SOLVE

The **SOLVE** statement instructs Medici to perform a solution for one or more specified bias points.

```
SOLVE

 Initial Guesses, Biasing, and Fermi Potentials
   [ {INITIAL | PREVIOUS | PROJECT | LOCAL | P.LOCAL} ]
   [ {V(name1)=<n> | I(name1)=<n> | T(name1)=<n> | Q(name1)=<n>} ]....
   [ {V(name200)=<n> | I(name200)=<n> | T(name200)=<n> | Q(name200)=<n>} ]
   [N.REGION=<c>] [N.BIAS=<a>]
   [P.REGION=<c>] [P.BIAS=<a>]

 Steady State Analysis Parameters
   [ {  ( ELECTROD=<c> {VSTEP=<n> | ISTEP=<n>} NSTEPS=<n> )

 Continuation Method Parameters
      | ( CONTINUE ELECTROD=<c> C.VSTEP=<n> [ C.AUTO [C.TOLER=<n>] ]
          [C.VMIN=<n>] [C.VMAX=<n>] [C.IMIN=<n>] [C.IMAX=<n>]
          [C.DVMAX=<n>]
        )
 Transient Analysis Parameters
      | ( TSTEP=<n> {TSTOP=<n> | NSTEPS=<n>} [TMULT=<n>]
          [ {RAMPTIME=<n> | ENDRAMP=<n>} ] [DT.MAX=<n>]
        )
     }
   ]
 Hot Carrier and Parasitic Analysis Parameters
   [IMPACT.I] [GATE.CUR] [DQDV]

 Programmable Device AAM Parameters
   [FN.CUR]

 AC Small-Signal Analysis Parameters
   [ AC.ANALY FREQUENC=<n> [ FSTEP=<n> NFSTEP=<n> [MULT.FRE] ]
     [VSS=<n>] [TERMINAL=<c>]
     [S.OMEGA=<n>] [MAX.INNE=<n>] [TOLERANC=<n>] [HI.FREQ]
     [ S.PARAM [R.SPARA=<n>] ]
   ]
 Circuit Analysis AAM Parameters
   [ ELEMENT=<c> V.ELEMEN=<n> [VSTEP=<n> NSTEPS=<n>] ] [UIC]

 AC Analysis with a Circuit
   [ AC.ANALY FREQUENC=<n> AC.SOURC=<c>
     [ FSTEP=<n> NFSTEP=<n> [MULT.FRE] ]
   ]

 Output Choices
   [ OUT.FILE=<c> [SAVE.BIA]
     [ {  ( TIF [ALL] [BANDS] [CURRENTS] [GENERATI] [COMPONEN] )
        | ( [CURRENTS] [ASCII] [STRUCTUR=<c>] )
       }
     ]
   ]
```

(**SOLVE**, continued next page)

(**SOLVE**, continued from previous page)

```
 Optical Device AAM Parameters
   [ {  ( {  WAVE=<n>
           | ( [WAVE.STA=<n>] [WAVE.END=<n>] )
           | SPECTR
          }
        )
      | ( [FLUX=<n>]
          { [LAMBDA=<n>]
           | ( LAMBDA.S=<n> LAMBDA.E=<n> LAMBDA.N=<n> )
          }
        )
      | ( INTENSIT=<n> [INT.STEP=<n>] )
     }
   ]
   [L.MODULA  LSS=<n>]
```

Parameter	Type	Definition	Default	Units
Initial Guesses, Biasing, and Fermi Potentials				
INITIAL	logical	Specifies that the charge neutral assumption is used to compute the initial guess. This is the starting point for all device simulations.	True if no solution is available to use as an initial guess; otherwise, false.	
PREVIOUS	logical	Specifies that the previous solution is used as the initial guess. The previous solution is modified by setting the applied bias at the contacts. This is the default when a previous solution is available.	false	
PROJECT	logical	Specifies that a projection is used as the initial guess. This is the default when two previous solutions are available and the ratio of two successive bias steps is the same for each electrode where the bias has changed.	false	
LOCAL	logical	Specifies that local values of the quasi-Fermi potentials are used to compute an initial guess. This type of initial guess takes the previous solution, sets the applied bias, and then sets the majority carrier quasi-Fermi potentials to the applied bias throughout each region connected to an electrode by material of the same doping type.	false	
P.LOCAL	logical	Specifies that local quasi-Fermi potentials are used to compute the initial guess in heavily doped regions attached to electrodes, while the previous solution is used for the initial guess elsewhere. This type of initial guess may be helpful as an alternative to "previous" particularly when the heat equation is being solved.	False unless lattice temperature is being solved for.	
V(*name*)	number	The applied bias at the electrode specified by *name.* Any number of biases corresponding to electrodes can be specified on the same **SOLVE** statement.	Previous bias at electrode *name*	volts
I(*name*)	number	The terminal current at the electrode specified by *name*, if a current boundary condition was specified for this contact. Any number of terminal currents corresponding to electrodes can be specified on the same **SOLVE** statement.	Previous current at electrode *name*	amps/ micron

Parameter	Type	Definition	Default	Units
T(*name*)	number	The temperature at the thermal electrode specified by *name*. Values of temperature for multiple thermal electrodes can be specified on the same statement. This parameter is only used with the Lattice Temperature AAM.	Previous temperature at thermal electrode *name*	Kelvins
Q(*name*)	number	The charge at the electrode number specified by *name*, if a charge boundary condition was specified for this contact. The charge on multiple electrodes can be specified on the same statement. This parameter is only used with the Programmable Device AAM.	Previous charge at electrode *name*	Coulombs/ micron
N.REGION	char	The region names for which electron quasi-Fermi potentials are specified. If more than one region name is specified, separate their names with commas and enclose the entire group in parentheses (for example, "(substrate,drain)").	none	
N.BIAS	array	The electron quasi-Fermi potentials to use in the regions identified with **N.REGION**, if electrons are not being solved for. If more than one value is specified, separate each value with commas and enclose the entire group in parentheses (for example, "(5.0,3.0)"). Values specified here override any value established as a result of specifying **FIX.QF** on the **METHOD** statement.	Local quasi-Fermi potential based on bias and doping type.	volts
P.REGION	char	The region names for which hole quasi-Fermi potentials are specified. If more than one region name is specified, separate their names with commas and enclose the entire group in parentheses (for example, "(substrate,drain)").	none	
P.BIAS	array	The hole quasi-Fermi potentials to use in the regions identified with **P.REGION**, if holes are not being solved for. If more than one value is specified, separate each value with commas and enclose the entire group in parentheses (for example, "(5.0,3.0)"). Values specified here override any value established as a result of specifying **FIX.QF** on the **METHOD** statement.	Local quasi-Fermi potential based on bias and doping type.	volts
Steady State Analysis Parameters				
ELECTROD	char	The name of an electrode for which the applied bias or terminal current is stepped. To step more than one electrode, separate their names with commas and enclose the entire group in parentheses (for example, "(drain,gate,source)").	none	
VSTEP	number	The increment for the bias applied to one or more electrodes as specified by **ELECTROD**. If this parameter is specified, the bias at the specified electrode(s) is incremented **NSTEPS** times.	0.0	volts
ISTEP	number	The increment for the terminal current at one or more electrodes as specified by **ELECTROD**. If this parameter is specified, the current at the specified electrode(s) is incremented **NSTEPS** times.	0.0	amp/ micron
NSTEPS	number	The number of bias steps, current steps, or time steps to be performed.	0	none
Continuation Method Parameters				
CONTINUE	logical	Specifies that an automatic continuation procedure is used to trace I-V curves. This procedure automatically selects the bias step and switches from voltage to current boundary conditions as appropriate.	false	
C.VSTEP	number	Specifies the initial voltage step for the continuation method. If the value is > 0 the initial step is positive. If the value is less than 0 the initial steps in the negative voltage direction. **synonym: C.LENGTH**	none	volts
C.AUTO	logical	Specifies that automatic bias step selection is performed with the continuation method.	true	

Parameter	Type	Definition	Default	Units
C.TOLER	number	Local truncation error tolerance for continuation method. A smaller value causes the program to use more bias steps and produce a finer curve at the expense of CPU time. This parameter *does not* affect the accuracy of the computed points, only the spacing between them.	0.05	none
C.VMIN	number	Minimum terminating voltage for the continuation method. If the continuation method is tracing an I-V curve and the bias voltage at the electrode becomes less than this value, the tracing process is considered complete and the continuation terminates.	-5.0	volts
C.VMAX	number	Maximum terminating voltage for the continuation method. If the continuation method is tracing an I-V curve and the bias voltage at the electrode becomes greater than this value, the tracing process is considered complete and the continuation terminates.	5.0	volts
C.IMIN	number	Minimum terminating current for the continuation method. If the continuation method is tracing an I-V curve and the bias current at the electrode becomes less than this value, the tracing process is considered complete and the continuation terminates.	-1.0e-4	amps/ micron
C.IMAX	number	Maximum terminating current for the continuation method. If the continuation method is tracing an I-V curve and the bias current at the electrode becomes greater than this value, the tracing process is considered complete and the continuation terminates.	1.0e-4	amps/ micron
C.DVMAX	number	Maximum potential update allowed during continuation method. If the potential update exceeds this limit, the bias step is immediately reduced and the program tries again. This is useful because it stops the program from wasting time trying to solve for bias points that are not likely to converge. Since projection is used to find the initial guess during continuation, the potential updates are normally quite small and large updates indicate a possible problem.	50.0	kT/q

Transient Analysis Parameters

TSTEP	number	The time step between solutions. For simulations using automatic time step selection (see the **METHOD** statement), **TSTEP** is used to select the first time step only. All other time steps are chosen automatically by Medici.	none	seconds
TSTOP	number	The end of the time interval to be simulated.	none	seconds
TMULT	number	The multiplicative factor used to vary the size of successive time steps during a transient simulation when automatic time step selection is not used.	1.0	none
RAMPTIME	number	A time interval over which any bias change is applied as a linear ramp. If the ramp begins at time $t = t_0$, it ends at $t = t_0 +$ **RAMPTIME**.	0.0	seconds
ENDRAMP	number	The ending time for a period over which any bias change is applied as a linear ramp. If the ramp begins at time $t = t_0$, it ends at $t =$ **ENDRAMP**.	0.0	seconds
DT.MAX	number	Maximum time step as a ratio of the total simulation interval.	0.25	none

Hot Carrier and Parasitic Analysis Parameters

IMPACT.I	logical	Specifies that an impact ionization analysis is performed after each bias or time point is solved for.	false	
GATE.CUR	logical	Specifies that a gate current analysis is performed after each bias or time point is solved for.	false	

Parameter	Type	Definition	Default	Units
DQDV	logical	Causes Medici to calculate the capacitance at the electrodes. The capacitance is calculated by dividing the change in terminal charge by the change in voltage. This procedure gives one column of the capacitance matrix. This method can only be used if the voltage at one electrode is changed at a time, and if a previous solution resides in memory.	false	

Programmable Device AAM Parameters

FN.CUR	logical	Specifies that Fowler-Nordheim tunneling current is be calculated. During a transient analysis, the charge on any floating regions affected by this current is updated automatically. This parameter is only used with the Programmable Device AAM.	false	

AC Small-Signal Analysis Parameters

AC.ANALY	logical	Specifies that AC sinusoidal small-signal analysis is performed after the DC condition is solved for.	false	
FREQUENC	number	The frequency at which the AC small-signal analysis is performed.	none	Hz
FSTEP	number	The increment for frequency when performing an AC small-signal analysis at multiple frequencies. If **MULT.FRE** is not specified, the frequency for each analysis is obtained by adding **FSTEP** to the previous value of frequency. If **MULT.FRE** is specified, the frequency for each analysis is obtained by multiplying the previous value of frequency by **FSTEP**.	0.0	None if **MULT.FRE** is specified; otherwise, Hz.
NFSTEP	number	The number of additional frequencies at which an AC small-signal analysis is performed.	0	none
MULT.FRE	logical	Specifies that **FSTEP** is a multiplicative factor for incrementing frequency.	false	
VSS	number	The magnitude of the applied small-signal bias.	$0.1 \cdot KT/q$	volts
TERMINAL	char	The electrode(s) to which the AC bias is applied. More than one electrode may be specified, but each case is solved separately. To specify more than one electrode, separate them with commas, and enclose the entire group within parentheses (for example, "`(drain,gate,source)`").	all electrodes	
S.OMEGA	number	The SOR relaxation parameter used when solving the linear system during an AC small-signal analysis. This parameter is only used if **HI.FREQ** is false.	1.0	none
MAX.INNE	number	The maximum number of iterations when performing an AC small-signal analysis. **Default:** 25 or $2 \times max(35, \sqrt{3 \times nodes})$ if using **HI.FREQ**	See Definition	none
TOLERANC	number	The SOR convergence criterion when performing an AC small-signal analysis. If **HI.FREQ** is true, then this parameter specifies the Bi-CGSTAB convergence criterion when performing an AC small-signal analysis. The error norm is calculated as $\left\|(X_i - X_i^{'})/(X_i^{'})\right\|$ and represents the component-wise relative error in the solution vector. For a complete description please refer to Chapter 2, "ILUCGS Solver" on page 2-68.	1e-5	none
HI.FREQ	logical	Specifies that high frequency AC analysis mode is used. This option allows AC analysis at higher frequencies than the standard method of SOR iteration but it is much slower. When **HI.FREQ** is true, the AC system is solved using either Bi-CGSTAB or a direct method with iterative correction depending on whether a direct method or iterative method, respectively, is used for the DC solution. If **HI.FREQ** is not specified, the program tries SOR first, and if this method fails it automatically switches to the **HI.FREQ** method.	false	

Parameter	Type	Definition	Default	Units
S.PARAM	logical	Specifies that S-parameters should be calculated. If S-parameters are to be calculated then **TERMINAL** should be used to specify which electrodes are terminal "1" and terminal "2" (see below).	false	
R.SPARA	number	Transmission line impedance used in S-parameter calculation. Input the actual transmission line impedance multiplied by the device width.	50	Ohms × Microns

Circuit Analysis AAM Parameters

ELEMENT	char	A voltage or current source that has its voltage or current set to the value specified with the **V.ELEMEN** parameter. This parameter is only used with the Circuit Analysis AAM.	none	
V.ELEMEN	number	Specifies the voltage or current to be applied to the circuit element specified by the **ELEMENT** parameter. This value remains in effect for the remainder of the simulation. This parameter is only used with the Circuit Analysis AAM.	none	volts or amps
UIC	logical	Specifies that the voltages on the circuit nodes is forced to remain at the values specified on the **.IC** statement. This parameter is only used with the Circuit Analysis AAM.	false	

AC Analysis with a Circuit

AC.SOURC	char	Specifies the name of the AC small signal voltage or current source when AC analysis is performed with a circuit.	none	

Output Choices

OUT.FILE	char	The identifier for the file in which the solution information is saved. If multiple solutions are obtained from a single **SOLVE** statement, the last non-blank character of the supplied identifier is incremented in succession, resulting in a unique file for each solution. If necessary, the incrementing of the file identifiers extended to the characters prior to the last. **synonym: OUTFILE**	solution is not saved	
CURRENTS	logical	Specifies that electron, hole, and displacement current densities are written to the output file. For TIF files, the output also includes carrier velocities. For non-TIF files, the stored information, which also includes electric field and recombination, is only used with the **DIFFEREN** option on the **LOAD** statement.	false	
ASCII	logical	Specifies that the solution file is written as a formatted file.	false	
SAVE.BIA	logical	Specifies that solution files are only saved for the biases that **OUT.FILE** is specified for. That is, if a bias step is reduced because of convergence problems, solution files are not saved at the these additional bias points.	false	
STRUCTUR	char	Specifies which device data to write to the solution file. This parameter is only used with the Circuit Analysis AAM.	all devices	
TIF	logical	Specifies that the TIF format is used for the output file. The output automatically includes basic physical quantities such as doping, potential, carrier concentrations, carrier and lattice temperatures, electric field and total current density.	false	
ALL	logical	Specifies that all available physical quantities are written to the TIF file.	false	
BANDS	logical	Specifies that physical quantities associated with the band structure of the device are written to the TIF file. These include electron and hole quasi-Fermi potentials, and valence band, conduction band, and vacuum level potentials.	false	
GENERATI	logical	Specifies that impact ionization generation, band-to-band tunneling generation, photogeneration, and recombination are written to the TIF file.	false	

Parameter	Type	Definition	Default	Units
COMPONEN	logical	Specifies that components of vector quantities are written to the TIF file in addition to the magnitudes of these quantities.	false	

Optical Device Parameters

WAVE	number	Specifies the wavelength number from the sampling of wavelengths specified with the **WAVE.STA**, **WAVE.END**, and **WAVE.NUM** parameters on the **PHOTOGEN** statement. The charge generated within the device structure is only due to the selected wavelength number. If this parameter is not specified, the generation is due to the entire spectrum.	none	
WAVE.STA	number	Specifies the first of a series of wavelength numbers taken from the sampling of wavelengths specified with the **WAVE.STA**, **WAVE.END**, and **WAVE.NUM** parameters on the **PHOTOGEN** statement. A solution is performed for each wavelength number from **WAV.STA** through **WAV.END**. The charge generated within the device structure is only due to the specific wavelength number under consideration.	1	
WAVE.END	number	Specifies the last of a series of wavelength numbers taken from the sampling of wavelengths specified with the **WAVE.STA**, **WAVE.END**, and **WAVE.NUM** parameters on the **PHOTOGEN** statement. A solution is performed for each wavelength number from **WAV.STA** through **WAV.END.** The charge generated within the device structure is only due to the specific wavelength number under consideration.	**WAVE.NUM** from the **PHOTOGEN** statement	
SPECTR	logical	Specifies that a solution is to be performed for each of the wavelength numbers taken from the sampling of wavelengths specified with the **WAVE.STA**, **WAVE.END**, and **WAVE.NUM** parameters on the **PHOTOGEN** statement. The charge generated within the device structure is only due to the specific wavelength number under consideration.	false	
FLUX	number	Specifies that **PHOTOGEN** and **RAYTRACE** are to be reinitiated with the given light **FLUX** while the other parameters remain unchanged. The solutions are to be obtained for the photogeneration associated with this new wavelength. This is only for the monochrome ray.	none	photons/ cm^2-sec
LAMBDA	number	Specifies the wavelength for which ray tracing and photogeneration are reinitiated while the other parameters remain unchanged. The solutions are obtained using the photogeneration associated with this new wavelength.	none	micron
LAMBDA.S	number	Specifies the minimum wavelength for which ray tracing and photogeneration are reinitiated while the other parameters remain unchanged. Spectral simulations are reperformed.	none	micron
LAMBDA.E	number	Specifies the maximum wavelength for which ray tracing and photogeneration are reinitiated while the other parameters remain unchanged. Spectral simulations are reperformed.	none	micron
LAMBDA.N	number	Specifies the number of wavelengths between **LAMBDA.S** and **LAMBDA.E** for which ray tracing and photogeneration are reinitiated while the other parameters remain unchanged. Spectral simulations are reperformed.	none	none
INTENSIT	number	The light intensity to use for a new calculation of ray tracing and photogeneration. Unspecified ray tracing quantities retain the values specified on the **PHOTOGEN** statement. Solutions are to be obtained for the photogeneration associated with this new intensity.	none	Watts/ cm^2
INT.STEP	number	The light intensity step to use for new calculations of ray tracing and photogeneration. After an initial solution with the intensity given by **INTENSIT**, the intensity will be incremented by **INT.STEP** for each successive calculation for a total of **NSTEPS** additional steps.	none	Watts/ cm^2

Parameter	Type	Definition	Default	Units
L.MODULA	logical	Specifies that light modulation analysis is performed after the DC condition is solved for.	false	
LSS	logical	The magnitude of the applied small signal light intensity to be used with light modulation analysis.	none	Watts/ cm^2

Description

The **SOLVE** statement performs a solution for one or more specified bias points. The following sections discuss the various elements of the **SOLVE** statement including:

- Initial guesses
- Bias selection
- Circuit analysis
- Continuation method
- Transient simulations
- Post-Processing impact ionization
- Gate current
- AC small-signal analysis
- Optical analysis

See Also… To further illustrate the **SOLVE** statement, refer to:

- Input file *mdex1* in "Simulation of Gate Characteristics" on page 4-11
- Input file *mdex1g* in "Simulation of Gate Characteristics" on page 4-11
- Input file *mdex1d* in "Simulation of Drain Characteristics" on page 4-12
- Every other example where a solution is calculated

Initial Guesses

Medici automatically uses **INITIAL** as the initial guess for the first bias point for a given structure. For this bias point, 0 volts is assumed for any electrode where voltage is not specified.

If a previous solution exists, Medici uses it as the initial guess for the next solution. If two previous solutions are present and equivalent bias steps were taken for any electrode biases that were changed, a projection is used to obtain an improved initial guess for the next solution.

Bias Selection

The boundary conditions for the simulation to be performed are set by specifying the electrode applied biases:

- **V(DRAIN)**, **V(GATE)**, ..., **V(WHAT_EVER)**

or the terminal currents:

- **I(DRAIN)**, **I(SOURCE)**, ..., **I(ENOUGH)** at the contacts.

If terminal currents are specified at the contact, you should have previously specified this contact as one where current boundary conditions are to apply (see the **CONTACT** statement). If an electrode boundary condition is not specified, the previous bias or current is used by default.

Multiple Solutions

Multiple solutions with one **SOLVE** statement can be accomplished by specifying:

- Either the voltage or current step (**VSTEP** or **ISTEP**)
- The electrode(s) to be stepped (**ELECTROD**)
- The number of additional solutions to be performed (**NSTEPS**)

This is particularly convenient for obtaining I-V characteristics.

Synchronization in Saving Solutions

The **SAVE.BIA** parameter is useful in order to ensure synchronization of the reading and writing of solution files. This parameter forces writing of solution files only at bias, current, or time points actually specified. Solutions generated during a step cutback (due to nonconvergence) are not saved. For example, the following code fragment attempts to sweep multiple drain curves:

```
SOLVE  V(gate)=0  V(source)=0  V(drain)=0

$ Bias up the gate.
SOLVE  ELECTROD=gate  VSTEP=0.1  NSTEP=10  OUT.FILE=SOL01

$ Drain curves.
LOOP   STEPS=10
  ASSIGN  NAME=SFX  C.VAL=01  DELTA=1
  LOAD    IN.FILE="SOL"@SFX
  SOLVE  ELECTROD=DRAIN  VSTEP=0.5 NSTEP=20
L.END
```

If any bias point from the second **SOLVE** statement failed, then the filenames of solutions written would lose their intended correspondence to voltage (i.e., **SOLO1** $\rightarrow 0.1\text{v}$, **SOLO5** $\rightarrow 0.5\text{v}$). In order to enforce the correspondence, the **SAVE.BIA** parameter should be added to the second **SOLVE** statement:

```
SOLVE ELECT=gate VSTEP=0.1 NSTEP=10 OUT.F=SOL01 SAV.BIA
```

Circuit Analysis Parameters

Steady state or transient analysis may also be performed on circuits. If steady state analysis is performed then the **ELEMENT** parameter is used to specify the element

which is to be altered. This element may be a voltage source, current source or resistor. The value to be used for the element is specified with the **V.ELEMEN** parameter.

Multiple steps may be taken using **VSTEP** to determine the step size and **NSTEPS** to determine the number of steps.

Note:

The final value specified on the solve replaces the original value of the element.

For example, the following two **SOLVE** statements step source VCC and VDD from 0 to 5 and from 0 to 15 volts respectively. At the end of the simulation, VCC=5 and VDD=15 volts regardless of their original values of 7 and 3 volts.

```
VDD 1 0 7
VCC 2 0 3
SOLVE ELEMENT=VCC V.ELEMEN=0 VSTEP=1 NSTEP=5
SOLVE ELEMENT=VDD V.ELEMEN=0 VSTEP=3 NSTEP=5
```

Transient analysis with a circuit is very straightforward and is the same as simulation without circuit (see below). Voltage and current sources take on their time dependent values (see the V and I element).

Continuation Method

The continuation method can be used to trace difficult I-V characteristics such as those due to snap-back or latch-up. The continuation method automatically selects voltage or current boundary conditions based on the relative slope of the I-V characteristics and automatically selects bias points to resolve interesting features (refer to Chapter 2, "Continuation Method" on page 2-63 for more details).

User-Input

You are required to supply the following:

- The electrode (only one at a time) for which voltage and current is incremented
- The initial bias step to use (subsequent ones are selected by the program)

It is also wise to specify the terminating values for the voltage or current, although the defaults may be sufficient in some cases.

For example to step the drain from 1V to 10V with a maximum current of 1e-2 and an initial bias step of 0.5V, you would specify:

```
SOLVE   V(drain)=1 CONTINU ELECT=drain C.VSTEP=0.5 C.VMAX=10
+       C.IMAX=1E-2
```

Likewise, to start at 2V and to step to -5V with an initial voltage step of 0.3V with minimum and maximum currents of -3e-4 and 1e-5, respectively, the following statement could be used:

```
SOLVE  V(drain)=2  CONTINU  ELECT=drain  C.VSTEP=-0.3
+      C.VMIN=-5  C.VMAX=2  C.IMIN=-3e-4  C.IMAX=1e-5
```

Trace Back Problems

Occasionally the continuation method becomes confused at a sharp bend in an IV curve and traces back along the same path which it came up (see Figure 3-24). This problem can often be cured simply by reducing the continuation tolerance **C.TOLER** to a smaller value such as 0.01.

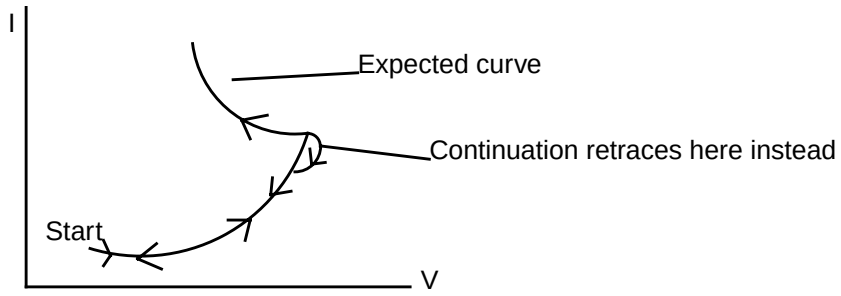

Figure 3-24 Continuation method becomes confused and retraces same curve

Transient Simulations

The Newton solution method must be used when performing a transient analysis. The use of the parameters relating to a transient analysis depend on the type of transient analysis which is being performed (see the **METHOD** statement).

A transient analysis is performed by specifying:

- The size of the initial time step with **TSTEP**
- The stopping time with **TSTOP**.

All intermediate time steps are calculated automatically, based on the size of the local truncation error. When automatic time step selection is not used, **TMULT** can be specified to increase or decrease the time step size for all successive steps.

Ramped Voltage or Current

A ramped voltage or current can be applied using one of two parameters:

- **RAMPTIME** specifies a time interval over which any bias change specified on the **SOLVE** statement is applied as a linear ramp.
- **ENDRAMP** causes the linear ramp to begin at the simulation time when the **SOLVE** statement is encountered, and ends at time t = **ENDRAMP**.

Post-Processing Impact Ionization

An impact ionization analysis is performed after each solution for which the parameter **IMPACT.I** is specified. This analysis calculates the generation rate at

each node of the simulation mesh based on the electric field and current densities at the most recently solved for bias or time point.

The generation rate is integrated over the entire device to arrive at a value for the total impact ionization current. For a MOS device, this may be interpreted as the substrate current due to impact ionization. This analysis also gives the location in the device structure where the generation rate is maximum, including the magnitude of electric field and current density at that location.

Gate Current

A gate current analysis is performed after each solution for which the parameter **GATE.CUR** is specified. This analysis calculates the electron, hole, and total current injected into all insulators present in the structure due to carriers capable of surmounting the insulator potential barrier.

Results of the gate current analysis are reported in the output file if the gate current is not negligible. An example of the output is:

```
Hot carrier injection analysis:
------------------------------

Electrode   Elec. Curr.     Hole Curr.    Tot. Current
              (A/um)          (A/um)        (A/um)
---------   ------------   ------------   ------------
Float_Gate  -1.5315E-11     0.0000E+00    -1.5315E-11
```

The hot carrier injection analysis reports that electrons are injected onto the floating gate with the current density of 1.5315E-11.

Fowler-Nordheim Tunneling Analysis

In addition to the hot-carrier contribution to the gate current turned on by the parameter **GATE.CUR**, a tunneling current analysis based on the Fowler-Nordheim model is performed after each solution for which **FN.CUR** is specified.

Results of the simulation are reported in the output file if the predicted current is not negligible. An example of the output is:

```
Fowler-Nordheim Tunneling Analysis:
-----------------------------------

Electrode        Tun. Current
                   (A/um)
---------        ------------
Float_Gate         7.6131E-12
S: Source         -7.6131E-12
```

In the example shown, tunneling occurs between the floating gate and a semiconductor region identified by "s:" before the number of the electrode attached to this region (in this case the source of the flash EEPROM). If the region is attached to more than one electrode, only the first two electrodes are reported.

AC Small-Signal Analysis

An AC sinusoidal small-signal analysis is performed after each DC solution whenever the parameter **AC.ANALY** is specified. The following parameters are used to delineate this process:

- The frequency at which to perform the analysis must be specified with **FREQUENC**.
- The analysis can be performed at a number of different frequencies (using the same DC solution) by using the parameters **FSTEP**, **NFSTEP**.

  Optionally, use **MULT.FRE** to increment the initial frequency by a multiplicative factor.
- Specify the magnitude of applied small-signal bias with the **VSS** parameter.

  This bias is applied separately to all contacts (the default) but may be applied only to selected contacts using the **TERMINAL** parameter.
- For high frequencies (approaching cutoff), if it is necessary to use a value of the SOR relaxation parameter less than unity, use the **S.OMEGA** parameter.
- To increase the value for the maximum number of SOR iterations allowed, use **MAX.INNE**.

Note:

The Newton solution method is required when performing AC small-signal analysis.

S-parameters

If S-parameters are requested, the program calculates these from the Y-parameters calculated by AC analysis.

- **TERMINAL** is used to specify which of the device electrodes are used for the S-parameter analysis (maximum of 2).
- **R.SPARA** is used to specify the characteristic transmission line impedance.

In order to obtain the correct S-parameters it is important to multiply the characteristic transmission line impedance by the actual device width (one micron). Note that Medici's default device width is one micron. As an example, if S-parameters for a BJT with width of 20 microns (in the z direction) are to be calculated at 100Mhz in the common emitter configuration with a characteristic transmission line impedance of 50 ohms:

```
SOLVE AC.ANAL FREQ=1e8 TERM=(BASE,COLLECT) S.PARA R.SPAR=50*20
```

AC Analysis with Circuit Simulation

If a simulation is performed with a circuit, then AC analysis may also be performed. The frequency and the source (either voltage or current) to which the AC voltage are applied are specified using the **FREQUENC** and **AC.SOURC** parameters.

The program then calculates the small signal voltages at all nodes in the circuit and the small signal currents in all inductors and voltage sources. For example, to apply an AC voltage at source VIN at frequencies of 1e6, 1e7, 1e8, and 1e9 Hz:

```
SOLVE AC.ANAL FREQ=1e6 AC.SOURC=VIN FSTEP=10 MULT NFSTEP=3
```

Optical Analysis

This section provides two examples of using the **SOLVE** statement in conjunction with ray tracing.

- Monochrome light DC response
- Multi-spectral light DC response

The light modulation analysis capability is also briefly described.

Monochrome Light DC Response

The following four **SOLVE** statements specify that solutions are to be obtained for the specified optical parameters:

```
SOLVE LAMBDA=0.7
SOLVE INTENSI=10
SOLVE FLUX=1e17
SOLVE LAMBDA=0.6 FLUX=1e20
```

For the first three **SOLVE** statements, ray tracing and the photogeneration calculation are repeated with the new wavelength (**LAMBDA**), intensity (**INTENSIT**) or photon flux (**FLUX**) as specified. The final **SOLVE** statement requests both a new wavelength and a new photon flux. For all four of the statements, unspecified ray tracing quantities retain their values from the previous **PHOTOGEN** statement.

Multi-Spectral Light DC Response

This example is similar to the monochrome example except that a spectral intensity file *AM0.DAT* (representing the AM0 spectrum of sunlight outside the atmosphere) is used:

```
PHOTOGEN  RAYTRACE  SP.FILE=AM0.DAT  WAVE.SCA=1E-3
+         WAVE.ST=0.2  WAVE.EN=0.8  WAVE.NUM=6
+         X.ORG=5  Y.ORG=190  ANGLE=-90
+         RAY.WIDT=10  RAY.NUM=1  TRANSPAR
+         INT.RATI=1E-2
SYMBOLIC  NEWTON  CARRIERS=2
SOLVE
SOLVE     WAVE=5
SOLVE     LAMBDA=0.55
SOLVE     LAMBDA.S=0.4  LAMBDA.E=0.6  LAMBDA.N=4
```

The above statements first perform photogeneration, ray tracing, and a solution with parameters as given on the **PHOTOGEN** statement. A solution is then obtained using only the carriers generated by the fifth wavelength from the sampling specified on the **PHOTOGEN** statement. Ray tracing is not repeated for this case, since the information is already available from the previous calculation.

The next **SOLVE** statement specifies **LAMBDA**=0.55. For this solution, ray tracing using the new wavelength is repeated, interpolating from the information in the spectral intensity file, *AM0.DATA,* if necessary. The calculation is repeated as if there were a new **PHOTOGEN** statement.

The last **SOLVE** statement is similar to the previous one, except that new calculations are requested for four different wavelengths between 0.4 μm and 0.6 μm.

Light Modulation Analysis

Light modulation analysis is requested by specifying the parameter **L.MODULA**. After a DC solution with photogeneration is obtained, light modulation analysis induces a sinusoidal optical generation at each node i such that:

$$G_{opt,i} = G_{opt,i0} + \tilde{G}_{opt,i} \exp(jwt)$$

where $G_{opt,i0}$ is the existing optical generation rate and $\tilde{G}_{opt,i}$ is the magnitude of the sinusoidal generation that depends on the light modulation magnitude specified with the parameter **LSS**. The frequency at which to perform the analysis, **FREQUENC**, must be specified. The analysis can be performed at different frequencies by using the parameters **FSTEP**, **NFSTEP**, and **MULT.FRE**.

3.3 Input/Output

The following statements print and plot results, write results to files, or read solutions from files.

Statement	Definition	Page
EXTRACT	Extracts selected data over device cross-sections.	3-160
PRINT	Prints values of a quantity over a device cross-section.	3-173
PLOT.1D	Plots a quantity along a line through the structure; plots terminal characteristics from data in a log file.	3-176
PLOT.2D	Initializes graphics display device; plots device boundaries, junctions, and depletion edges in two dimensions.	3-189
PLOT.3D	Initiates three-dimensional plots.	3-195
3D.SURFACE	Performs a three-dimensional surface projection plot.	3-203
CONTOUR	Plots two-dimensional contours of a quantity.	3-205
VECTOR	Plots current and field vectors over a device cross-section.	3-212
FILL	Fills areas of a two-dimensional plot.	3-217
E.LINE	Locates and plots potential gradient paths as part of a 2D plot; calculates and plots quantities along potential gradient paths as part of a 1D plot.	3-220
LABEL	Plots a line or character string on a 1D or 2D plot.	3-226
LOG	Specifies files for storing terminal and user-defined data.	3-231
LOAD	Reads a solution stored in a file.	3-236
SAVE	Writes solution or mesh information to a file.	3-239