EF}F$	No	-
NTNOI	Noise factor for short-channel devices for TNOIMOD=0 only	1.0	No	-
TNOIA	Coefficient of channel-length dependence of total channel thermal noise	1.5	No	-
TNOIB	Channel-length dependence parameter for channel thermal noise partitioning	3.5	No	-
Layout-Dependent Parasitics Model Parameters				
DMCG	Distance from S/D contact center to the gate edge	0.0 m	No	-
DMCI	Distance from S/D contact center to the isolation edge in the channel length direction	DMCG	No	-
DMDG	Same as DMCG but for merged device only	0.0 m	No	-
DMCGT	DMCG of test structures	0.0 m	No	-
NF (instance parameter only)	Number of device fingers	1	No	Fatal error if less than one
DWJ	Offset of the S/D junction width	DWC (in CVmodel)	No	-
MIN	Whether to minimize the number of drain or source diffusions for even-number fingered device	0 (minimize the drain diffusion number)	No	-
XGW	Distance from the gate	0.0 m	No	-

Name	Description	Default Value	Binnable	Note
	contact to the channel edge			
XGL	Offset of the gate length due to variations in patterning	0.0 m	No	-
XL (v2.0 only)	Channel length offset due to mask/etch effect	0.0 m	No	-
XW (v2.0 only)	Channel width offset due to mask/etch effect	0.0 m	No	-
NGCON	Number of gate contacts	1	No	Fatal error if less than one; if not equal to 1 or 2, warning message issued and reset to 1
Asymmetric Source/Drain Junction Diode Model Parameters				
IJTHSREV IJTHDREV	Limiting current in reverse bias region	0.1 A	No	If not positive, reset to 0.1 A
IJTHSFWD IJTHDFWD	Limiting current in forward bias region	0.1 A	No	If not positive, reset to 0.1 A
XJBVS XJBVD	Fitting parameter for diode breakdown	1.0	No	Note-8
BVS BVD	Breakdown voltage	10 V	No	If not positive, reset to 10 V
JSS JSD	Bottom junction reverse saturation current density	1.0e-4 A/m^2	No	-
JSWS JSWD	Isolation-edge sidewall reverse saturation current density	0.0 A/m	No	-
JSWGS JSWGD	Gate-edge sidewall reverse saturation current density	0.0 A/m	No	-
CJS CJD	Bottom junction capacitance per unit area at zero bias	5.0e-4 F/m^2	No	-
MJS MJD	Bottom junction capacitance grating coefficient	0.5	No	-
MJSWS MJSWD	Isolation-edge sidewall junction capacitance grading coefficient	0.33	No	-
CJSWS	Isolation-edge sidewall	5.0e-10 F/m	No	-

Name	Description	Default Value	Binn able	Note
CJSWD	junction capacitance per unit area			
CJSWGS CJSWGD	Gate-edge sidewall junction capacitance per unit length	CJSWS CJSWD	No	-
MJSWGS MJSWGD	Gate-edge sidewall junction capacitance grading coefficient	MJSWS MJSWD	No	-
PB	Bottom junction built-in potential	1.0 V	No	-
PBSWS PBSWD	Isolation-edge sidewall junction built-in potential	1.0 V	No	-
PBSWGS PBSWGD	Gate-edge sidewall junction built-in potential	PBSWS PBSWD	No	-
Temperature Dependence Parameters				
TNOM	Temperature at which parameters are extracted	27 oC	No	-
UTE	Mobility temperature exponent	-1.5	Yes	-
KT1	Temperature coefficient for threshold voltage	-0.11 V	Yes	-
KT1L	Channel length dependence of the temperature coefficient for threshold voltage	0.0 Vm	Yes	-
KT2	Body-bias coefficient of Vth temperature effect	0.022	Yes	-
UA1	Temperature coefficient for UA	1.0e-9 m/V	Yes	-
UB1	Temperature coefficient for UB	-1.0e-18 $(m/V)^2$	Yes	-
UC1	Temperature coefficient for UC	0.067 V^{-1} for MOBMOD=1; 0.025 m/V^2 for MOBMOD=0 and 2	Yes	-
AT	Temperature coefficient for saturation velocity	3.3e4 m/s	Yes	-
PRT	Temperature coefficient for *Rdsw*	0.0 ohm-m	Yes	-
NJS NJD	Emission coefficients of junction for source and drain junctions, respectively	1.0	No	-
XTIS	Junction current	3.0	No	-

Name	Description	Default Value	Binnable	Note
XTID	temperature exponents for source and drain junctions, respectively			
TPB	Temperature coefficient of PB	0.0 V/K	No	-
TPBSW	Temperature coefficient of PBSW	0.0 V/K	No	-
TPBSWG	Temperature coefficient of PBSWG	0.0 V/K	No	-
TCJ	Temperature coefficient of CJ	0.0 K^{-1}	No	-
TCJSW	Temperature coefficient of CJSW	0.0 K^{-1}	No	-
TCJSWG	Temperature coefficient of CJSWG	0.0 K^{-1}	No	-
dW and dL Parameters				
WL	Coefficient of length dependence for width offset	0.0 m^{WLN}	No	-
WLN	Power of length dependence of width offset	1.0	No	-
WW	Coefficient of width dependence for width offset	0.0 m^{WWN}	No	-
WWN	Power of width dependence of width offset	1.0	No	-
WWL	Coefficient of length and width cross term for width offset	0.0 $m^{WWN+WLN}$	No	-
LL	Coefficient of length dependence for length offset	0.0 m^{LLN}	No	-
LLN	Power of length dependence for length offset	1.0	No	-
LW	Coefficient of width dependence for length offset	0.0 m^{LWN}	No	-
LWN	Power of width dependence for length offset	1.0	No	-
LWL	Coefficient of length and width cross term for length offset	0.0 $m^{LWN+LLN}$	No	-
LLC	Coefficient of length	LL	No	-

Name	Description	Default Value	Binnable	Note
	dependence for CV channel length offset			
LWC	Coefficient of width dependence for CV channel length offset	LW	No	-
LWLC	Coefficient of length and width cross term for CV channel length offset	LWL	No	-
WLC	Coefficient of length dependence for CV channel width offset	WL	No	-
WWC	Coefficient of width dependence for CV channel width offset	WW	No	-
WWLC	Coefficient of length and width cross- term for CV channel width offset	WWL	No	-
Range Parameters for Model Application				
LMIN	Minimum channel length	0.0 m	No	-
LMAX	Maximum channel length	1.0 m	No	-
WMIN	Minimum channel width	0.0 m	No	-
WMAX	Maximum channel width	1.0 m	No	-

Notes 1 to 8

Note-1:
If γ_1 is not given, it is calculated by

$$\gamma_1 = \frac{\sqrt{2q\varepsilon_{si}\mathrm{NDEP}}}{C_{oxe}}$$

If γ_2 is not given, it is calculated by

$$\gamma_2 = \frac{\sqrt{2q\varepsilon_{si}\mathrm{NSUB}}}{C_{oxe}}$$

Note-2:
If NDEP is not given and γ_1 is given, NDEP is calculated from

$$\mathrm{NDEP} = \frac{\gamma_1^2 C_{oxe}^2}{2q\varepsilon_{si}}$$

If none of NDEP or γ_1 is not given, NDEP defaults to 1.7e17 cm^{-3} and γ_1 is calculated from NDEP.

Note-3:
If VBX is not given, it is calculated by

$$\frac{q\mathrm{NDEP}\cdot\mathrm{XT}^2}{2\varepsilon_{si}} = \Phi_s - VBX$$

Note-4:
If VTH0 is not given, it is calculated by

$$\mathrm{VTH0} = \mathrm{VFB} + \Phi_s + \mathrm{K1}\sqrt{\Phi_s - V_{bs}}$$

where VFB = -1.0 V. If VTH0 is given, VFB defaults to

$$\mathrm{VFB} = \mathrm{VTH0} - \Phi_s - \mathrm{K1}\sqrt{\Phi_s - V_{bs}}$$

Note-5:
If K1 and K2 are not given, they are calculated as

$$\mathrm{K1} = \gamma_2 - 2\mathrm{K2}\sqrt{\Phi_s - \mathrm{VBM}}$$

$$\mathrm{K2} = \frac{(\gamma_1 - \gamma_2)(\sqrt{\Phi_s - \mathrm{VBX}} - \sqrt{\Phi_s})}{2\sqrt{\Phi_s}(\sqrt{\Phi_s - \mathrm{VBM}} - \sqrt{\Phi_s}) + \mathrm{VBM}}$$

Note-6:

If CGSO is not given, it is calculated as follows:
if (DLC is given and > 0) {
CGSO = DLC·*Coxe*-CGSL
If (CGSO < 0)
CGSO = 0
} else
CGSO = 0.6·XJ·*Coxe*

If CGDO is not given, it is calculated as follows:
if (DLC is given and > 0) {
CGDO = DLC·*Coxe*-CGDL
If (CGDO < 0)
CGDO = 0
} else
CGDO = 0.6·XJ·*Coxe*

If CGBO is not given, it is calculated as follows:
CGBO = 2·DWC·*Coxe*

Note-7:
If CF is not given, it is calculated by

$$\mathrm{CF} = \frac{2\cdot EPSROX\cdot\varepsilon_0}{\pi}\log\left(1 + \frac{4.0\cdot 10^{-7}}{\mathrm{TOXE}}\right)$$

Note-8:
For DIOMOD = 0, if XJBVS < 0, it is reset to 1.0
For DIOMOD = 2, if XJBVS <= 0, it is reset to 1.0
For DIOMOD = 0, if XJBVD < 0, it is reset to 1.0
For DIOMOD = 2, if XJBVD <= 0, it is reset to 1.0

For a detailed BSIM4 model reference, download the BSIM4 manual. The URL is:

http://www-device.eecs.berkeley.edu/~bsim3/bsim4.html

Supported Analyses

All

EKV MOS version v2.6 Model Parameters (Level 23)

For a detailed EKV model reference, download the EKVv2.6 manual. The URL is:

http://legwww.epfl.ch/ekv/model.html

Name	Description	Default Value	Range
Process Related Parameters			
COX	Gate oxide capacitance per unit area	0.7e-3 F/m	-
XJ	Junction depth	0.1e-6 m	≥ 1e-9
DW	Channel width correction	0 m	-
DL	Channel length correction	0 m	-
Basic Intrinsic Model Parameters			
VTO	Long-channel threshold voltage	0.5 V	-
GAMMA	Body effect parameter	$1\ \sqrt{V}$	≥ 0
PHI	Bulk Fermi potential (*2)	0.7 V	≥ 0.1
KP	Transconductance parameter	$50e\text{-}6\ A/V^2$	-
E0 (EO)	Mobility reduction coefficient	1e12 V/m	≥ 1e5
UCRIT	Longitudinal critical field	2e6 V/m	≥ 1e5
THETA	Mobility reduction coefficient	0 1/V	≥ 0
Channel Length Modulation and Charge Sharing Parameters			
LAMBDA	Depletion length coefficient (channel length modulation)	0.5	≥ 0
WETA	Narrow-channel effect coefficient	0.25	-
LETA	Short-channel effect coefficient	0.1	-
Reverse Short-Channel Effect Parameters			
Q0 (QO)	Reverse short channel effect peak charge density	$0\ A \cdot s/m^2$	-
LK	Reverse short channel effect characteristic length	0.29e-6 m	≥ 1e-8
Impact Ionization Related Parameters			
IBA	First impact ionization coefficient	0 1/m	-
IBB	Second impact ionization coefficient	3e8 V/m	≥ 1e8
IBN	Saturation voltage factor for impact ionization	1.0	≥ 0.1
Intrinsic Model Temperature Parameters			
TNOM	Nominal device temperature	Circuit TNOM	-
TCV	Threshold voltage temperature coefficient	1e-3 V/K	-

Name	Description	Default Value	Range
BEX	Mobility temperature exponent	-1.5	-
UCEX	Longitudinal critical field temperature exponent	0.8	-
IBBT	Temperature coefficient for IBB	9e-4 1/K	-
Flicker Noise Parameters			
KF	Flicker noise coefficient	0	≥ 0
AF	Flicker noise exponent	1	-
Setup Parameters			
NQS[1]	Non-Quasi-Static (NQS) operation switch	0	-
SATLIM[2]	Ratio defining the saturation limit i_f / i_r	Exp(4)	-
EKVINT[3]	Interpolation function selector	0	
Extrinsic Model Parameters			
CBD	Zero-bias B-D junction capacitance	0 F	≥ 0
CBS	Zero-bias B-S junction capacitance	0 F	≥ 0
IS	Bulk junction saturation current	1.0e-14 A	≥ 0
PB	Bulk junction potential	0.8 V	> 0
PBSW	Bulk junction sidewall potential	0.8 V	> 0
TT	Bulk junction transit time	0 s	≥ 0
CGSO	Gate-source overlap capacitance per meter channel width	0 F/m	≥ 0
CGDO	Gate-drain overlap capacitance per meter channel width	0 F/m	≥ 0
CGBO	Gate-bulk overlap capacitance per meter channel width	0 F/m	≥ 0
RD	Drain resistance	0 Ω	≥ 0
RS	Source resistance	0 Ω	≥ 0
RDC	Drain contact resistance	0 Ω	≥ 0
RSC	Source contact resistance	0 Ω	≥ 0
RSH	Drain and source diffusion sheet resistance	0.0 Ω /☐	≥ 0
CJ	Zero-bias bulk junction bottom capacitance per square-meter of junction area	$0.0\,\mathrm{F/m^2}$	≥ 0
MJ	Bulk junction bottom grading coefficient	0.5	> 0
CJSW	Zero-bias bulk junction sidewall capacitance per meter of junction perimeter	0.0 F/m	≥ 0
MJSW	Bulk junction sidewall grading coefficient	0.33	> 0

Name	Description	Default Value	Range
JS	Bulk junction saturation current per m^2 of junction area	$0.0\ A/m^2$	≥ 0
JSW	Bulk junction sidewall saturation current per length	0.0 A/m	≥ 0
N	Emission coefficient	1.0	≥ 1
FC	Forward bulk junction capacitance coefficient	0.5	> 0
XTI	Bulk junction current temperature exponent	3.0	≥ 1
TR1	First-order temperature coefficient for resistors (RD, RS, RDC, RSC, RSH)	0.0 1/ºC	-
TR2	Second-order temperature coefficient for resistors (RD, RS, RDC, RSC, RSH)	$0.0\ (°C)^{-2}$	-

[1]NQS=1 switches Non-Quasi-Static operation on, default is off.
[2]Only used for operating point information.
[3]Specify a value different from zero to enable the simple interpolation function.

For a detailed EKV model reference, download the EKVv2.6 manual. The URL is:

http://legwww.epfl.ch/ekv/model.html

Supported Analyses

Pole-Zero analysis not supported.

N Heterojunction Bipolar Transistors (HBTs)

General form:

```
NXXXXXXX NC NB NE <NS> MNAME <AREA> <OFF> <IC=VBE,VCE>
+ <TEMP=T>
```

Example:

```
N23 10 24 13 NMOD IC=0.6,5.0
n2 5 4 0 nnd
```

`NC`, `NB` and `NE` are the collector, base and emitter nodes, respectively. `NS` is the substrate node. If this is not given, ground is assumed. `MNAME` is the model name, `AREA` is the area factor, and `OFF` indicates an optional initial value for the element in a dc analysis. If the area factor is omitted, 1.0 is assumed. The optional initial value `IC=VBE,VCE` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. The optional `TEMP` value is the temperature at which this device operates. It overrides the temperature specified in the option value.

HBT Model

```
.MODEL [model name] HNPN <model parameters>
.MODEL [model name] HPNP <model parameters>
```

The heterojunction bipolar transistor model in AIM-Spice is a modification of the Ebers-Moll bipolar transistor model.

Name	Parameter	Units	Default
IS	Transport saturation current	A	1e-16
BF	Ideal maximum forward beta	-	100
NF	Forward current emission coefficient	-	1.0
ISE	B-E leakage saturation current	A	0
NE	B-E leakage emission coefficient	-	1.2
BR	Ideal maximum reverse beta	-	1
NR	Reverse current emission coefficient	-	1
ISC	B-C leakage saturation current	A	0
NC	B-C leakage emission coefficient	-	2
RB	Base resistance	Ω	0
RE	Emitter resistance	Ω	0
RC	Collector resistance	Ω	0
CJE	B-E zero bias depletion capacitance	F	0
VJE	B-E built-in potential	V	0.75
MJE	B-E junction exponential factor	-	0.33
TF	Ideal forward transit time	s	0
XTF	Coefficient for bias dependence of TF	-	0

Name	Parameter	Units	Default
VTF	Voltage describing VBC dependence of TF	V	infinite
ITF	High current parameter for effect on TF	A	0
PTF	Excess phase at f=1.0/(TF · 2π) Hz	Deg	
CJC	B-C zero bias depletion capacitance	F	0
VJC	B-C built-in potential	Volt	0.75
MJC	B-C junction exponential factor	-	0.33
XCJC	Fraction of B-C depletion capacitance connected to internal base node.	-	1
TR	Ideal reverse transit-time	s	0
CJS	zero-bias collector-substrate capacitance	F	0
VJS	Substrate junction built-in potential	V	0.75
MJS	Substrate junction exponential factor	-	0
XTB	Forward and reverse beta temperature exponent	-	0
EG	Energy gap for temperature effect on IS	eV	1.11 (Si)
XTI	Temperature exponent for effect on IS	-	3
KF	Flicker-noise coefficient	-	0
AF	Flicker-noise exponent	-	1
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
TNOM	Parameter measurement temperature	°C	27
IRB0	Base region recombination saturation current	A	0
IRS1	Surface recombination saturation current 1	A	0
IRS2	Surface recombination saturation current 2	A	0
ICSAT	Collector saturation current	A	0
M	Knee shape parameter	-	3

The modification to the Ebers-Moll model consists of two new contributions to the generation/recombination current and a limitation on the intrinsic collector current.

Recombination in the base region is modeled by the expression

$$I_{rb} = \mathrm{IRB0}\left(\mathrm{e}^{V_{be}/V_{th}} - 1\right)$$

Surface recombination is modeled by the expression.

$$I_{rs} = \mathrm{IRS1}\left(\mathrm{e}^{V_{be}/V_{th}} - 1\right) + \mathrm{IRS2}\left(\mathrm{e}^{V_{be}/2V_{th}} - 1\right)$$

where IRS1 and IRS2 are proportional to the emitter perimeter.

If the model parameters M and ICSAT are given, the intrinsic collector current is modified according to the following expression:

$$I_c = \frac{I_{co}}{\left[1 + (I_{co} \,/\, \mathrm{ICSAT})^{\mathrm{M}}\right]^{1/\mathrm{M}}}$$

Supported Analyses
Noise and Pole-Zero Analysis not supported.

O Lossy Transmission Lines (LTRA)

General form:

```
OXXXXXXX N1 N2 N3 N4 MNAME
```

Example:

```
o23 1 0 2 0 lmod
ocon 10 5 20 5 interconnect
```

This is a two-port convolution model for single-conductor lossy transmission lines. `N1` and `N2` are the nodes at port 1, `N3` and `N4` are the nodes at port 2. It is worth mentioning that a lossy transmission line with zero loss may be more accurate than the lossless transmission line.

LTRA Model

```
.MODEL [model name] LTRA <model parameters>
```

The uniform RLC/RC/LC/RG transmission line model (LTRA) models a uniform constant-parameter distributed transmission line. In case of RC and LC, the URC and TRA models may also be used. However, the newer LTRA model is usually faster and more accurate. The operation of the LTRA model is based on the convolution of the transmission line's impulse response with its inputs see [**Error! Bookmark not defined.**].

The LTRA model parameters are as follows:

Name	Parameter	Units	Default
R	Resistance/Length	Ω/m	0.0
L	Inductance/Length	H/m	0.0
C	Capacitance/Length	F/m	0.0
G	Conductance/Length	1/Ωm	0.0
LEN	Length of line	m	-
REL	Breakpoint control	-	1
ABS	Breakpoint control	-	1
NOSTEPLIMIT	Don't limit timestep to less than line delay	Flag	not set
NOCONTROL	Don't do complex timestep control	Flag	not set
LININTERP	Use linear interpolation	Flag	not set
MIXEDINTERP	Use linear when quadratic seems bad	Flag	not set
COMPACTREL	Special RELTOL for history compaction		RELTOL
COMPACTABS	Special ABSTOL for history compaction		ABSTOL
TRUNCNR	Use Newton-Raphson method for timestep control	Flag	not set

Name	Parameter	Units	Default
TRUNCDONTCUT	Don't limit timestep to keep impulse-response errors low	Flag	not set

The types of lines implemented so far are : uniform transmission line with series loss only (RLC), uniform RC line (RC), lossless transmission line (LC), and distributed series resistance and parallel conductance only (RG). Any other combination will yield erroneous results and should be avoided. The length (LEN) of the line must be specified.

Here follows a detailed description on some of the model parameters:

NOSTEPLIMIT is a flag that will remove the default restrictions of limiting time-step to less than the line delay in the RLC case.

NOCONTROL is a flag that prevents the default limitation on the time-step based on convolution error criteria in the RLC and RC cases. This speeds up the simulation, but may in some cases reduce the accuracy.

LININTERP is a flag that, when set, will use linear interpolation instead of the default quadratic interpolation for calculating delayed signals.

MIXEDINTERP is a flag that, when set, uses a metric for judging whether quadratic interpolation is applicable, and if not so, uses linear interpolation. Otherwise it uses the default quadratic interpolation.

TRUNCDONTCUT is a flag that removes the default cutting of the time-step to limit errors in the actual calculation of impulse-response related quantities.

COMPACTREL and COMPACTABS are quantities that control the compacting of the past history of values stored for convolution. Large values of these parameters result in lower accuracy but usually increase the simulation speed. These are to be used with the TRYTOCOMPACT option.

TRUNCNR is a flag that turns *on* the use of Newton-Raphson iterations to determine an appropriate timestep in the timestep control routines. The default is a trial and error procedure by cutting the previous timestep in half.

If you want to increase the speed of the simulation, follow these guidelines:

The most efficient option for increasing the speed of the simulation is REL. The default value of 1 is usually safe from the point of view of accuracy, but occasionally increases the computation time. A value greater than 2 eliminates all breakpoints and may be worth trying depending on the nature of the rest of the circuit, keeping in mind that it may not be safe from the point of view of accuracy. Breakpoints can usually be entirely eliminated if the circuit is not expected to have sharp discontinuities. Values between 0 and 1 are usually not needed, but may be used for setting a large number of breakpoints.

It is also possible to experiment with COMPACTREL when the option TRYTOCOMPACT is specified. The legal range is between 0 and 1. Larger values usually decrease the accuracy of the simulation, but in some cases improve speed. If TRYTOCOMPACT is not specified, history compacting is not attempted and the accuracy is high. The flags NOCONTROL, TRUNCDONTCUT and NOSTEPLIMIT also increase speed at the expense of accuracy in some cases.

Supported Analyses
Noise and Pole-Zero Analysis not supported.

Q Bipolar Junction Transistors (BJTs)

General form:

```
QXXXXXXX NC NB NE <NS> MNAME <AREA> <OFF> <IC=VBE,VCE> <TEMP=T>
```

Example:

```
Q23 10 24 13 QMOD IC=0.6,5.0
q2 5 4 0 qnd
```

`NC`, `NB` and `NE` are the collector, base and emitter nodes, respectively. `NS` is the substrate node. If this is not given, ground is assumed. `MNAME` is the model name, `AREA` is the area factor, and `OFF` indicates a optional initial value for the element in a dc analysis. If the area factor is omitted, 1.0 is assumed. The optional initial value `IC=VBE,VCE` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. The optional `TEMP` value is the temperature at which this device operates. It overrides the temperature specified as a option.

BJT Model

```
.MODEL [model name] NPN <model parameters>
.MODEL [model name] PNP <model parameters>
```

The bipolar transistor model in AIM-Spice is an adaptation of the Gummel-Poon model. In AIM-Spice the model is extended to include high bias effects. The model automatically simplifies to Ebers-Moll if certain parameters are not given (VAF, IKF, VAR, IKR).

Name	Parameter	Units	Default
IS	Transport saturation current	A	1e-16
BF	Ideal maximum forward beta	-	100
NF	Forward current emission coefficient	-	1.0
VAF	Forward Early voltage	V	infinite
IKF	Corner for forward beta high current roll-off	A	infinite
ISE	B-E leakage saturation current	A	0
NE	B-E leakage emission coefficient	-	1.2
BR	Ideal maximum reverse beta	-	1
NR	Reverse current emission coefficient	-	1
VAR	Reverse Early voltage	V	infinite
IKR	Corner for reverse beta high current roll-off	A	infinite
ISC	B-C leakage saturation current	A	0
NC	B-C leakage emission coefficient	-	2
RB	Zero bias base resistance	Ω	0
IRB	Current where base resistance falls halfway to its minimum value	A	infinite

Name	Parameter	Units	Default
RBM	Minimum base resistance at high currents	Ω	RB
RE	Emitter resistance	Ω	0
RC	Collector resistance	Ω	0
CJE	B-E zero bias depletion capacitance	F	0
VJE	B-E built-in potential	V	0.75
MJE	B-E junction exponential factor	-	0.33
TF	Ideal forward transit time	s	0
XTF	Coefficient for bias dependence of TF	-	0
VTF	Voltage describing VBC dependence of TF	V	infinite
ITF	High current parameter for effect on TF	A	0
PTF	Excess phase at f=1.0/(TF · 2π) Hz	Deg	
CJC	B-C zero bias depletion capacitance	F	0
VJC	B-C built-in potential	V	0.75
MJC	B-C junction exponential factor	-	0.33
XCJC	Fraction of B-C depletion capacitance connected to internal base node.	-	1
TR	Ideal reverse transit-time	s	0
CJS	zero-bias collector-substrate capacitance	F	0
VJS	Substrate junction built-in potential	V	0.75
MJS	Substrate junction exponential factor	-	0
XTB	Forward and reverse beta temperature exponent	-	0
EG	Energy gap for temperature effect on IS	eV	1.11 (Si)
XTI	Temperature exponent for effect on IS	-	3
KF	Flicker-noise coefficient	-	0
AF	Flicker-noise exponent	-	1
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5
TNOM	Parameter measurement temperature	°C	27

Temperature Effects
The temperature appears explicitly in the exponential terms.

Temperature dependence of the saturation current in the model is determined by:

$$I_S(T_1) = I_S(T_0)\left(\frac{T_1}{T_0}\right)^{\mathrm{XTI}} \exp\left(\frac{q\mathrm{EG}(T_1 - T_0)}{kT_1T_0}\right)$$

where k is Boltzmann's constant, q is the electronic charge, EG is the energy gap, and XTI is the saturation current temperature exponent. EG and XTI are model parameters.

The temperature dependence of the forward and reverse beta is given by:

$$\beta(T_1) = \beta(T_0)\left(\frac{T_1}{T_0}\right)^{\mathrm{XTI}}$$

where XTB is a user supplied model parameter. Temperature effects on beta are implemented by appropriate adjustment of the model parameters BF, ISE, BR, and ISC.

Supported Analyses
All.

R Resistors

General form:

```
RXXXXXXX N1 N2 VALUE
```

Examples:

```
R1 1 2 100
RB 1 2 10K
RBIAS 4 8 10K
```

N1 and N2 are the two element nodes. VALUE is the resistance in Ohm. The value can be positive or negative, but not zero.

Semiconductor Resistors

General form:

```
RXXXXXXX N1 N2 <VALUE> MNAME <L=LENGTH> <W=WIDTH> <TEMP=T>
+ <TC1=First order temperature coefficient>
+ <TC2=Second order temperature coefficient>
```

Example:

```
rload 2 10 10K
RMOD 3 7 RMODEL L=10U W=1U
```

This is a more general model for the resistor than the one presented above. It gives you the possibility to model temperature effects and to calculate the resistance based on geometry and processing information . VALUE, if given, defines the resistance, and information on geometry and processing will be ignored. MNAME specifies the model name and the resistance value is calculated based on information about the process and geometry in the .model card. If VALUE is not given, LENGTH must be specified. If WIDTH is not given, it will be given the default value. The optional TEMP value is the temperature at which this device operates. It overrides the temperature specified in the option value. TC1 and TC2 overrides the corresponding model parameters.

Resistor Model

```
.MODEL [model name] R <model parameters>
.MODEL [model name] RES <model parameters>
```

The resistor model contains process related parameters and the resistance value is a function of the temperature. The parameters are:

Name	Parameter	Unit	Default
DEFW	Default width	m	1e-6
NARROW	Narrowing due to side etching	m	0.0
RSH	Sheet resistance	Ω/☐	0.0
SF	Scale factor	-	1.0
TC1	First order temperature coefficient	1/°C	0.0

Name	Parameter	Unit	Default
TC2	Second order temperature coefficient	$1/°C^2$	0.0
TNOM	Parameter measurement temperature	°C	27

If VALUE is specified on the device line, the resistance value is calculated as follows:

$$R = \mathrm{SF} \cdot \mathrm{VALUE}$$

If VALUE is not specified, the following expression is used for calculating the resistance value:

$$R = \mathrm{SF} \cdot \mathrm{RSH} \cdot \frac{\mathrm{L} - \mathrm{NARROW}}{\mathrm{W} - \mathrm{NARROW}}$$

DEFW defines a default value of W. If either RSH or L is given, a default value of 1 kOhm is used for *R*.

Temperature Effects

The temperature dependence of the resistance is given by a polynomial:

$$R(T) = R(\mathrm{TNOM})\left[1 + \mathrm{TC1}(T - \mathrm{TNOM}) + \mathrm{TC2}(T - \mathrm{TNOM})^2\right]$$

where *T* is the operating temperature, TNOM is the nominal temperature, and TC1 and TC2 are the first- and second order temperature coefficients respectively.

Supported Analyses

All.

S Voltage Controlled Switch

General form:

```
SXXXXXXX N+ N- NC+ NC- MODEL <ON> <OFF>
```

Examples:

```
s1 1 2 3 4 switch1 ON
s2 5 6 3 0 sm2 off
```

`N+` and `N-` are the positive and negative connecting nodes of the switch, respectively. `NC+` and `NC-` are the positive and negative controlling nodes, respectively.

Switch Model

```
.MODEL [model name] SW <model parameters>
```

The switch model allows modeling of an almost ideal switch in AIM-Spice. The switch is not quite ideal in the resistance cannot change from 0 to infinity, but must have a finite positive value. The *on* and *off* resistances should therefore be chosen very small and very large, respectively, compared to other circuit elements. The model parameters are as follows:

Name	Parameter	Units	Default
VT	Threshold voltage	V	0
VH	Hysteresis voltage	V	0
RON	On resistance	Ω	1
ROFF	Off resistance	Ω	1/GMIN

An ideal switch is highly non-linear. The use of switches can cause large discontinuities in node voltages. A rapid change such as that associated with a switching operation can cause problems with roundoff and tolerance which may lead to erroneous results or problems in selecting proper time steps. To reduce such problems, follow these steps:

Do not set the switch impedances higher and lower than necessary.

Reduce the tolerance during a transient analysis. This is done by specifying a value for TRTOL less than the default value of 7.0. Use for example 1.0.

When switches are placed near capacitors, you should reduce the size of CHGTOL to, for example, 1e-16.

Supported Analyses

All.

T Transmission Lines (Lossless)

General form:

```
TXXXXXXX N1 N2 N3 N4 Z0=VALUE <TD=VALUE>
+ <F=FREQ <NL=NRMLEN>> <IC=V1,I1,V2,I2>
```

Example:

```
T1 1 0 2 0 Z0=50 TD=10NS
```

`N1` and `N2` are the nodes for port 1, `N3` and `N4` are the nodes for port 2. `Z0` is the characteristic impedance of the line. The length of the line can be specified in two different ways. The transmission delay `TD` can be specified directly. Alternatively, a frequency `F` may be given together with the normalized length of the line, `NL` (normalized with respect to the wavelength at the frequency `F`). If a frequency is specified and `NL` is omitted, 0.25 is assumed. Note that even though both ways of specifying line length is enclosed in brackets, one must be specified.

Note that this element models only one propagation mode. If all four modes are distinct in the actual circuit, then two modes may be excited. To simulate such a situation, two transmission-line elements are required.

The optional initial values consists of voltages and currents at each of the two ports. Note that these values are used only if the option UIC are specified in a transient analysis.

Supported Analyses

Noise and Pole-Zero Analysis not supported.

U Uniform Distributed RC Lines (URC)

General form:

```
UXXXXXXX N1 N2 N3 MNAME L=LENGTH <N=LUMPS>
```

Example:

```
U1 1 2 0 URCMOD L=50U
URC2 1 12 2 UMODL L=1MIL N=6
```

`N1` and `N2` are the two nodes of the RC line itself, while `N3` is the node of the capacitances. `MNAME` is the name of the model, `LENGTH` is the length of the line in meters. `LUMPS,` if given, is the number of segments to use in modeling the RC line.

URC Model

```
.MODEL [model name] URC <model parameters>
```

The model is accomplished by a subcircuit expansion of the URC line into a network of lumped RC segments with internally generated nodes. The RC segments are in a geometric progression, increasing toward the middle of the URC line, with K as a proportionality constant. The number of lumped segments used, if not specified on the URC line, is determined by the following expression:

$$N = \frac{\log\left(F_{\max}\frac{R}{L}\frac{C}{L}2\pi I^2\frac{(K-1)^2}{K^2}\right)}{\log K}$$

The URC line is made up strictly of resistor and capacitor segments unless the ISPERL parameter is given a non-zero value, in which case the capacitors are replaced with reverse biased diodes with a zero-bias junction capacitance equivalent to the capacitance replaced, and with a saturation current of ISPERL amps per meter of transmission line and an optional series resistance equivalent to RSPERL Ohm per meter.

Name	Parameter	Units	Default
K	Propagation constant	-	2.0
FMAX	Maximum frequency	Hz	1.0G
RPERL	Resistance per unit length	Ω/m	1000
CPERL	Capacitance per unit length	F/m	1e-15
ISPERL	Saturation current per unit length	A/m	0
RSPERL	Diode resistance per unit length	Ω /m	0

Supported Analyses

All.

V Independent Voltage Sources

General form:

```
VXXXXXXX N+ N- <<DC> DC/TRAN VALUE> <AC <ACMAG <ACPHASE>>>
+ <DISTOF1 <F1MAG <F1PHASE>>> <DISTOF2 <F2MAG <F2PHASE>>>
```

Examples:

```
vin 21 0 pulse(0 5 1ns 1ns 1ns 5us 10us)
vcc 10 0 dc 6
vmeas 12 9
```

`N+` and `N-` are the positive and negative nodes, respectively. Note that the voltage source need not to be grounded. Positive current flows from the positive node through the source to the negative node. If you insert a voltage source with a zero value, it can be used as an Ampere meter.

`DC/TRAN` is the source value during a dc or a transient analysis. The value can be omitted if it is zero for both the DC and transient analysis. If the source is time invariant, its value can be prefixed with `DC`.

`ACMAG` is amplitude value and `ACPHASE` is the phase value of the source during an ac analysis. If `ACMAG` is omitted after the keyword `AC`, 1 is assumed. If `ACPHASE` is omitted, 0 is assumed.

`DISTOF1` and `DISTOF2` are the keywords that specify that the independent source has distortion inputs at the frequencies `F1` and `F2` respectively (see the description of the distortion analysis parameters). The keywords may be followed by an optional magnitude and phase. The default values of the magnitude and phase are 1.0 and 0.0 respectively.

All independent sources can be assigned time varying values during a transient analysis. If a source is assigned a time varying value, the value at t=0 is used during a dc analysis. There are 5 predefined functions for time varying sources: pulse, exponent, sinusoidal, piece-wise linear, and single frequency FM. If parameters are omitted, the default values shown in the tables below will be assumed. DT and T2 are the increment time and final time in a transient analysis, respectively (see Transient Analysis).

Pulse

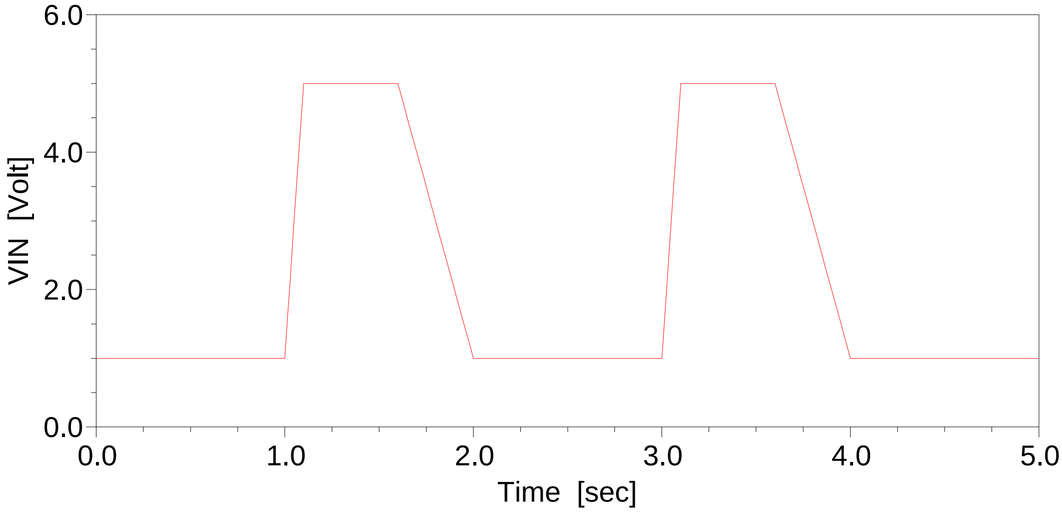
General form:

```
PULSE(V1 V2 TD TR TF PW PER)
```

Parameters	Default values	Units
V1 (initial value)	None	V
V2 (pulsed value)	None	V
TD (delay time)	0.0	s
TR (rise time)	DT	s
TF (fall time)	DT	s
PW (pulse width)	T2	s
PER (period)	T2	s

Example:

```
VIN 3 0 PULSE(1 5 1S 0.1S 0.4S 0.5S 2S)
```



Sinus

General form:

```
SIN(V0 VA FREQ TD THETA)
```

Parameters	**Default values**	**Units**
V0 (offset)	None	V
VA (amplitude)	None	V
FREQ (frequency)	1/T2	Hz
TD (delay)	0.0	s
THETA(damping factor)	0.0	1/s

The shape of the waveform is:

$\underline{0 < time < \mathrm{TD}}$

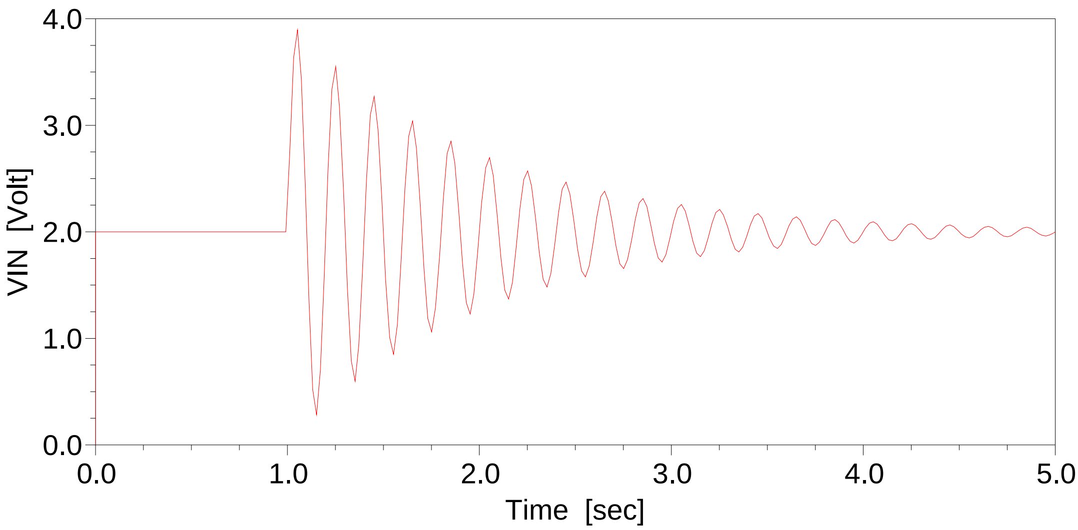
$$V = \mathrm{V0}$$

$\underline{\mathrm{TD} < time < \mathrm{T2}}$

$$V = \mathrm{V0} + \mathrm{VA} \cdot \sin(2\pi \cdot \mathrm{FREQ} \cdot (time + \mathrm{TD})) \cdot \exp(-(time - \mathrm{TD}) \cdot \mathrm{THETA})$$

Example:

```
VIN 3 0 SIN(2 2 5 1S 1)
```



Exponent

General form:

```
EXP(V1 V2 TD1 TAU1 TD2 TAU2)
```

Parameters	Default values	Units
V1 (initial value)	None	V
VA (pulsed value)	None	V
TD1(rise delay time)	0.0	s
TAU1(rise time constant)	DT	s
TD2 (delay fall time)	TD1+DT	s
TAU2 (fall time constant)	DT	s

The shape of the waveform is:

<u>0 < *time* < TD1</u>

$$V = \mathrm{V1}$$

<u>TD1 < *time* < TD2</u>

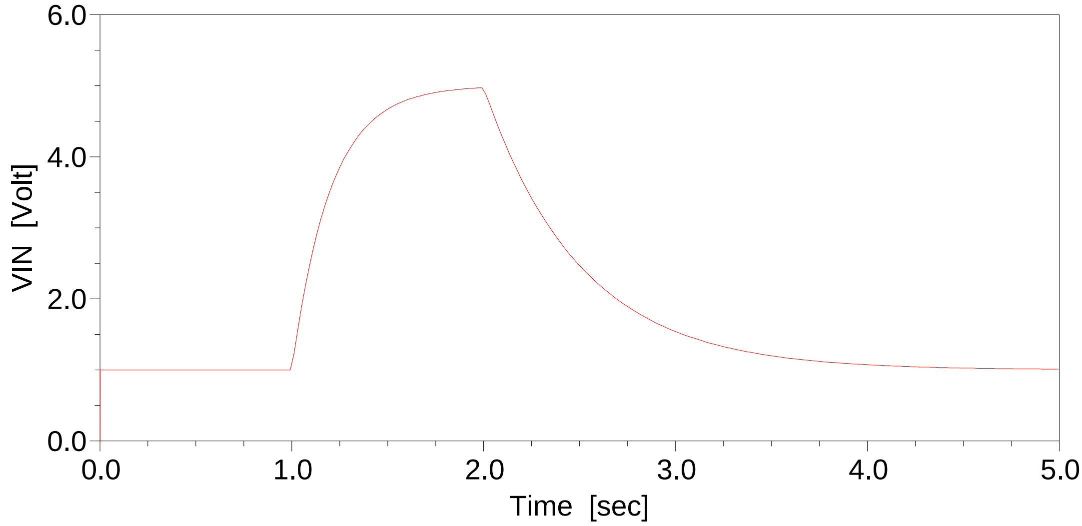
$$V = \mathrm{V1} + (\mathrm{V2} - \mathrm{V1}) \cdot (1 - \exp(-(time - \mathrm{TD1}) / \mathrm{TAU1}))$$

<u>TD2 < time < T2</u>

$$V = \mathrm{V1} + (\mathrm{V2} - \mathrm{V1}) \cdot (1 - \exp(-(time - \mathrm{TD1}) / \mathrm{TAU1})) + (\mathrm{V1} - \mathrm{V2}) \cdot (1 - \exp(-(time - \mathrm{TD2}) / \mathrm{TAU2}))$$

Example:

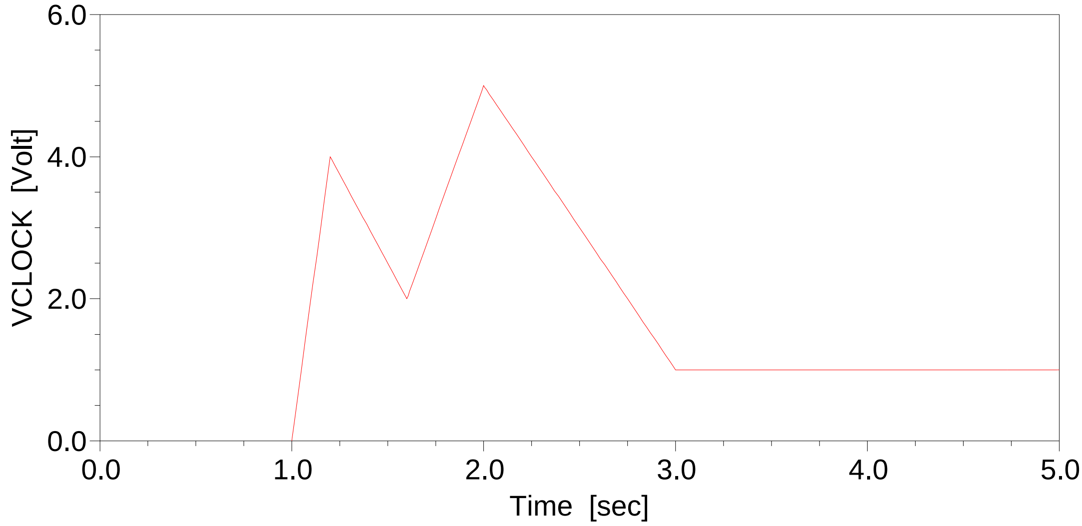
```
VIN 3 0 EXP(1 5 1S 0.2S 2S 0.5S)
```



Piece-wise Linear
General form:
```
PWL(T1 V1 <T2 V2 T3 V3 T4 V4 T5 V5 ....>)
```

Parameters and default values:
Every pair of values (T_i, V_i) specifies that the value of the source is V_i at T_i. The value of the source between these values is calculated using a linear interpolation.

Example:
```
VCLOCK 7 5 PWL(0 0 1 0 1.2 4 1.6 2.0 2.0 5.0 3.0 1.0)
```



Single frequency FM
General form:
```
SFFM(V0 VA FC MDI FS)
```

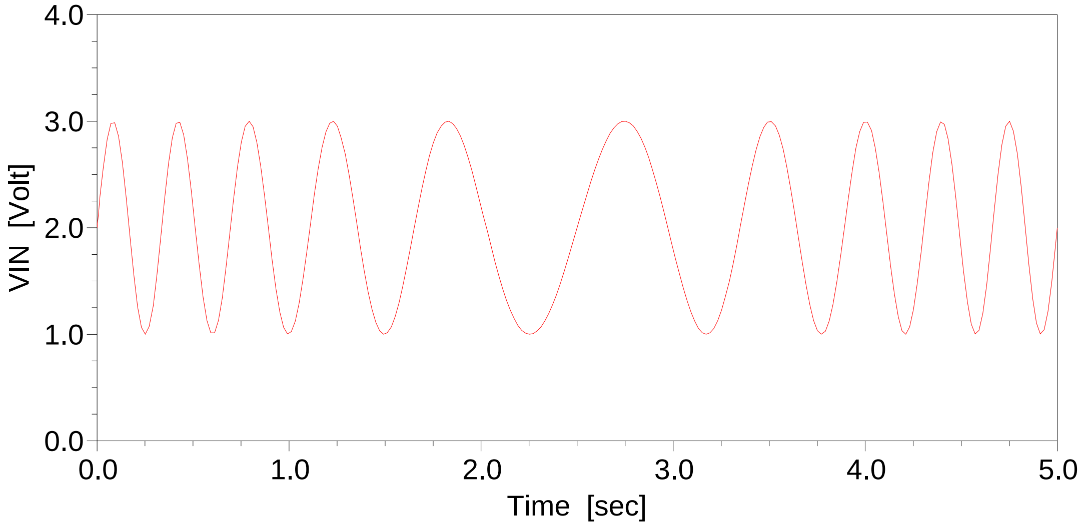
Parameters	Default values	Units
V0 (offset)	None	V
VA (amplitude)	None	V
FC (carrier frequency)	1/T2	Hz
MDI (modulation index)	None	-
FS (signal frequency)	1/T2	Hz

The shape of the waveform is:

$$V = \mathrm{V0} + \mathrm{VA} \cdot \sin\left(\left(2\pi \cdot \mathrm{FC} \cdot time\right) + \mathrm{MDI} \cdot \sin\left(2\pi \cdot \mathrm{FS} \cdot time\right)\right)$$

Example:

```
VIN 12 0 SFFM(2 1 2 5 0.2)
```



Supported Analyses

All

W Current Controlled Switch

General form:

```
WYYYYYYY N+ N- VNAME MODEL <ON> <OFF>
```

Examples:

```
w1 1 2 vclock switchmod1
w2 3 0 vramp sm1 ON
wreset 5 6 vclk lossyswitch OFF
```

N+ and N- are the positive and negative nodes of the switch, respectively. The control current is defined as the current flowing through the specified voltage source. The direction of positive control current is from the positive node through the source to the negative node.

Switch Model

```
.MODEL [model name] CSW <model parameters>
```

The switch model allows modeling of an almost ideal switch in AIM-Spice. The switch is not quite ideal in the resistance cannot change from 0 to infinity, but must have a finite positive value. The *on* and *off* resistances should therefore be chosen very small and very large, respectively, compared to other circuit elements. The model parameters are as follows:

Name	Parameter	Units	Default
IT	Threshold current	A	0
IH	Hysteresis current	A	0
RON	On resistance	Ω	1
ROFF	Off resistance	Ω	1/GMIN

An ideal switch is highly non-linear. The use of switches can cause large discontinuities in node voltages. A rapid change such as that associated with a switching operation can cause problems with roundoff and tolerance which may lead to erroneous results or problems in selecting proper time steps. To reduce such problems, follow these steps:

Do not set the switch impedances higher and lower than necessary.

Reduce the tolerance during a transient analysis. This is done by specifying a value for TRTOL less than the default value of 7.0. Use for example 1.0.

When switches are placed near capacitors, you should reduce the size of CHGTOL to, for example, 1e-16.

Supported Analyses

All.

X Subcircuit Calls

General form:

```
XYYYYYYY N1 <N2 ...> SUBNAME <PAR=VAL> <PAR={EXPRESSION}>
```

Example:

```
X1 2 4 17 3 1 MULTI
```

A line that starts with an 'X' is used to instantiate a subcircuit that has been defined using the `.subckt` command. N1, N2, … are names of nodes to be connected externally. `SUBNAME` is the name of the subcircuit being instantiated, as specified by the `.subckt` command. `<PAR=VAL>` and `<PAR={EXPRESSION}>` specifies that the parameter `PAR` is assigned a value inside the subcircuit. This parameter assignment takes precedence over any parameter assignments occurring in the `.subckt` command.

Z Metal Semiconductor Field Effect Transistors (MESFETs)

General form (Level 1):

```
ZXXXXXXX ND NG NS MNAME <A=VALUE> <OFF> <IC=VDS,VGS>
```

General form (Level 2 and 3):

```
ZXXXXXXX ND NG NS MNAME <L=VALUE> <W=VALUE> <OFF>
+ <IC=VDS,VGS> <TD=T> <TS=T>
```

Example:

```
z1 7 2 3 zm1 off
z1 0 2 0 mesmod l=1u w=20u
```

`ND`, `NG` and `NS` are the drain, gate and source nodes, respectively. `MNAME` is the model name, `A` is the area factor, `L` is the channel length, `W` is the channel width, and `OFF` indicates a optional initial value for the element in a dc analysis. If the area factor is omitted, 1.0 is assumed. The optional initial value `IC=VDS,VGS` is meant to be used together with UIC in a transient analysis. See the description of the .IC command for a better way to set transient initial conditions. The optional `TD` and `TS` values for Levels 2 and 3 are the operation drain and source temperatures, respectively, in centigrade. They override the temperature specified in the option value. If length and/or width are not specified, AIM-Spice will use default values, $L=1\mu m$ and $W=20\mu m$ for Levels 2 and 3.

MESFET Model

```
.MODEL [model name] NMF <model parameters>
.MODEL [model name] PMF <model parameters>
```

In AIM-Spice, three MESFET models are implemented. The difference between the models is in the formulation of the IV-characteristics. The parameter LEVEL selects which model to use.

LEVEL=1	Model proposed by Statz et al. [9]
LEVEL=2	Unified extrinsic model for uniformly doped channel (as described in Section 4.4.3 in [1])
LEVEL=3	Unified extrinsic model for delta doped channel (as described in Section 4.4.4 in [1])

MESFET model parameters common for all levels:

Name	Parameter	Units	Default
VTO	Zero-bias threshold voltage	V	-2.0 (level 1) -1.26 (level 2, 3)
RD	Drain ohmic resistance	Ω	0
RS	Source ohmic resistance	Ω	0

Model parameters specific for Level 1:

Name	Parameter	Units	Default
IS	Junction saturation current	A	1e-14
BETA	Transconductance parameter	A/V^2	2.5e-3
B	Doping tail extending parameter	1/V	0.3
ALPHA	Saturation voltage parameter	1/V	2
LAMBDA	Channel length modulation parameter	1/V	0
CGS	Zero-bias G-S junction capacitance	F	0
CGD	Zero-bias G-D junction capacitance	F	0
PB	Gate junction potential	V	1
KF	Flicker noise coefficient	-	0
AF	Flicker noise exponent	-	1
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5

The model parameters for MESFET Levels 2 and 3 are listed below. Note that the default values correspond to the *n*-channel MESFET used as an example in Section 4.4 in [1].

Name	Parameter	Units	Default
D	Depth of device (level 2 only)	m	0.12μm
DU	Depth of uniformly doped layer (level 3 only)	m	0.035μm
RG	Gate ohmic resistance	Ω	0
RDI	Internal drain ohmic resistance	Ω	0
RSI	Internal source ohmic resistance	Ω	0
RI	Resistance in series with C_{gs} (level 2 only)	Ω	0
RF	Resistance in series with C_{gd} (level 2 only)	Ω	0
PHIB	Effective Schottky barrier height	eV	0.5
ASTAR	Effective Richardson constant	A / m^2K^2	4.0E4
GGR	Junction conductance at reverse bias	$1 / \Omega m^2$	40
DEL	Reverse junction conductance inverse ideality factor	-	0.04
N	Junction ideality factor	-	1
LAMBDA	Output conductance parameter	1/V	0.045
LAMBDAHF	Output conductance parameter at high frequencies	1/V	0.045
VS	Saturation velocity (level 2 only)	m/s	1.5E5
BETA	Transconductance parameter (level 3 only)	A / V^2	0.0085
ETA	Subthreshold ideality factor	-	1.73
M	Knee shape parameter	-	2.5
ALPHA	Bulk charge parameter	1/V	0

Name	Parameter	Units	Default
MC	Knee shape parameter	-	3.0
SIGMA0	DIBL parameter	-	0.081
VSIGMAT	DIBL parameter	V	1.01
VSIGMA	DIBL parameter	V	0.1
MU	Low field mobility	m^2 / Vs	0.23
THETA	Mobility enhancement coefficient	m^2 / V^2s	0
MU1	First temperature parameter for mobility	m^2 / Vs	0
MU2	Second temperature parameter for mobility	m^2 / Vs	0
ND	Substrate doping (level 2 only)	m^{-3}	3.0E23
NDU	Uniform layer doping (level 3 only)	m^{-3}	1.0E22
DELTA	Transition width parameter	-	5.0
TC	Transconductance compression factor	1/V	0
ZETA	Transconductance compensation factor	-	1.0
NDELTA	Doping of delta doped layer (level 3 only)	m^{-3}	6.0E24
TH	Thickness of delta doped layer (level 3 only)	m	0.01μm
TVTO	Temperature coefficient for VTO	V/K	0
TLAMBDA	Temperature coefficient for LAMBDA	°C	∞
TETA0	First temperature coefficient for ETA	°C	∞
TETA1	Second temperature coefficient for ETA	°C	0 K
TMU	Temperature coefficient for mobility	°C	27
XTM0	First exponent for temperature dependence of mobility	-	0
XTM1	Second exponent for temperature dependence of mobility	-	0
XTM2	Third exponent for temperature dependence of mobility	-	0
TPHIB	Temperature coefficient for PHIB	eV/K	0
TGGR	Temperature coefficient for GGR	1/K	0
KS	Sidegating coefficient	-	0
VSG	Sidegating voltage	V	0
TF	Characteristic temperature determined by traps	°C	TEMP
FLO	Characteristic frequency for frequency dependent output conductance	Hz	0

Name	Parameter	Units	Default
DELFO	Frequency range used for frequency dependent output conductance calculation	Hz	0
AG	Drain-source correction current gain	-	0
RTC1	First order temperature coefficient for parasitic resistances	1/°C	0
RTC2	Second order temperature coefficient for parasitic resistances	1/°C^2	0

For Levels 2 and 3 you can choose between intrinsic or extrinsic model by proper use of parameters RD, RS, and RDI, RSI. If you specify values for RD and RS, you select the intrinsic model with parasitic resistances applied externally. The extrinsic model is selected by specifying values for RDI and RSI.

Temperature effects (level 2 and 3 only)

The temperature appears explicitly in the several exponential terms. In addition, the temperature dependence of several key parameters are modeled as shown below (in terms of absolute temperatures).

The dependence of the threshold voltage on temperature is modeled by the equation

$$V_T = \mathrm{VT0} - \mathrm{TVTO(TS - TNOM)}$$

where TNOM is the nominal temperature specified as an option.

The mobility is adjusted according to

$$\mu_{imp} = \mathrm{MU}\left(\frac{\mathrm{TS}}{\mathrm{TMU}}\right)^{\mathrm{XTM0}}$$

$$\mu_{po} = \mathrm{MU1}\left(\frac{\mathrm{TMU}}{\mathrm{TS}}\right)^{\mathrm{XTM1}} + \mathrm{MU2}\left(\frac{\mathrm{TMU}}{\mathrm{TS}}\right)^{\mathrm{XTM2}}$$

$$\frac{1}{\mu_{n0}} = \frac{1}{\mu_{imp}} + \frac{1}{\mu_{po}}$$

where μ_{imp} is the impurity scattering limited mobility, μ_{po} is the polar optical scattering limited mobility and μ_{n0} is the effective zero bias mobility used in calculating the drain current.

The output conductance parameter is adjusted according to

$$\lambda = \mathrm{LAMBDA}\left(1 - \frac{\mathrm{TS}}{\mathrm{TLAMBDA}}\right).$$

The subthreshold ideality factor is adjusted according to

$$\eta = \mathrm{ETA}\left(1+\frac{\mathrm{TS}}{\mathrm{TETA0}}\right)+\frac{\mathrm{TETA1}}{\mathrm{TS}}$$

The following equation is used to adjust all the parasitic resistances:

$$R(\mathrm{TS}) = R(\mathrm{TNOM})\left[1+\mathrm{RTC1}(\mathrm{TS}-\mathrm{TNOM})+\mathrm{RTC2}(\mathrm{TS}-\mathrm{TNOM})^2\right],$$

Drain current equations

$$I_d = \frac{g_{ch}V_{ds}(1+\lambda V_{ds})}{\left[1+\left(V_{ds}/V_{sat}\right)^m\right]^{1/m}}$$

$$m = \mathrm{M} + \mathrm{ALPHA}\cdot V_{gte}$$

$$V_{sat} = \frac{I_{sat}}{g_{ch}}$$

$$g_{ch} = \frac{g_{chi}}{1+g_{chi}(\mathrm{RSI}+\mathrm{RDI})}$$

$$g_{chi} = qn_s \mathrm{W}\mu_n / \mathrm{L}$$

$$I_{sat} = \frac{I_{sata}I_{satb}}{I_{sata}+I_{satb}}$$

$$I_{sata} = \frac{2\cdot\mathrm{ZETA}\cdot\beta V_{gte}^2}{\left(1+2\beta V_{gte}\mathrm{RSI}+\sqrt{1+4\beta V_{gte}\mathrm{RSI}}\right)\left(1+\mathrm{TC}\cdot V_{gte}\right)}$$

$$I_{satb} = \frac{qn_0\mu_n V_{th}\mathrm{W}}{\mathrm{L}}\exp\left(\frac{V_{gt}}{\eta V_{th}}\right)$$

$$\beta = \frac{2\varepsilon_s\cdot\mathrm{VS}\cdot\mathrm{W}}{\mathrm{D}(V_{po}+3V_L)}$$

$$V_L = \mathrm{VS}\cdot\mathrm{L}/\mu_n$$

$$\mu_n = \mathrm{MU} + \mathrm{THETA}\cdot V_{gte}$$

$$V_{gte} = \frac{V_{th}}{2}\left[1+\frac{V_{gt}}{V_{th}}+\sqrt{\mathrm{DELTA}^2+\left(\frac{V_{gt}}{V_{th}}-1\right)^2}\right]$$

$$V_{gt} = V_{gs} - V_T + \sigma V_{ds}$$

$$\sigma = \frac{\mathrm{SIGMA0}}{1 + \exp\left(\dfrac{V_{gs} - V_T - \mathrm{VSIGMAT}}{\mathrm{VSIGMA}}\right)}$$

For level 2:

$$n_s = \left\{\left[\mathrm{ND}\cdot\mathrm{D}\cdot\left(1 - \sqrt{1 - \frac{V_{gte}}{V_{po}}}\right)\right]^{-1} + \frac{1}{n_0}\exp\left(-\frac{V_{gt}}{\eta\cdot V_{th}}\right)\right\}^{-1}$$

$$n_0 = \frac{\varepsilon_s \eta V_{th}}{q\mathrm{D}}$$

$$V_{po} = \frac{q\cdot\mathrm{ND}\cdot\mathrm{D}^2}{2\varepsilon_s}$$

For level 3:

$$n_s = \frac{n_{sa} n_{sb}}{n_{sa} + n_{sb}}$$

$$n_{sa} = \begin{cases} \mathrm{NDELTA}\cdot\mathrm{TH}\left\{1 - \dfrac{\mathrm{DU}}{\mathrm{TH}}\left[\sqrt{1 + \dfrac{\mathrm{NDU}}{\mathrm{NDELTA}}\left(\dfrac{V_{po\delta} - V_{gte}}{V_{pou}}\right)}\right]\right\}, & \text{for } V_{gt} \le V_{po\delta} \\ \mathrm{NDELTA}\cdot\mathrm{TH} + \mathrm{NDU}\cdot\mathrm{DU}\left(1 - \sqrt{\dfrac{V_{po} - V_{gte}}{V_{pou}}}\right), & \text{for } V_{gt} > V_{po\delta} \end{cases}$$

$$n_{sb} = n_0 \exp\left(\frac{V_{gt}}{\eta V_{th}}\right)$$

$$n_0 = \frac{\varepsilon_s \eta V_{th}}{q(\mathrm{DU} + \mathrm{TH})}$$

$$V_{po} = V_{pou} + V_{po\delta}$$

$$V_{pou} = \frac{q\cdot\mathrm{NDU}\cdot\mathrm{DU}^2}{2\varepsilon_s}$$

$$V_{po\delta} = \frac{q\cdot\mathrm{NDELTA}\cdot\mathrm{TH}\cdot(2\cdot\mathrm{DU} + \mathrm{TH})}{2\varepsilon_s}$$

Gate current equations

$$I_g = J_{gs}\frac{\mathrm{LW}}{2}\left[\exp\left(\frac{V_{gs}}{\mathrm{N}\cdot V_{ths}}\right)-1\right]+\frac{\mathrm{LW}}{2}g_{gs}V_{gs}\exp\left(-\frac{qV_{gs}\mathrm{DEL}}{k_B\mathrm{TS}}\right)+$$
$$\frac{\mathrm{LW}}{2}\left[J_{gd}\exp\left(\frac{V_{gd}}{\mathrm{N}\cdot V_{thd}}\right)-J_{gs}\right]+\frac{\mathrm{LW}}{2}g_{gd}V_{gd}\exp\left(-\frac{qV_{gd}\mathrm{DEL}}{k_B\mathrm{TS}}\right)$$

$$J_{gs} = \frac{\mathrm{ASTAR}\cdot\mathrm{TS}^2}{2}\exp\left(-\frac{\Phi_{bs}}{k_B\mathrm{TS}}\right)$$

$$J_{gd} = \frac{\mathrm{ASTAR}\cdot\mathrm{TD}^2}{2}\exp\left(-\frac{\Phi_{bd}}{k_B\mathrm{TD}}\right)$$

$$V_{ths} = k_B\mathrm{TS}/q,\quad V_{thd} = k_B\mathrm{TD}/q$$

$$g_{gs} = g_{gd} = \mathrm{GGR}\cdot\exp(\mathrm{TGGR}\cdot(\mathrm{TS}-\mathrm{TNOM}))$$

$$\Phi_{bs} = \Phi_{bd} = \mathrm{PHIB}-\mathrm{TPHIB}\cdot(\mathrm{TS}-\mathrm{TNOM})$$

Supported Analyses

Level 1: All
Level 2, 3: Noise and Pole-Zero analyses not supported

References

[9] H. Statz, P. Newman, I. W. Smith, R. A. Pucel, and H. A. Haus, "GaAs FET Device and Circuit Simulation in SPICE," *IEEE Trans. on Electron Devices*, vol. 34, no. 2, pp. 160-169, Feb. 1987.

[10] K. Lee, M. Shur, T. A. Fjeldly and T. Ytterdal, *Semiconductor Device Modeling for VLSI*, 1993, Prentice Hall, New Jersey.

Bugs Reported by Berkeley

Convergence problems can sometimes be avoided by relaxing the maximum stepsize parameter for a transient analysis.

The base node of the bipolar transistor (BJT) is incorrectly modeled and should not be used. Use instead a semiconductor capacitor to model base effects.

Charge storage in MOS devices based on the Meyer model is incorrectly calculated.

Transient simulations of strictly resistive circuits (typical for first runs or tests) allow a time step that is too large (e.g., a sinusoidal source driving a resistor). There is no integration error to restrict the time step. Use the maximum stepsize parameter or include reactive elements.