Spice Simulation

20151014

* Qucs .... component level spice simulation (frontend)

* Ngspice .... device level spice simulation

general spice info

http://people.rit.edu/~lffeee/SPICE_MOSFET_Model_Intro.pdf

qucs tutorial

http://qucs.sourceforge.net/docs/tutorial/getstarted.pdf

http://qucs.sourceforge.net/docs/tutorial/spicetoqucs.pdf

ngspice MOSFET spice model simulation

☆ http://www.idea2ic.com/BSIM_PARAMETER_TEST_METHODS

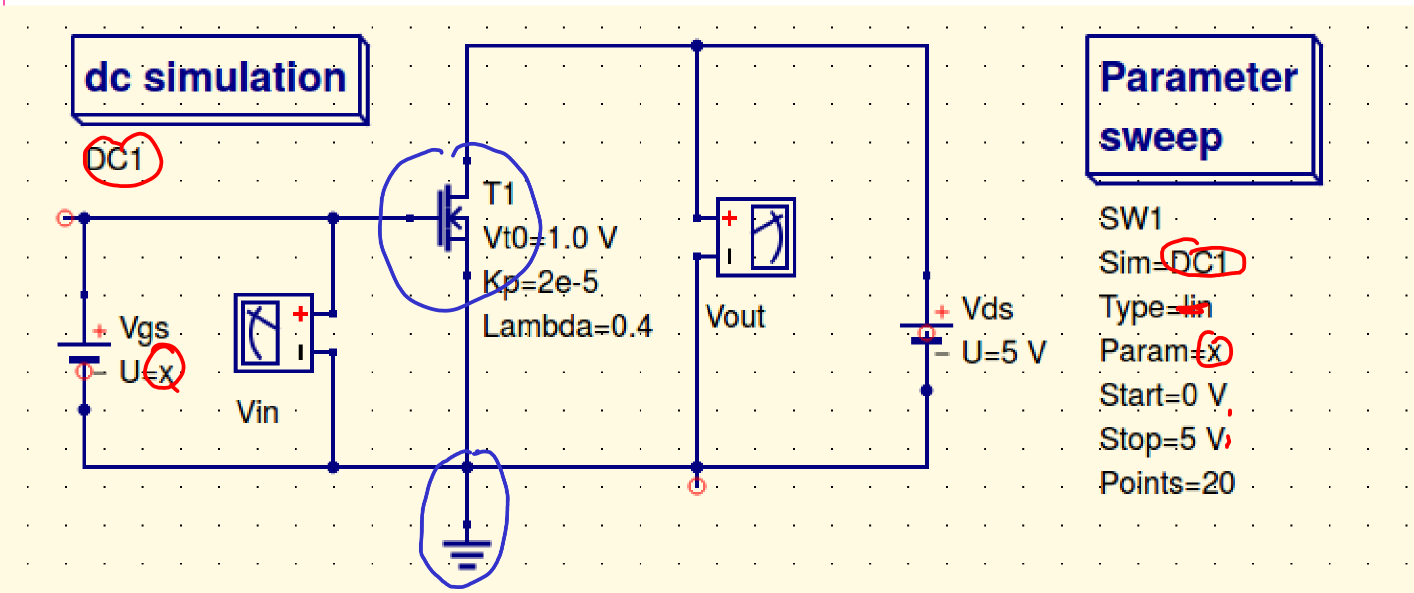
☆☆ /BSIM_PARAMETER_TEST_METHODS.html

⑥ http://qucs.sourceforge.net/tech/node71.html

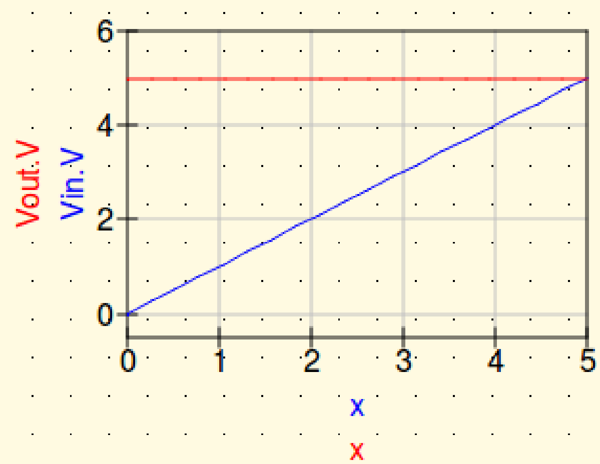
Qucs MOSFET

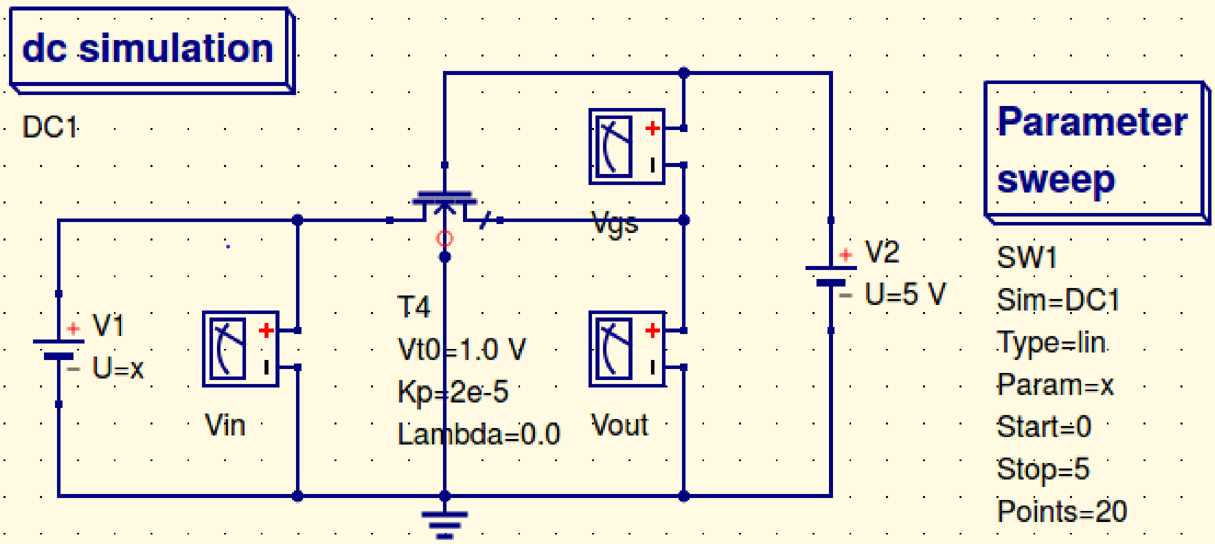
1st. Generation Model parameter values ← as in the chap 3. of the text book

※ ngspice —call→ qucs
←

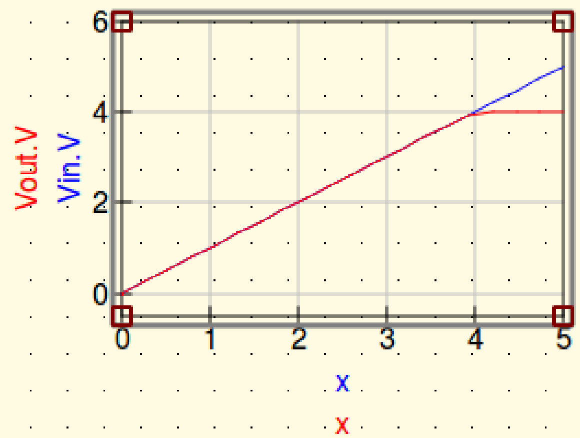


x	Vin.V	Vout.V
0	0	5
0.263	0.263	5
0.526	0.526	5
0.789	0.789	5
1.05	1.05	5
1.32	1.32	5
1.58	1.58	5

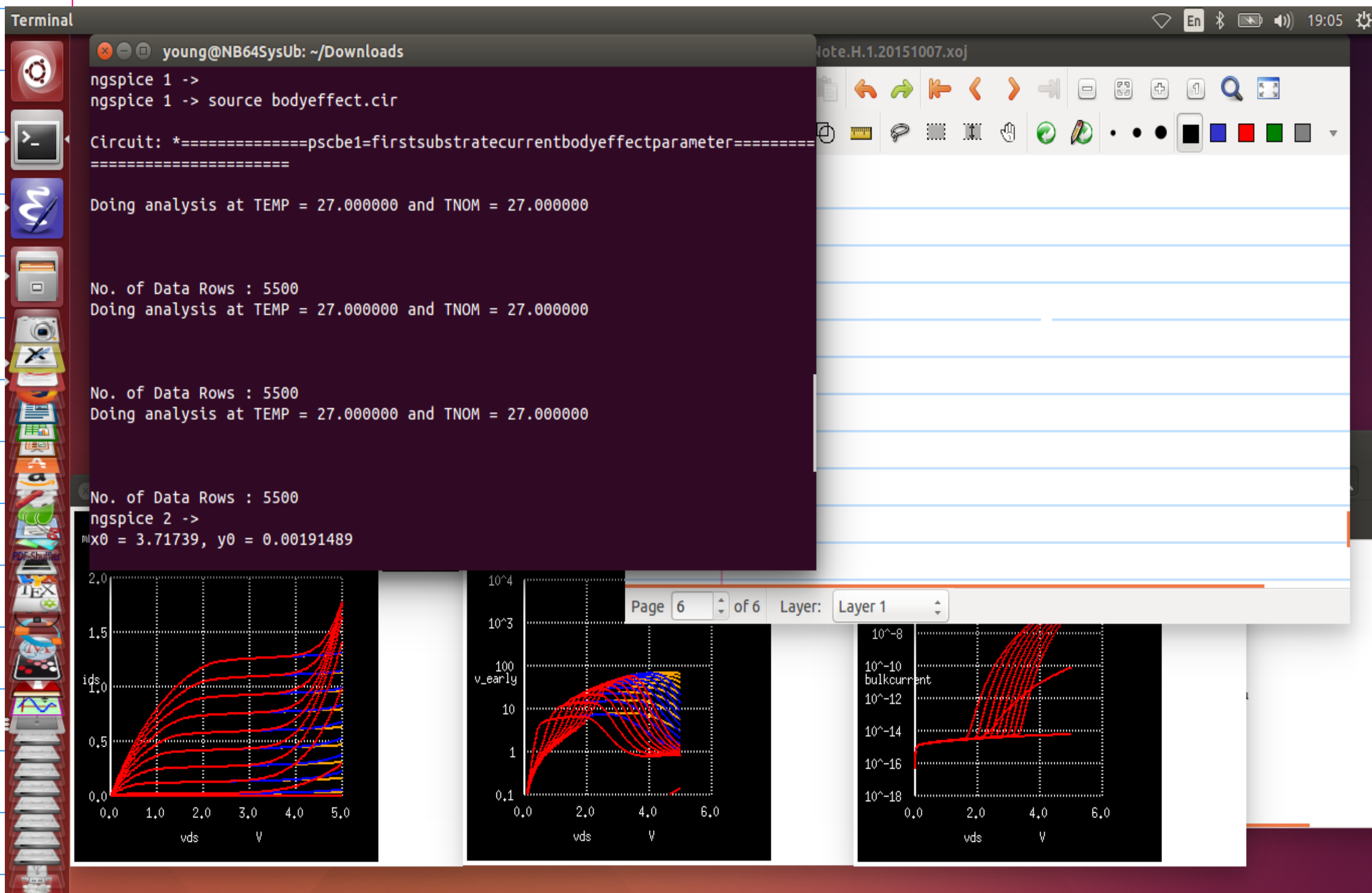




x	Vin.V	Vout.V	Vgs.V
3.68	3.68	3.68	1.32
3.95	3.95	3.95	1.05
4.21	4.21	4	1
4.47	4.47	4	1
4.74	4.74	4	1
5	5	4	1



ngspice simulation result



cut & paste a part from the

BSIM_ParametersSanity_01.txt.pdf

www.idea2ic.com

save as "bodyeffect.cir"

run ngspice

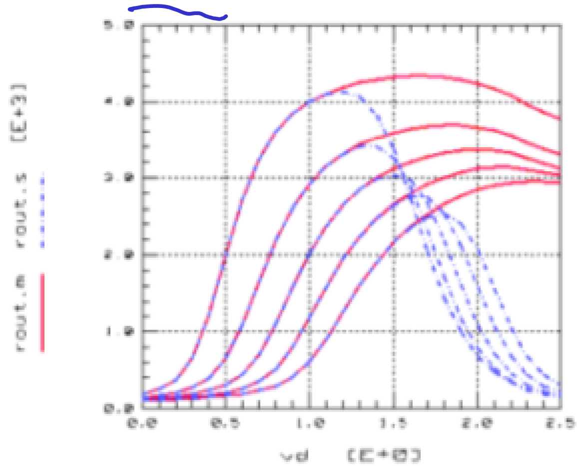
ngspice> source "bodyeffect.cir"

prompt

code from www.idea2ic.com

```
==============pscbe1=FirstSubstrateCurrentBodyeffectParameter==========
*------------------VAF---------------------------------------------------
+ lint=.12e-06       pclm=.19            pscbe1=3.79e+08      pscbe2=9.4e-05
+ delta=0.01655      pdiblc1=0.39        pdiblc2=0.0086       drout=0.56
*------------------------------------------------------------------------
```

Figure 97 Substrate Current Body Effect (SCBE)




```
NMOS_PSCBE1        pscbe1=1.79e+08   2.79e+08  3.79e+08
*
*                          __________          ______
*                         |       v1_|_      _|_   v2 |
*                         |       / 0v\     / 0v\     |
*                         |       \___/     \___/     |
*                         |         |  1      | 2     |
*                         |D      VC_|_      _|_  VB  |
*      G                 _|  m1   /5v \     /0v \     |
*                    ____||______ \___/     \___/    _|_
*                   |    ||->    |    |       |      ///
* VG                |     |      |__/ |\______|
*                 /.7v\   |___________|
*                 \___/        _|_
*                   |          ///
*                  _|_
*                  ///
.OPTIONS   GMIN=1e-15     METHOD=gear    ABSTOL=1e-15
*========= ====== ====== ====== ====== ====== ====== ====== ======
Vds        D      0      dc      .1v
Vgs        G      0      dc      1.2v
Vbs        2      B      dc      0v
v1         D      1      dc      0v
v2         0      2      dc      0v
m1         1      G      0       B      N1    W=3u   L=1u AD=7p AS=7p PD=10u PS=10u
.control
destroy    all
```

```
.control
destroy     all
altermod    N1      pscbel=1.79e+08
*DC         SOURC1  VSTART  VSTOP   VSTEP   SOURC2  START2  STOP2   STEP2
dc          Vds     1m      5       0.01    vgs     0       5       .5
altermod    N1      pscbel=2.79e+08
*DC         SOURC1  VSTART  VSTOP   VSTEP   SOURC2  START2  STOP2   STEP2
dc          Vds     1m      5       0.01    vgs     0       5       .5
altermod    N1      pscbel=3.79e+08
*DC         SOURC1  VSTART  VSTOP   VSTEP   SOURC2  START2  STOP2   STEP2
dc          Vds     1m      5       0.01    vgs     0       5       .5

let ic1 = mag(dc1.i(v1))
let ic2 = mag(dc2.i(v1))
let ic3 = mag(dc3.i(v1))
plot        ic1 ic2 ic3   xlabel   VDS   ylabel   IDS

let ev1 = mag(ic1/(deriv(ic1)+1e-7))
let ev2 = mag(ic2/(deriv(ic2)+1e-7))
let ev3 = mag(ic3/(deriv(ic3)+1e-7))
plot        ev1 ev2 ev3    ylog   ylimit .1 10k     xlabel   VDS   ylabel   V_early

let ib1 = mag(dc1.i(v2))
let ib2 = mag(dc2.i(v2))
let ib3 = mag(dc3.i(v2))
plot        ib1 ib2 ib3     ylog   xlabel   VDS   ylabel   BulkCurrent

.endc
```

code from www.idea2ic.com

BSIM3

```
.model          N1                  NMOS
+ Level=  49       Tnom=27.0           version=3.24
+ mobmod=2         capmod=3            noimod=2
**-----------------Process-------------------------------------------
+ tox=160e-10      toxm=160e-10
+ ngate=8.000e+19  xj=0.25e-06         nch=0.5e+17
*------------------V_threshold---------------------------------------
+ vth0=0.72        lvth0=0.025         nlx=0.12e-06      kt1=-0.9821
+ dvt0=2.2         dvt1=0.53           dvt2=-1.521E-01
*------------------NarrowChannel-------------------------------------
+ w0=2.6e-04       wint=0.16e-06       ww=-9.525E-14    wwn=1.0
+ dvt0w=0          dvt1w=5.3e6         dvt2w=-1.E-01
+ k3=2.53          k3b=-5              dwg=0            dwb=0
*------------------Bulk----------------------------------------------
+ k1=1.04          k2=-1.209E-01       kt2=-0.2916
+ cdsc=-2.4E-4     cdscd=-1.506E-04    cdscb=-2.219E-04

*------------------Mobility------------------------------------------
+ u0=678           ua=8.964e-10        ub=1.472e-18     uc=-4.441E-17
+ ute=-1.176       ua1=5.705e-09       ub1=-1.147E-17   uc1=-1.302E-01
+ vsat=86000       at=20380            elm=2
*------------------Resistance----------------------------------------
+ rsh=70           rdsw=375            prt=-3.287E+02
+ wr=0.7586        prwb=0              prwg=-4.441E-17
*------------------VAF-----------------------------------------------
+ lint=.12e-06     pclm=.19            pscbe1=3.79e+08    pscbe2=9.4e-05
+ delta=0.01655    pdiblc1=0.39        pdiblc2=0.0086     drout=0.56
*------------------Subthreshold--------------------------------------
+ nfactor=1.8      cit=-5.0E-04        voff=-7.862E-02
+ eta0=4.441e-16   etab=-2.E-01        dsub=0.7
*------------------HotElectrons-------------------------------------
+ alpha0=1.61e-05  alpha1=8.276E-05    beta0=36.68
*------------------Capacitance---------------------------------------
+ cjswg=2.73e-10   mjswg=0.2           pbswg=8.800e-01
+ cj=0.0002424     mj=0.3551           pb=0.5614
+ cjsw=2.73e-10    mjsw=0.3873         pbsw=0.8
+ cgso=9e-13       cgdo=9e-13          cgbo=7e-10
+ dlc=5e-08        dwc=1.5e-07         xpart=0
*------------------BulkDiode----------------------------------------
+ js=5.858e-08     jsw=1.25E-10        xti=2.000e+00     nj=1.08
*------------------BulkChargeEffect----------------------------------
+ a0=0.7           a1=1                a2=1               ags=0.05583
+ b0=6.305e-08     b1=6.579e-08        keta=-1.531E-02
*------------------Noise????-----------------------------------------------
+ af=1             kf=0                ef=1              em=4.1E+07
+ noia=1E+20       noib=50000          noic=-1.4E-12
*------------------dLdW?????---------------------------------------
+ wl=0             wln=1                ww1=0
+ ll=0             lln=1                lw=0               lwn=1
+ lwl=0            llc=2E-13            lwc=0              lwlc=0
+ wlc=0            wwc=0                wwlc=0
*------------------Bsim???-----------------------------------
+ wk3=0            lk3=0                pk3=1.257
+ lk3b=0           wk3b=0               pk3b=0
+ pa0=0.0489       la0=-1.052           lags=0.01093
+ wags=0           pags=0.1573          lketa=0
+ wdwg=0           ldwb=0               wdwb=0
*------------------HspiceBSIM4??------------------------------------------
+ hdif=2.7E-07     ldif=0               lu0=0      ldwg=0
+ ucl=-1.098E-11   acm=13               wu0=1
+ wua=3.641E-11    lua=9.782E-10        pua=-4.46E-10   lub=-7.249E-19
+ wub=1.056E-20    pub=8.812E-19        pu0=1
+ wuc=1.177E-11    luc=-2.164E-10       puc=1.231E-10
*------------------Flagged!!---------------------------------------
* nqsmod           lmlt=1.000e+00       wmlt=1.000e+00
* tlev=0.000e+00   tlevc=0.000e+00
*-------------------------------------------------------------------

.end

* source /Users/don_sauer/Downloads/stabie/SI_Lib/Tests.cir
```

Altermod operates on models and is used to change model parameters. The above example will change the parameter `tox` in all devices using the model `nc1`, which is defined as

```
*** BSIM3v3 model
.MODEL nc1 nmos LEVEL=8 version = 3.2.2
+ acm = 2 mobmod = 1 capmod = 1 noimod = 1
+ rs = 2.84E+03 rd = 2.84E+03 rsh = 45
+ tox = 20E-9 xj = 0.25E-6 nch = 1.7E+17
+ ...
```

If you invoke the model by the MOS device

```
M1 d g s b nc1 w=10u l=1u
```

you might also insert the device name M1 for `mod` as in

```
altermod M1 tox = 10e-9
```

The model parameter `tox` will be modified, however not only for device M1, but for all devices using the associated MOS model nc1!

17.5.13 Dc*: Perform a DC-sweep analysis

General Form:

```
dc Source-Name Vstart Vstop Vincr [ Source2 Vstart2 Vstop2 Vincr2 ]
```

Do a dc transfer curve analysis. See the previous chapter 15.3.2 for more details. Several options may be set (15.1.2).

15.3.2 .DC: DC Transfer Function

General form:

```
.dc srcnam vstart vstop vincr [src2 start2 stop2 incr2]
```

Examples:

```
.dc VIN 0.25 5.0 0.25
.dc VDS 0 10 .5 VGS 0 5 1
.dc VCE 0 10 .25 IB 0 10U 1U
.dc RLoad 1k 2k 100
.dc TEMP -15 75 5
```

The .dc line defines the dc transfer curve source and sweep limits (again with capacitors open and inductors shorted). `srcnam` is the name of an independent voltage or current source, a resistor or the circuit temperature. `vstart`, `vstop`, and `vincr` are the starting, final, and incrementing values respectively. The first example causes the value of the voltage source VIN to be swept from 0.25 Volts to 5.0 Volts in increments of 0.25 Volts. A second source (`src2`) may optionally be specified with associated sweep parameters. In this case, the first source is swept over its range for each value of the second source. This option can be useful for obtaining semiconductor device output characteristics. See the example circuit description on transistor characteristics (21.3).

21.3 MOSFET Characterization

The following deck computes the output characteristics of a MOSFET device over the range 0-10V for VDS and 0-5V for VGS.

Example:

```
MOS OUTPUT CHARACTERISTICS
.OPTIONS NODE NOPAGE
VDS 3 0
VGS 2 0
M1 1 2 0 0 MOD1 L=4U W=6U AD=10P AS=10P
* VIDS MEASURES ID, WE COULD HAVE USED VDS, BUT ID WOULD BE NEGATIVE
VIDS 3 1
.MODEL MOD1 NMOS VTO=-2 NSUB=1.0E15 UO=550
.DC VDS 0 10 .5 VGS 0 5 1
.END
```

Spice Model Selection : Level

ngspice manual

Level	Name	Model	Version	Developer	References	Notes
1	MOS1	Shichman-Hodges	-	Berkeley		This is the classical quadratic model.
2	MOS2	Grove-Frhoman	-	Berkeley		Described in [2]
3	MOS3			Berkeley		A semi-empirical model (see [1])
4	BSIM1			Berkeley		Described in [3]
5	BSIM2			Berkeley		Described in [5]
6	MOS6			Berkeley		Described in [2]
9	MOS9			Alan Gillespie		
8, 49	BSIM3v0		3.0	Berkeley		extensions by Alan Gillespie
8, 49	BSIM3v1		3.1	Berkeley		extensions by Serban Popescu
8, 49	BSIM3v32		3.2 - 3.2.4	Berkeley		Multi version code
8, 49	BSIM3		3.3.0	Berkeley		Described in [13]
10, 58	B4SOI		4.3.1	Berkeley		
14, 54	BSIM4v4		4.0 - 4.4	Berkeley		Multi version code
14, 54	BSIM4v5		4.5.0	Berkeley		
14, 54	BSIM4v6		4.6.5	Berkeley		
14, 54	BSIM4		4.7.0	Berkeley		
44	EKV			EPFL		adms configured
45	*PSP*		*1.0.2*	*Gildenblatt*		*adms configured*
55	B3SOIFD			Berkeley		
56	B3SOIDD			Berkeley		
57	B3SOIPD			Berkeley		
60	STAG		SOI3	Southampton		
61, 68	HiSIM2		2.7.0	Hiroshima		
62, 73	HiSIM_HV		1.2.2	Hiroshima		High Voltage Version for LDMOS

NGSPICE level 1, 2, 3 and 6 parameters (1/2)

Name	Parameter	Units	Default	Example
LEVEL	Model index	-	1	
VTO	Zero-bias threshold voltage (V_{T0})	V	0.0	1.0
KP	Transconductance parameter	A/V^2	2.0e-5	3.1e-5
GAMMA	Bulk threshold parameter	$\sqrt{V}$	0.0	0.37
PHI	Surface potential (U)	V	0.6	0.65
LAMBDA	Channel length modulation (MOS1 and MOS2 only) (λ)	$1/V$	0.0	0.02
RD	Drain ohmic resistance	Ω	0.0	1.0
RS	Source ohmic resistance	Ω	0.0	1.0
CBD	Zero-bias B-D junction capacitance	F	0.0	20fF
CBS	Zero-bias B-S junction capacitance	F	0.0	20fF
IS	Bulk junction saturation current (I_S)	A	1.0e-14	1.0e-15
PB	Bulk junction potential	V	0.8	0.87
CGSO	Gate-source overlap capacitance per meter channel width	F/m	0.0	4.0e-11
CGDO	Gate-drain overlap capacitance per meter channel width	F/m	0.0	4.0e-11
CGBO	Gate-bulk overlap capacitance per meter channel width	F/m	0.0	2.0e-11
RSH	Drain and source diffusion sheet resistance	$\Omega/\square$	0.0	10

Level	Name	Model	Version	Developer	References	Notes
1	MOS1	Shichman-Hodges	-	Berkeley		This is the classical quadratic model.
2	MOS2	Grove-Frhoman	-	Berkeley		Described in [2]
3	MOS3			Berkeley		A semi-empirical model (see [1])

MOSFET . model as in the textbook.

NGSPICE level 1, 2, 3 and 6 parameters (2/2)

Name	Parameter	Units	Default	Example
CJ	Zero-bias bulk junction bottom cap. per sq-meter of junction area	F/m^2	0.0	2.0e-4
MJ	Bulk junction bottom grading coeff.	-	0.5	0.5
CJSW	Zero-bias bulk junction sidewall cap. per meter of junction perimeter	F/m	0.0	1.0e-9
MJSW	Bulk junction sidewall grading coeff.	-	0.50 (level1) 0.33 (level2, 3)	
JS	Bulk junction saturation current			
TOX	Oxide thickness	m	1.0e-7	1.0e-7
NSUB	Substrate doping	cm^{-3}	0.0	4.0e15
NSS	Surface state density	cm^{-2}	0.0	1.0e10
NFS	Fast surface state density	cm^{-2}	0.0	1.0e10
TPG	Type of gate material: +1 opp. to substrate, -1 same as substrate, 0 Al gate	-	1.0	
XJ	Metallurgical junction depth	m	0.0	1M
LD	Lateral diffusion	m	0.0	0.8M
UO	Surface mobility	$cm^2/V{\cdot}sec$	600	700
UCRIT	Critical field for mobility degradation (MOS2 only)	V/cm	1.0e4	1.0e4
UEXP	Critical field exponent in mobility degradation (MOS2 only)	-	0.0	0.1
UTRA	Transverse field coeff. (mobility) (deleted for MOS2)	-	0.0	0.3
VMAX	Maximum drift velocity of carriers	m/s	0.0	5.0e4
NEFF	Total channel-charge (fixed and mobile) coefficient (MOS2 only)	-	1.0	5.0
KF	Flicker noise coefficient	-	0.0	1.0e-26
AF	Flicker noise exponent	-	1.0	1.2
FC	Coefficient for forward-bias depletion capacitance formula	-	0.5	
DELTA	Width effect on threshold voltage (MOS2 and MOS3)	-	0.0	1.0
THETA	Mobility modulation (MOS3 only)	$1/V$	0.0	0.1
ETA	Static feedback (MOS3 only)	-	0.0	1.0
KAPPA	Saturation field factor (MOS3 only)	-	0.2	0.5
TNOM	Parameter measurement temperature	$^{\circ}C$	27	50

11.1 MOSFET devices

General form:

```
MXXXXXXX nd ng ns nb mname <m=val> <l=val> <w=val>
+ <ad=val> <as=val> <pd=val> <ps=val> <nrd=val>
+ <nrs=val> <off> <ic=vds, vgs, vbs> <temp=t>
```

Examples:

```
M1 24 2 0 20 TYPE1
M31 2 17 6 10 MOSN L=5U W=2U
M1 2 9 3 0 MOSP L=10U W=5U AD=100P AS=100P PD=40U PS=40U
```

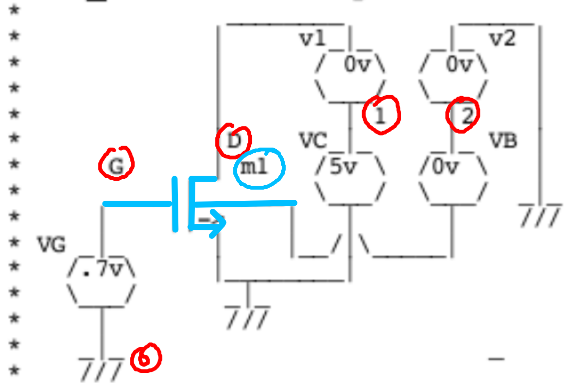
Note the suffixes in the example: the suffix “u” specifies microns (1e-6 m) and “p” sq-microns (1e-12 m^2).

The instance card for MOS devices starts with the letter M. **nd**, **ng**, **ns**, and **nb** are the drain, gate, source, and bulk (substrate) nodes, respectively. **mname** is the model name and **m** is the multiplicity parameter, which simulates “m” paralleled devices. All MOS models support the “**m**” multiplier parameter. Instance parameters **l** and **w**, channel length and width respectively, are expressed in meters. The areas of drain and source diffusions: **ad** and **as**, in squared meters (m^2).

If any of **l**, **w**, **ad**, or **as** are not specified, default values are used. The use of defaults simplifies input file preparation, as well as the editing required if device geometries are to be changed. **pd** and **ps** are the perimeters of the drain and source junctions, in meters. **nrd** and **nrs** designate the equivalent number of squares of the drain and source diffusions; these values multiply the sheet resistance **rsh** specified on the `.model` control line for an accurate representation of the parasitic series drain and source resistance of each transistor. **pd** and **ps** default to 0.0 while **nrd** and **nrs** to 1.0. **off** indicates an (optional) initial condition on the device for dc analysis. The (optional) initial condition specification using **ic=vds,vgs,vbs** is intended for use with the **uic** option on the `.tran` control line, when a transient analysis is desired starting from other than the quiescent operating point. See the `.ic` control line for a better and more convenient way to specify transient initial conditions. The (optional) **temp** value is the temperature at which this device is to operate, and overrides the temperature specification on the `.option` control line.

The temperature specification is ONLY valid for level 1, 2, 3, and 6 MOSFETs, not for level 4 or 5 (BSIM) devices.

NMOS_PSCBE1   pscbe1=1.79e+08   2.79e+08 3.79e+08




```
.OPTIONS   GMIN=1e-15    METHOD=gear   ABSTOL=1e-15
*======== ====== ====== ====== ====== ====== ====== ====== ======
Vds        D      0      dc      .1v
Vgs        G      0      dc      1.2v
Vbs        2      B      dc      0v
v1         D      1      dc      0v
v2         0      [illegible]      dc      0v
m1         1      G      0       B      N1     W=3u   L=1u AD=7p AS=7p PD=10u PS=10u
```