

S-DEMON 3.1 USER'S MANUAL

M. A. Stettler
A. Das
M. S. Lundstrom

School of Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana 47907
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S-DEMON (Version 3.1) is a computer program that simulates electron transport through Silicon *DE*vices by the *MON*te Carlo technique. The program will print and plot histograms of the carrier distribution function at different positions as well as other quantities of interest such as the average velocity, carrier density, and energy. For a more thorough discussion of the theoretical basis and the implementation of S-DEMON, the user is directed to the references [1-7]. Material parameters taken from reference [7].

This text begins with general notes on installing and running S-DEMON. Next, a description of the input file format is given, followed by a complete list of the program commands. Appendix A lists the default input file. Appendix B gives several examples of input files. Appendix C discusses the output format, and presents some actual output generated from one of the input files in Appendix B.

The development of S-DEMON was supported by the Semiconductor Research Corporation. Version 3.1 updates include: (i) include files were added for the common blocks (by Carl Huster), (ii) energy histograms were added (by Farzin Assad), (iii) backscattering parameters were computed (by Mark Lundstrom). The final code was put together by Brad Barrett.

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S-DEMON INSTALLATION NOTES

S-DEMON is coded in standard FORTRAN 77, and runs in the UNIX environment. At Purdue S-DEMON runs on a Sun workstation, a computer with a single precision word length of 32 bits. All of the calculations are performed using double precision arithmetic. In addition, real numbers as small as $\approx 10^{-60}$ are used. Some systems, for example the VAX 11/780 running UNIX, cannot represent real numbers smaller than $\approx 10^{-38}$. To install S-DEMON on other computers, some modifications may be required. These notes give some basic guidelines for installing the program in a general unix system.

Currently, all implemented code is consistent with FORTRAN 77 guidelines. One external subroutine library is used:

IMSL version 10.0: the International Mathematical and Statistical Library

S-DEMON uses two IMSL routines: DRNUNF, a double precision uniform (0,1) random number generator, and DRNNOF, a double precision normal random deviate (or gaussian) number generator. These routines can be substituted with others if IMSL is not available.

S-DEMON is supplied with a number of files. The subroutine file, *profiles.f* contains the routines UDOP, UFIELD, and UMAT, which the user can rewrite to define his or her own doping, electric field, or material profiles. To compile S-DEMON on a UNIX system, the statement used is:

make

If the subroutines UDOPE, UMAT, or UFIELD need to be used, they would be modified by editing *profiles.f*, and then remaking the executable.

The program is executed by the command:

sdemon < infile > table

where *sdemon* is the compiled program, *infile* is the file containing the input file, and *table* is the file to which the output tables will be written. In a non-UNIX environment, different file handling procedures may need to be employed.

The output of the program is in four files:

table the output file specified on the program execution line

mc.table_tagname where "tagname" is a user defined name in the SAVE card

mc.histo_tagname where "tagname" is same name as above

mc.ehisto_tagname where "tagname" is same name as above

Appendix C discusses the contents of each of these files and shows some example output.

INPUT FILE FORMAT

S-DEMON is run by specifying program commands in a file containing the "input file." The construction of the input file is loosely based on the FORTRAN NAMELIST statement. An input "card" is basically a title used to organize the program commands and assignment statements, which are referred to as "keys". S-DEMON has 10 cards, each with several keys assigned to it. The format of a card is:

```
NAME KEY1=VALUE1, KEY2=STRING2, ..., KEYn=VALUEn
+ ARRAY1=VA1/VA2/VA3/VA4, ARRAY2=WA1/WA2
+ ARRAY2=WA3/WA4
```

Each card begins in column 1 with its name; a card may be up to 5 lines long. If a card is longer than one line, the continuation symbol, +, must appear in column 1 for lines 2, 3, 4, etc. Commas or blanks are assumed to be separators; any number of separators may appear between assignments. *However, do not use tabs anywhere in the input file.* An assignment cannot contain any blanks, i.e.

```
KEY1= - 12.0
```

is not valid. The above assignment should read:

```
KEY1=-12.0
```

Values are assigned to arrays by separating the values by /'s. In the example card shown above, values are defined for ARRAY1(1), ARRAY1(2), ARRAY1(3), ARRAY1(4), for ARRAY2(1), ARRAY2(2), and for ARRAY2(3) and ARRAY2(4). Any parameter that does not appear in the card assumes its default value. Only those keys that are changed from their default value need to be specified. If the default values are used for all parameters of the card, the card need not appear.

Special care should be taken when continuing cards since array elements cannot be continued across lines. For example, the following card is NOT ALLOWED:

```
NAME KEY1=VALUE1, KEY2=STRING2, ..., KEYn=VALUEn
+ ARRAY1=VA1/VA2/VA3/VA4, ARRAY2=WA1/WA2/
+ WA3/WA4
```

The array should either be contained on one line or continued as shown above in the first example.

The input file consists of a title card followed by several others. The *TITLE card, which consists of up to 80 characters, is basically just a comment line; however, it must not be omitted. See Appendix B for its correct use. For the other cards, order is not significant. On the following pages, the keys for these cards are briefly described.

GRID

The grid card is used to specify the number of spatial bins in the structure. Simulation statistics (e.g. average velocity, energy, etc.) are collected for each bin. More bins will give better spatial resolution to the results at the expense of greater computation time.

The GRID keys are:

BINS

The number of bins into which the device is to be divided. Allowed values are integers between 1 and 100. Default value: BINS=30

HISTBINS(i)

Sets the location of the velocity and energy distribution histograms. Ensemble velocity and energy distributions may be accumulated at four locations in the device. Proper values for HISTBINS(i) are integers between 1 and BINS. If HISTBINS(i) is specified, all four values must be given in non-descending order. Default value: $\text{HISTBINS} = 1/\frac{1}{3} \cdot \text{BINS}/\frac{2}{3} \cdot \text{BINS}/\text{BINS}$

SOLVE

The SOLVE card is used to specify solution criteria for the simulation. The values of these parameters should be chosen carefully since they affect the accuracy of the solution.

The SOLVE keys are:

CARRIERS

The total number of particles to be simulated. To obtain accurate solutions, CARRIERS should be set to at least 2000 or more. Default value: CARRIERS=2000

TSAMPLE

The sampling time interval in seconds. Carrier statistics are collected each TSAMPLE seconds. TSAMPLE should be specified small enough so that a carrier does not skip over a bin between sampling times. Default value: TSAMPLE=1.0e-15

GAMMA

GAMMA is the self-scattering rate in seconds. GAMMA should be chosen so that the largest scattering rate that occurs in the structure is less than $1./\text{GAMMA}$. Specifying GAMMA too small, however, will increase computation time. Default value: GAMMA=1.0e-14

SEED

A real, positive number used to initiate the random number sequence for the simulation. Changing SEED will change the specific trajectories of the carriers, but average values after a large number of carriers should not be affected. Using the same seed value will guarantee reproducible results. Default value: SEED=43.6539

DEVICE

The DEVICE card is used to specify certain device-related parameters for the simulation such as the device length and operating temperature. An external file, perhaps generated from another simulation program, that defines the entire device structure can also be assigned here.

The DEVICE keys are:

TEMP

A real variable that specifies the operating temperature in degrees Kelvin. Default value: TEMP=300.0

LENGTH

The device length in micrometers. This key should be set unless the FILE key is used, in which case XMAX and XMIN should be set. Note that the device is assumed to be directed along the z-axis in real space. Default value: LENGTH=1.0

FILE

A string identifying a data file that is to be used for defining the device structure. The format of the file, which contains position, doping density, and the field, is described in subroutine RUFIELD. If a FILE is specified, it overrides the pertinent keys on the FIELD and DOPING cards except for the UDEFINE keys; in which case the FILE values for field, doping can still be overridden by the user-defined subroutines UDOPE and UFIELD if the appropriate keys are set TRUE. Default value: FILE=*****

XMIN

A portion of the data in FILE may be selected to define the device. The minimum position to be used is XMIN (in micrometers). This position of the data file will be translated to 0.0 for use in S-DEMON. Default value: XMIN=0.0

XMAX

The maximum position of the data in FILE that is to be used to specify the device. Default value: XMAX=1.0

FIELD

The FIELD card is used to specify the position-dependent field; the FIELD card is overridden in some situations by the DEVICE card.

The FIELD keys are:

XFIELD(i)

An array giving the right-most endpoint of the positions (in micrometers) where field is specified. See FIELD key description for an example. Note that the field must be specified at $x=\text{LENGTH}$. If UDEFINE is TRUE on the DEVICE card, then the field is read from a file instead. Default value: XFIELD=1.0

FIELD(i)

An array giving the field in volts per centimeter at each of the points specified in the XFIELD array. Up to five intervals each containing constant fields may be specified. For more detailed profiles use the UDEFINE key on this card or the FILE key on the DEVICE card. For instance, if XFIELD=.25/.5/.75 and FIELD=-1.e3/-2.e3/-1.e3, a -1.e3 V/cm field will be assigned from $x=0.0$ to $x=.25$ microns and from $x=0.5$ to $x=.75$ microns, with a -2.e3 V/cm field in between (negative fields accelerate electrons in the positive z direction). Default value: FIELD=-1000.0

DIRECT

Specifies the crystallographic orientation of the applied field. Allowable values are 100 and 111. Default value: DIRECT=100.

UDEFINE

A logical variable that, if true, tells the program that the user is supplying a FORTRAN subroutine UFIELD (an example is already located within the main program) to define the field versus position. Default value: UDEFINE=FALSE

DOPING

The DOPING card is used to specify the position-dependent donor and acceptor concentrations and related parameters. The DOPING card is overridden in some situations by the DEVICE card. Note that a simple scattering model is used for ionized impurity scattering which does not distinguish between minority and majority electrons. The number of scattering centers is just $N_A + N_D$, and the term $\left| N_A - N_D \right|$ is used to find the Debye length.

The DOPING keys are:

XSTEP(i)

Doping profiles consisting of up to 5 piece-wise intervals of constant doping may be specified. For more detailed profiles, use the UDEFINE key or the FILE key on the DEVICE card. XSTEP(i), where $1 \leq i \leq 5$, specifies the right endpoint (in microns) of the i^{th} section. Default value: XSTEP(1)=1.0

NASTEP(i)

The donor concentration per cubic centimeter in the i^{th} section. NASTEP(i) must be ≥ 0 . Default value: NASTEP(1)=0.0

NDSTEP(i)

The acceptor concentration per cubic centimeter in the i^{th} section. NDSTEP must be ≥ 0 . Default value: NDSTEP(1)=0.0

UDEFINE

A logical variable that, if true, tells the program that the user is supplying a FORTRAN subroutine UDOPE (an example is already located in the main program) to define the donor and acceptor concentrations versus position. Default value: UDEFINE=FALSE

CONTACT

The nature of the contact from which electrons will be injected (at $x=0.0$) is specified on this card.

The CONTACT keys are:

FRONT

A string that identifies the desired electron energy distribution injected at the front contact. If FRONT=MAXWELL, electrons injected at $z=0$ are selected from a Maxwellian distribution. If FRONT=VMAXWELL, the electrons are selected from a Maxwellian distribution weighted by the \hat{z} component of the velocity. If FRONT=DELTA, electrons are injected at $z=0$ from a delta function distribution. The energy at which the delta function is located is specified in the RAMP key. If FRONT=EFLUX, electrons are injected from an user specified distribution. To use this option, the user must create three external files called xflux, yflux, and zflux which specify the distribution function for each valley (see the definitions of XFRAC, YFRAC, and ZFRAC below). Each of these files should have two columns, the first should contain energy values (in eV) and the second the "weighted" distribution function corresponding to those energies. The weighting function can be normalized arbitrarily, with larger numbers signifying a proportionally higher probability that the corresponding energy will be selected. Default value: FRONT=VMAXWELL.

PBC

PBC is a logical variable that, if true, causes periodic boundary conditions to be used. An initial electron is chosen with energy $\frac{3}{2}k_B T$ at the front contact. This condition is useful for simulation of bulk material and periodic structures. If PBC=TRUE, the FRONT key is ignored. Default value: PBC=FALSE.

RAMP

Electrons may be injected from a launching ramp of height RAMP in electron volts at the front contact. RAMP represents the minimum energy for the Maxwellian distribution or the location in energy of the delta function when FRONT=DELTA. Default value: RAMP=0.00

XFRAC

The fraction (between 0.0 and 1.0) of the incoming carriers that reside in the valleys along the x-axis (<100> direction) in k-space. Default value: XFRAC=.333

YFRAC

The fraction (between 0.0 and 1.0) of the incoming carriers that reside in the valleys along the y-axis (<010> direction) in k-space. Default value: YFRAC=0.333

ZFRAC

The fraction (between 0.0 and 1.0) of the incoming carriers that reside in the valleys along the z-axis (<001> direction) in k-space. Default value: ZFRAC=0.333

PRINT

The PRINT card specifies the desired printed output.

The PRINT keys are:

TABLE

A logical variable that, if true, specifies that a table of quantities of interest (e.g. average velocity, carrier density, energy, etc.) versus position be printed. See Appendix C for the information contained in the table. Default value: TABLE=TRUE

NMAX

Sets the maximum carrier concentration (in units of cm^{-3}) in the device. Default value: NMAX= 10^{16}

JMAX

Sets the maximum current density (in $amps/cm^2$). If JMAX is set greater than zero, then the NMAX key is ignored. Determined by NMAX in the default situation.

RATES

Prints a table of scattering rates versus energy. Up to four different rates can be requested. Proper syntax is RATES=SCAT/SCAT/SCAT/SCAT where SCATs should be replaced by the names of the scattering mechanisms requested. Allowable rate names are NAP (elastic nonpolar acoustic phonon), INABS (inelastic nonpolar acoustic phonon absorption), INEMS (inelastic nonpolar acoustic phonon emission), IONIMP (ionized impurity), GTYPE (intervalley scattering between valleys on the same axis in k-space), FTYPE (intervalley scattering between valleys on perpendicular axes in k-space), and TOTAL (total scattering rate). Default: No rates are printed

SIZE

Sets the size of the subhistories. A subhistory is a specific number of samples of carrier statistics. The number of subhistories per bin is printed in the output files, and can be used to gauge the statistical significance of the results. Default value: SIZE=1000

FLUX

If FLUX=TRUE, the flux statistics are collected and printed. Default value: FLUX=FALSE.

SAVE

The SAVE card is used to store the computed results.

The SAVE keys are:

SAVE

Stores the output in files "mc.histo_tagname", "mc.ehisto_tagname", and "mc.table_tagname" for plotting. See Appendix C for the format of these files. If SAVE=FALSE these files are not created. Default value: SAVE=TRUE

TAG

A character string used to name the output files. Example: TAG=run1 and SAVE=TRUE would create the data files "mc.table_run1", "mc.histo_run1" and "mc.ehisto_run1" at the end of the simulation. The tag name must start with a letter and must be no long than eight characters. Default value: TAG=OUTMON

COMPUTE

The COMPUTE card is used to specify various computations to be performed during the simulation.

The COMPUTE keys are:

NPARA

Sets the conduction band energy model used in the simulation. If NPARA=TRUE, a nonparabolic E-k relationship is used. If NPARA=FALSE, a parabolic E-k relationship is used. Default value: NPARA=TRUE

VALLEY

A string that identifies the conduction band valley that is to be examined for evaluating ensemble averages. All valleys are treated during the simulation, but histograms and ensemble averages are computed only for the specified valley. Allowed values are VALLEY=X to examine the valleys on the x-axis (<100> direction in k-space) VALLEY=Y to examine the valleys on the y-axis (<010> direction in k-space), VALLEY=Z to examine the valleys on the z-axis (<001> direction in k-space), or VALLEY=ALL to consider all valleys. Default value: VALLEY=ALL

FAST

Specifies that fast self-scattering be used. Default value: FAST=TRUE

The following keys turn individual scattering mechanisms on or off. Disabling unimportant scattering mechanisms speeds execution of S-DEMON, and may simplify transport analysis in some situations.

INTVAL

A logical variable that enables equivalent INTerVALley scattering. Note that if INTVAL=FALSE, the carriers will stay in the valley they start out in; starting valley probabilities are controlled by the XFRAC, YFRAC, and ZFRAC keys on the CONTACT card. Default value: INTVAL=TRUE.

NAP

A logical variable that enables non-polar acoustic phonon intravalley scattering. The ELASTIC variable determines whether elastic or inelastic acoustic phonon scattering is used. Default value: NAP=TRUE.

ELASTIC

For low fields and temperatures set ELASTIC=FALSE to employ the more rigorous inelastic computations for non-polar acoustic phonon scattering. Default value: ELASTIC=TRUE.

IONIMP

A logical variable that enables ionized impurity scattering. If RIDLEY is not set to TRUE, the Brooks-Herring method will be used to perform the scattering calculations. Default value: IONIMP=TRUE.

RIDLEY

A logical variable that causes Ridley's third body exclusion scattering model to be used instead of Brooks-Herring. Default value: RIDLEY=FALSE.

BACKSCAT

A logical variable that specifies that a "backscattering histogram" is to be computed. For this analysis, electrons should be injected from the left contact only, and an absorbing right contact should be used. The program will produce a file, zmax.refl, which contains the number of electrons injected from the contact which have penetrated to a depth z , then eventually left (backscatter from the structure) from the injecting (left) contact. Default value: BACKSCAT=FALSE.

References

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- [5] C. Jacoboni, L. Reggiani, *Rev. Mod. Phys.*, Vol. 55, No. 3 (1983).
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APPENDIX A: DEFAULT INPUT FILE

The default input file is listed below.

```
*TITLE  DEFAULT INPUT FILE
GRID   BINS=30
SOLVE  CARRIERS=2000, GAMMA=1.0e-14, TSAMPLE=1.0e-15
+      SEED=43.6539
DEVICE  TEMP=300.0, LENGTH=1.0, FILE=*****
+      UDEFINE=FALSE, XMIN=0.0, XMAX=1.0
FIELD  XFIELD=0.0/1.0, FIELD=-1000./-1000., UDEFINE=FALSE
DOPING  XSTEP=1.0, NASTEP=0.0, NDSTEP=0.0
+      UDEFINE=FALSE
CONTACT FRONT=VMAXWELL, PBC=FALSE, RAMP=0.0,
+      XFRAC=.333, YFRAC=0.333, ZFRAC=0.333
PRINT  TABLE=TRUE, NMAX=1.0e16
SAVE   SAVE=TRUE, TAG=OUTMON
COMPUTE NAP=TRUE, ELASTIC=TRUE, INTVAL=TRUE,
+      IONIMP=TRUE, RIDLEY=FALSE, VALLEY=ALL,
+      NPARA=TRUE
```

APPENDIX B: EXAMPLE INPUT FILES

This is an example of an input file for the simulation of a long bulk region with a constant applied field. The boundary conditions are set periodic (PBC=TRUE) since the structure to be simulated is just bulk Si, therefore symmetric. Ionized impurity scattering is set to FALSE to speed execution, since there is no doping concentration specified. Note that the cards with no keys present are not required, but are shown merely to remind the user that default values are being assumed. The simulation described by this input file could be used to generate one point on a velocity-field characteristic.

```
*title  calculations for velocity-field
grid    bins=1
solve   carriers=4000
device  length=0.5 temp=300
field   xfield=.5 field=-.3e5
doping
contact pbc=true
print   table=true
save    save=true, tag=velofld
compute fast=false, intval=true, npara=true
+       nap=true, ionimp=false, valley=all
```

This input file was used for examining velocities of electrons in the y-axis valleys through a device with a spatially pulsed electric field. The BINS number is set to maximum (100) in order to get the best resolution of velocity per position in the device. GAMMA is reduced so that the self-scattering rate is above the large scattering rate induced by the high field region. TSAMPLE is reduced to compensate for the short bin length. Statistics are requested for the y valleys only, so VALLEY=Y.

```
*title  calculations for velocity-field
grid    bins=100
solve   carriers=2000, gamma=1.0e-15,tsample=5.0e-16
device  length=.75
field   xfield=.25/.5/.75, field=-5.e3/-1.e5/-5.e3
doping
contact
print   info=5,table=true
save    save=true, tag=pulse
compute fast=true, intval=true, npara=true
+       nap=true, ionimp=false, valley=y
```

This example demonstrates the application of a user defined field profile. The field profile of the base-collector junction in a model bipolar transistor has been specified by the user in the subroutine UFIELD (located in the main program of S-DEMON). The base is defined to extend from $x=0.$ to $x=.2$ microns and is doped 10^{18} cm^{-3} p-type. Bins where histograms are to be taken are listed in the HISTOGRAM key of the GRID card. The position of each bin corresponds with the device length divided by the total number of bins multiplied by the bin number (i.e. bin 25 is at .25 microns in the device for this example). The tabular output (abridged) from this simulation is displayed in APPENDIX C.

```
*title  calculations for base-collector junction
grid    bins=60 histbins=16/20/22/50
solve   carriers=4000, gamma=1.0e-15,tsample=5.0e-16
device  length=.60
field   udefine=true
doping  xstep=.20/.6 nstep=1.e18/0.0
contact pbc=false
print   info=5, table=true, rates=ionimp/total
save    save=true, tag=bjt
compute fast=true, intval=true, npara=true
+       nap=true, ionimp=true, valley=all
```

```
subroutine ufield(x,field)
```

```
c
c*****
c
c      UFIELD
c
c      User-defined subroutine which accepts the position in
c      microns (x) and returns the value of the field (field) at that point
c      in V/cm.
c
c*****
c
c      if(x.le. 0.20)then
c          field=-1.e3
c      else
c          field= -1.e5+(x-.20)*1.e5
c      endif
c      return
c      end
```

APPENDIX C: OUTPUT FORMAT AND EXAMPLE

S-DEMON results are stored in three output files. The files are:

1) TABLE : output file specified on the program execution line

Format:

(lines 1-15) the input file is printed

(lines 16-1018) optional; any requested scattering rates are printed

column 1: carrier energy (eV)

column 2-6: scattering rates (1/sec)

(lines 1020-?) the device structure is printed

column 1: bin number

column 2: position (microns)

column 3: N_D doping concentration (cm^{-3})

column 4: N_A doping concentration (cm^{-3})

column 5: electric field (V/cm)

(next lines) a table of the results is printed

column 1: bin number

column 2: position (microns)

column 3: number of subhistories taken in that bin

column 4: electron concentration (cm^{-3})

column 5: velocity (cm/sec)

column 6: total energy (eV)

column 7: z-directed kinetic energy (eV)

column 8: fraction of the electrons in the x valleys in k-space

column 9: fraction of the electrons in the y valleys in k-space

column 10: fraction of the electrons in the z valleys in k-space

column 11: current density (A/cm^2)

column 12: transit time to that position from left contact (10^{-9} sec)

(next lines) simulation summary, the information given is

companion data output files

device length

number of bins

bin width

number of carriers simulated

average collisions per carrier

number carriers absorbed by left contact

number carriers absorbed by right contact

number/percentage of scattering events by each scattering mechanism

If SAVE=TRUE, these external files will be printed:

2) MC.TABLE_TAG : plotting file, tag name specified in the SAVE card

Format:

column 1: bin number
column 2: position (microns)
column 3: number of subhistories taken in that bin
column 4: electron concentration (cm^{-3})
column 5: velocity (cm/sec)
column 6: total energy (eV)
column 7: z-directed kinetic energy (eV)
column 8: fraction of the electrons in the x valleys in k-space
column 9: fraction of the electrons in the y valleys in k-space
column 10: fraction of the electrons in the z valleys in k-space
column 11: current density (A/cm^2)
column 12: transit time to that position from left contact (10^{-9} sec)
column 13: electric field (V/cm)

3) MC.HISTO_TAG : velocity histogram plotting file, tag name specified in the SAVE card

Format:

column 1: velocity (cm/sec)
column 2: normalized no. of samples at each velocity at first specified bin
column 3: normalized no. of samples at each velocity at second specified bin
column 4: normalized no. of samples at each velocity at third specified bin
column 5: normalized no. of samples at each velocity at fourth specified bin

Note: bin positions are specified in GRID card under the key HISTBINS

3) MC.EHISTO_TAG : energy histogram plotting file, tag name specified in the SAVE card

Format:

column 1: energy (cm/sec)
column 2: normalized no. of samples at each energy at first specified bin
column 3: normalized no. of samples at each energy at second specified bin
column 4: normalized no. of samples at each energy at third specified bin
column 5: normalized no. of samples at each energy at fourth specified bin

Note: bin positions are specified in GRID card under the key HISTBINS

Some typical results generated from the third example in Appendix B. All of the text results are from the table output file and the plots (extensively edited) were made from the mc.table_bjt and mc.histo_bjt data files.

```
*title  calculations for velocity-field
grid    bins=60 histbins=16/20/22/50
solve   carriers=4000, gamma=1.e-15,tsample=5.e-16
device  length=.6 temp=300.
field   udefine=true
doping  xstep=.2/.6 nastep=1.e18/0.0
contact
print   table=true, size=1000
save    save=true, tag=bjt
compute fast=true, intval=true, ionimp=true
+       npara=true, nap=true, valley=all
```

*** device structure ***

```
bin  x(microns)  nd(/cm!3)  na(/cm!3)  field(v/cm)

 1  0.5000E-02  0.0000E+00  0.1000E+19  -.1000E+04
 2  0.1500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 3  0.2500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 4  0.3500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 5  0.4500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 6  0.5500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 7  0.6500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 8  0.7500E-01  0.0000E+00  0.1000E+19  -.1000E+04
 9  0.8500E-01  0.0000E+00  0.1000E+19  -.1000E+04
10  0.9500E-01  0.0000E+00  0.1000E+19  -.1000E+04
11  0.1050E+00  0.0000E+00  0.1000E+19  -.1000E+04
12  0.1150E+00  0.0000E+00  0.1000E+19  -.1000E+04
13  0.1250E+00  0.0000E+00  0.1000E+19  -.1000E+04
14  0.1350E+00  0.0000E+00  0.1000E+19  -.1000E+04
15  0.1450E+00  0.0000E+00  0.1000E+19  -.1000E+04
16  0.1550E+00  0.0000E+00  0.1000E+19  -.1000E+04
17  0.1650E+00  0.0000E+00  0.1000E+19  -.1000E+04
18  0.1750E+00  0.0000E+00  0.1000E+19  -.1000E+04
19  0.1850E+00  0.0000E+00  0.1000E+19  -.1000E+04
20  0.1950E+00  0.0000E+00  0.1000E+19  -.1000E+04
21  0.2050E+00  0.0000E+00  0.0000E+00  -.9950E+05
22  0.2150E+00  0.0000E+00  0.0000E+00  -.9850E+05
23  0.2250E+00  0.0000E+00  0.0000E+00  -.9750E+05
24  0.2350E+00  0.0000E+00  0.0000E+00  -.9650E+05
25  0.2450E+00  0.0000E+00  0.0000E+00  -.9550E+05
26  0.2550E+00  0.0000E+00  0.0000E+00  -.9450E+05
27  0.2650E+00  0.0000E+00  0.0000E+00  -.9350E+05
28  0.2750E+00  0.0000E+00  0.0000E+00  -.9250E+05
29  0.2850E+00  0.0000E+00  0.0000E+00  -.9150E+05
30  0.2950E+00  0.0000E+00  0.0000E+00  -.9050E+05
```

31 0.3050E+00 0.0000E+00 0.0000E+00 -.8950E+05
32 0.3150E+00 0.0000E+00 0.0000E+00 -.8850E+05
33 0.3250E+00 0.0000E+00 0.0000E+00 -.8750E+05
34 0.3350E+00 0.0000E+00 0.0000E+00 -.8650E+05
35 0.3450E+00 0.0000E+00 0.0000E+00 -.8550E+05
36 0.3550E+00 0.0000E+00 0.0000E+00 -.8450E+05
37 0.3650E+00 0.0000E+00 0.0000E+00 -.8350E+05
38 0.3750E+00 0.0000E+00 0.0000E+00 -.8250E+05
39 0.3850E+00 0.0000E+00 0.0000E+00 -.8150E+05
40 0.3950E+00 0.0000E+00 0.0000E+00 -.8050E+05
41 0.4050E+00 0.0000E+00 0.0000E+00 -.7950E+05
42 0.4150E+00 0.0000E+00 0.0000E+00 -.7850E+05
43 0.4250E+00 0.0000E+00 0.0000E+00 -.7750E+05
44 0.4350E+00 0.0000E+00 0.0000E+00 -.7650E+05
45 0.4450E+00 0.0000E+00 0.0000E+00 -.7550E+05
46 ...

[etc.]

*** table of results ***

bin	x(microns)	no. sub	n/cm ³	v(cm/sec)	u(eV)	uz(eV)	n(g)/n	n(l)/n	n(x)/n	j(a/cm ²)	t(psec)
1	0.5000E-02	1151	0.1000E+17	0.8204E+06	0.3866E-01	0.1284E-01	0.3336E+00	0.3406E+00	0.3258E+00	0.1315E+04	0.6094E+00
2	0.1500E-01	1084	0.9412E+16	0.8876E+06	0.4000E-01	0.1350E-01	0.3495E+00	0.3232E+00	0.3274E+00	0.1338E+04	0.1736E+01
3	0.2500E-01	1017	0.8836E+16	0.9511E+06	0.4007E-01	0.1360E-01	0.3412E+00	0.3272E+00	0.3316E+00	0.1346E+04	0.2787E+01
4	0.3500E-01	983	0.8530E+16	0.9913E+06	0.3931E-01	0.1344E-01	0.3174E+00	0.3446E+00	0.3380E+00	0.1355E+04	0.3796E+01
5	0.4500E-01	969	0.8409E+16	0.9897E+06	0.3937E-01	0.1324E-01	0.3229E+00	0.3345E+00	0.3426E+00	0.1333E+04	0.4807E+01
6	0.5500E-01	881	0.7654E+16	0.1090E+07	0.4062E-01	0.1386E-01	0.3011E+00	0.3433E+00	0.3557E+00	0.1337E+04	0.5724E+01
7	0.6500E-01	826	0.7176E+16	0.1182E+07	0.4094E-01	0.1417E-01	0.2955E+00	0.3586E+00	0.3460E+00	0.1359E+04	0.6570E+01
8	0.7500E-01	824	0.7156E+16	0.1163E+07	0.3999E-01	0.1344E-01	0.3149E+00	0.3507E+00	0.3345E+00	0.1334E+04	0.7430E+01
9	0.8500E-01	775	0.6737E+16	0.1252E+07	0.4110E-01	0.1378E-01	0.3404E+00	0.3417E+00	0.3179E+00	0.1351E+04	0.8228E+01
10	0.9500E-01	735	0.6380E+16	0.1325E+07	0.4020E-01	0.1356E-01	0.3429E+00	0.3304E+00	0.3267E+00	0.1354E+04	0.8983E+01
11	0.1050E+00	685	0.5947E+16	0.1406E+07	0.4061E-01	0.1361E-01	0.3472E+00	0.3299E+00	0.3229E+00	0.1339E+04	0.9695E+01
12	0.1150E+00	648	0.5636E+16	0.1489E+07	0.3984E-01	0.1338E-01	0.3566E+00	0.3436E+00	0.2998E+00	0.1344E+04	0.1037E+02
13	0.1250E+00	564	0.4905E+16	0.1716E+07	0.4121E-01	0.1426E-01	0.3493E+00	0.3493E+00	0.3014E+00	0.1348E+04	0.1095E+02
14	0.1350E+00	517	0.4497E+16	0.1865E+07	0.4058E-01	0.1390E-01	0.3401E+00	0.3615E+00	0.2984E+00	0.1343E+04	0.1149E+02
15	0.1450E+00	465	0.4047E+16	0.2072E+07	0.4067E-01	0.1388E-01	0.3168E+00	0.3560E+00	0.3272E+00	0.1343E+04	0.1197E+02
16	0.1550E+00	398	0.3467E+16	0.2418E+07	0.4089E-01	0.1420E-01	0.3128E+00	0.3724E+00	0.3147E+00	0.1343E+04	0.1238E+02
17	0.1650E+00	333	0.2898E+16	0.2908E+07	0.4175E-01	0.1456E-01	0.3324E+00	0.3673E+00	0.3003E+00	0.1350E+04	0.1273E+02
18	0.1750E+00	270	0.2362E+16	0.3586E+07	0.4404E-01	0.1519E-01	0.3446E+00	0.3334E+00	0.3220E+00	0.1357E+04	0.1300E+02
19	0.1850E+00	208	0.1817E+16	0.4644E+07	0.4558E-01	0.1543E-01	0.3089E+00	0.3456E+00	0.3454E+00	0.1352E+04	0.1322E+02
20	0.1950E+00	139	0.1225E+16	0.6948E+07	0.4610E-01	0.1657E-01	0.3137E+00	0.3397E+00	0.3466E+00	0.1363E+04	0.1336E+02
21	0.2050E+00	65	0.5762E+15	0.1461E+08	0.8840E-01	0.4637E-01	0.3417E+00	0.3359E+00	0.3223E+00	0.1349E+04	0.1343E+02
22	0.2150E+00	68	0.5989E+15	0.1411E+08	0.1436E+00	0.7396E-01	0.3724E+00	0.3207E+00	0.3070E+00	0.1354E+04	0.1350E+02
23	0.2250E+00	74	0.6634E+15	0.1266E+08	0.1850E+00	0.8570E-01	0.3782E+00	0.3258E+00	0.2961E+00	0.1346E+04	0.1358E+02
24	0.2350E+00	85	0.7492E+15	0.1131E+08	0.2155E+00	0.9268E-01	0.3863E+00	0.3098E+00	0.3038E+00	0.1357E+04	0.1367E+02
25	0.2450E+00	88	0.7771E+15	0.1094E+08	0.2379E+00	0.1024E+00	0.3851E+00	0.3042E+00	0.3107E+00	0.1362E+04	0.1376E+02
26	0.2550E+00	94	0.8222E+15	0.1032E+08	0.2651E+00	0.1100E+00	0.3815E+00	0.2973E+00	0.3211E+00	0.1359E+04	0.1386E+02
27	0.2650E+00	91	0.8047E+15	0.1047E+08	0.2876E+00	0.1188E+00	0.3709E+00	0.2993E+00	0.3298E+00	0.1349E+04	0.1395E+02
28	0.2750E+00	92	0.8148E+15	0.1036E+08	0.2949E+00	0.1208E+00	0.3573E+00	0.3027E+00	0.3400E+00	0.1352E+04	0.1405E+02
29	0.2850E+00	93	0.8177E+15	0.1041E+08	0.3093E+00	0.1266E+00	0.3344E+00	0.3037E+00	0.3619E+00	0.1364E+04	0.1415E+02

30	0.2950E+00	95	0.8293E+15	0.1024E+08	0.3113E+00	0.1243E+00	0.3682E+00	0.3058E+00	0.3260E+00	0.1361E+04	0.1424E+02
31	0.3050E+00	92	0.8175E+15	0.1028E+08	0.3187E+00	0.1308E+00	0.3869E+00	0.2963E+00	0.3168E+00	0.1346E+04	0.1434E+02
32	0.3150E+00	95	0.8351E+15	0.1015E+08	0.3129E+00	0.1252E+00	0.3858E+00	0.2943E+00	0.3199E+00	0.1358E+04	0.1444E+02
33	0.3250E+00	93	0.8247E+15	0.1028E+08	0.3077E+00	0.1232E+00	0.3863E+00	0.3130E+00	0.3006E+00	0.1358E+04	0.1454E+02
34	0.3350E+00	95	0.8421E+15	0.1006E+08	0.3107E+00	0.1250E+00	0.3942E+00	0.2985E+00	0.3073E+00	0.1357E+04	0.1464E+02
35	0.3450E+00	103	0.9020E+15	0.9445E+07	0.3007E+00	0.1175E+00	0.4278E+00	0.2716E+00	0.3007E+00	0.1365E+04	0.1474E+02
36	0.3550E+00	107	0.9438E+15	0.8942E+07	0.2979E+00	0.1146E+00	0.4120E+00	0.2973E+00	0.2906E+00	0.1352E+04	0.1485E+02
37	0.3650E+00	100	0.8882E+15	0.9583E+07	0.2993E+00	0.1173E+00	0.3803E+00	0.3115E+00	0.3083E+00	0.1364E+04	0.1496E+02
38	0.3750E+00	100	0.8807E+15	0.9641E+07	0.2839E+00	0.1097E+00	0.4140E+00	0.2940E+00	0.2920E+00	0.1360E+04	0.1506E+02
39	0.3850E+00	100	0.8829E+15	0.9558E+07	0.2900E+00	0.1146E+00	0.3881E+00	0.3201E+00	0.2918E+00	0.1352E+04	0.1517E+02
40	0.3950E+00	104	0.9147E+15	0.9192E+07	0.2832E+00	0.1116E+00	0.4065E+00	0.2966E+00	0.2968E+00	0.1347E+04	0.1528E+02
41	0.4050E+00	100	0.8785E+15	0.9649E+07	0.2817E+00	0.1100E+00	0.3969E+00	0.2807E+00	0.3224E+00	0.1358E+04	0.1538E+02
42	0.4150E+00	103	0.9070E+15	0.9363E+07	0.2753E+00	0.1079E+00	0.4236E+00	0.2644E+00	0.3120E+00	0.1361E+04	0.1549E+02
43	0.4250E+00	101	0.8895E+15	0.9621E+07	0.2752E+00	0.1072E+00	0.4053E+00	0.2876E+00	0.3071E+00	0.1371E+04	0.1559E+02
44	0.4350E+00	99	0.8652E+15	0.9777E+07	0.2762E+00	0.1082E+00	0.4241E+00	0.2922E+00	0.2837E+00	0.1355E+04	0.1569E+02
45	0.4450E+00	96	0.8503E+15	0.9944E+07	0.2700E+00	0.1060E+00	0.4077E+00	0.2980E+00	0.2944E+00	0.1355E+04	0.1579E+02
46	...										

[etc.]

*** s-demon summary ***

companion output files in: mc.table_bjt
mc.histo_bjt

device length: 0.60000 micrometers

spatial bins: 60

bin width: 0.10000E-01 micrometers

carrier simulated: 4000

ave collisions/carrier: 129.12925

carriers absorbed in left contact: 3373

carriers absorbed in right contact: 627

*** scattering mechanism summary ***

total scattering events: 11214441

self scattering events: 10697924 : 95.39

fast-self-scattering: 10596289 : 94.49

f-type intervalley: 16618 : 0.15

g-type intervalley: 45873 : 0.41

inelastic NAP absorption: 17885 : 0.16

inelastic NAP emission: 21931 : 0.20

ionized impurity: 414210 : 3.69