HSPICE® RF User Guide

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HSPICE® RF User Guide, Y-2006.03-SP1

Contents

About This Manual

This manual contains detailed reference information, application examples, and design flow descriptions that show how HSPICE RF features can be used for RF circuit characterization. The manual supplements the HSPICE user documentation by describing the additional features, built on top of the standard HSPICE feature set, that support the design of RF and high-speed circuits. Where necessary, the manual describes differences that might exist between HSPICE RF and HSPICE.

Note:

> This manual discusses only HSPICE RF features. For information on other HSPICE applications, see the other HSPICE manuals, listed in The HSPICE Documentation Set on page xiv.

Inside This Manual

This manual contains the chapters described below. For descriptions of the other manuals in the HSPICE documentation set, see the next section, The HSPICE Documentation Set.

Chapter	Description
Chapter 1, HSPICE RF Features and Functionality	Introduces HSPICE RF features and functionality.
Chapter 2, Getting Started	Describes how to set up your environment, invoke HSPICE RF, customize your simulation, and redirect input and output.
Chapter 3, HSPICE RF Tutorial	Provides a quick-start tutorial for users new to HSPICE RF.
Chapter 7, Testbench Elements	Describes the specialized elements supported by HSPICE RF for high-frequency analysis and characterization.
Chapter 8, Steady-State Harmonic Balance Analysis	Describes how to use harmonic balance analysis for frequency-driven, steady-state analysis.

Chapter	Description
Chapter 9, Oscillator and Phase Noise Analysis	Describes how to use HSPICE RF to perform oscillator and phase noise analysis on autonomous (oscillator) circuits.
Chapter 10, Power-Dependent S Parameter Extraction	Describes how to use periodically driven nonlinear circuit analyses as well as noise parameter calculation.
Chapter 11, Harmonic Balance-Based AC and Noise Analyses	Describes how to use harmonic balance-based AC analysis as well as nonlinear, steady-state noise analysis.
Chapter 12, Envelope Analysis	Describes how to use envelope simulation.
Chapter 13, Post-Layout Analysis	Describes the post-layout flow, including post-layout back-annotation, DSPF and SPEF files, linear acceleration, check statements, and power analysis.
Chapter 14, Using HSPICE with HSPICE RF	Describes how various analysis features differ in HSPICE RF as compared to standard HSPICE.
Chapter 16, Advanced Features	Describes how to invoke HSPICE RF and how to perform advanced tasks, including redirecting input and output.

The HSPICE Documentation Set

This manual is a part of the HSPICE documentation set, which includes the following manuals:

Manual	Description
HSPICE Simulation and Analysis User Guide	Describes how to use HSPICE to simulate and analyze your circuit designs. This is the main HSPICE user guide.
HSPICE Signal Integrity Guide	Describes how to use HSPICE to maintain signal integrity in your chip design.

Manual	Description
HSPICE Applications Manual	Provides application examples and additional HSPICE user information.
HSPICE and HSPICE RF Command Reference	Provides reference information for HSPICE commands.
HPSPICE Elements and Device Models Manual	Describes standard models you can use when simulating your circuit designs in HSPICE, including passive devices, diodes, JFET and MESFET devices, and BJT devices.
HPSPICE MOSFET Models Manual	Describes standard MOSFET models you can use when simulating your circuit designs in HSPICE.
HSPICE RF Manual	Describes a special set of analysis and design capabilities added to HSPICE to support RF and high-speed circuit design.
AvanWaves User Guide	Describes the AvanWaves tool, which you can use to display waveforms generated during HSPICE circuit design simulation.
HSPICE Quick Reference Guide	Provides key reference information for using HSPICE, including syntax and descriptions for commands, options, parameters, elements, and more.
HSPICE Device Models Quick Reference Guide	Provides key reference information for using HSPICE device models, including passive devices, diodes, JFET and MESFET devices, and BJT devices.

Searching Across the HSPICE Documentation Set

Synopsys includes an index with your HSPICE documentation that lets you search the entire HSPICE documentation set for a particular topic or keyword. In a single operation, you can instantly generate a list of hits that are hyperlinked to the occurrences of your search term. For information on how to perform searches across multiple PDF documents, see the HSPICE release notes (available on SolvNet at http://solvnet.synopsys.com/ReleaseNotes) or the Adobe Reader online help.

Note:

To use this feature, the HSPICE documentation files, the Index directory, and the index.pdx file must reside in the same directory. (This is the default installation for Synopsys documentation.) Also, Adobe Acrobat must be invoked as a standalone application rather than as a plug-in to your web browser.

Other Related Publications

For additional information about HSPICE, see:

- The HSPICE release notes, available on SolvNet (see Known Limitations and Resolved STARs, below)
- Documentation on the Web, which provides PDF documents and is available through SolvNet at http://solvnet.synopsys.com/DocsOnWeb
- The Synopsys MediaDocs Shop, from which you can order printed copies of Synopsys documents, at http://mediadocs.synopsys.com

You might also want to refer to the documentation for the following related Synopsys products:

- CosmosScope
- Aurora
- Raphael
- VCS

Known Limitations and Resolved STARs

You can find information about known problems and limitations and resolved Synopsys Technical Action Requests (STARs) in the *HSPICE Release Notes* in SolvNet.

To see the *HSPICE Release Notes*:

1. Go to https://solvnet.synopsys.com/ReleaseNotes. (If prompted, enter your user name and password. If you do not have a Synopsys user name and password, follow the instructions to register with SolvNet.)
2. Click HSPICE, then click the release you want in the list that appears at the bottom.

Conventions

The following conventions are used in Synopsys documentation.

Convention	Description
`Courier`	Indicates command syntax.
`Italic`	Indicates a user-defined value, such as *`object_name`*.
`Bold`	Indicates user input—text you type verbatim—in syntax and examples.
[ ]	Denotes optional parameters, such as: `write_file [-f` *`filename`*`]`
`...`	Indicates that parameters can be repeated as many times as necessary: *`pin1 pin2 ... pinN`*
|	Indicates a choice among alternatives, such as `low | medium | high`
\	Indicates a continuation of a command line.
/	Indicates levels of directory structure.
Edit > Copy	Indicates a path to a menu command, such as opening the Edit menu and choosing Copy.
Control-c	Indicates a keyboard combination, such as holding down the Control key and pressing c.

Customer Support

Customer support is available through SolvNet online customer support and through contacting the Synopsys Technical Support Center.

Accessing SolvNet

SolvNet includes an electronic knowledge base of technical articles and answers to frequently asked questions about Synopsys tools. SolvNet also gives you access to a wide range of Synopsys online services, which include downloading software, viewing Documentation on the Web, and entering a call to the Support Center.

To access SolvNet:

1. Go to the SolvNet Web page at http://solvnet.synopsys.com.
2. If prompted, enter your user name and password. (If you do not have a Synopsys user name and password, follow the instructions to register with SolvNet.)

If you need help using SolvNet, click Help on the SolvNet menu bar.

Contacting the Synopsys Technical Support Center

If you have problems, questions, or suggestions, you can contact the Synopsys Technical Support Center in the following ways:

- Open a call to your local support center from the Web by going to http://solvnet.synopsys.com/EnterACall (Synopsys user name and password required).
- Send an e-mail message to your local support center.
  - E-mail support_center@synopsys.com from within North America.
  - Find other local support center e-mail addresses at http://www.synopsys.com/support/support_ctr.
- Telephone your local support center.
  - Call (800) 245-8005 from within the continental United States.
  - Call (650) 584-4200 from Canada.
  - Find other local support center telephone numbers at http://www.synopsys.com/support/support_ctr.

1 HSPICE RF Features and Functionality

Introduces HSPICE RF features and functionality.

HSPICE RF is a special set of analysis and design capabilities that support the design of RF and high-speed circuits. This functionality, built on top of the standard HSPICE feature set, is also useful for analog and signal integrity applications. Although the HSPICE and HSPICE RF simulators share a common set of device models and simulation capabilities, HSPICE RF includes several modeling, simulation, and measurement additions that augment the ultimate-accuracy analog circuit simulation capabilities of HSPICE.

Note:

> This manual describes the additional features and capabilities of HSPICE RF. Where necessary, the manual describes differences between HSPICE RF and HSPICE. For information about standard HSPICE device models, syntax, and simulation control, you can refer to one of the other HSPICE manuals in the HSPICE documentation set, listed in The HSPICE Documentation Set on page xiv.

HSPICE RF Overview

HSPICE RF consists of:

- The hspicerf simulation engine
- The CosmosScope (cscope) waveform display tool

The hspicerf simulation engine contains extensions to HSPICE for RF design. These extensions are in the form of new analysis commands and new elements. The hspicerf simulation engine processes command and element syntax for new RF simulation features but also accepts standard HSPICE netlist files as input.

The CosmosScope waveform display tool has been enhanced with special features for reading and analyzing data created by the HSPICE RF simulation engine. For a basic overview on how to use CosmosScope to view HSPICE RF output, see Using the CosmosScope Waveform Display on page 12.

HSPICE RF Features

This section briefly introduces the features of both the simulation engine and the waveform display tool.

HSPICE RF supports most HSPICE capabilities, and also includes:

- Steady-state frequency-domain analyses for linear and nonlinear circuits.
- High-performance transient analysis for faster simulation of high-speed digital and analog circuits.
- Port-wise automated `.AC` analyses for S (scattering) parameters. The `.LIN` command invokes extraction of noise and linear transfer parameters of a multi-port linear network. Extracts the S parameter and generates the N-port model.

  This command is used in conjunction with the `.AC` command to measure multiport S, Y, and Z parameters, noise parameters, stability and gain factors, and matching coefficients. Additionally, it is used with the Port element, which identifies the network ports and their impedances. You can also use mixed mode with `.LIN`.
- The Port (P) element identifies ports used in LIN analysis (multiport S, Y, or Z parameter and noise parameter extraction). A port element behaves as a noiseless impedance or a voltage source in series with an impedance, depending on the simulation being performed. Different impedances can be specified for DC, transient, AC, HB, and HBAC analyses.
- The S element describes a linear network using multi-port S, Y, or Z parameters in the form of a frequency table. These parameters can come from a `.LIN` simulation or from physical measurement. The standard Touchstone and CITIfile formats are supported in addition to a proprietary HSPICE format.
- The syntax of voltage and current sources as well as Port elements supports the syntax for specifying power sources. In this case, the source value is interpreted as a power value in Watts or dBm units, and the Port element is

implemented as a voltage source with a series impedance. The `.HBLSP` command invokes periodically driven nonlinear circuit analyses for power-dependent S parameters.

- Harmonic Balance (`.HB`) analysis using Direct and Krylov solvers. The `.HB` command invokes the single and multitone Harmonic Balance algorithm for periodic steady state analysis.
- `TRANFORHB` element parameter to recognize V/I sources that include SIN and PULSE transient descriptions as well as PWL and VMRF sources.
- Harmonic balance-based periodic AC analysis. The `.HBAC` command invokes periodic AC analysis for analyzing small-signal perturbations on circuits operating in a large-signal periodic steady state.
- Harmonic Balance-based Periodic Noise analysis (`.HBNOISE`) for noise analysis of periodically modulated circuits, includes stationary, cyclostationary, and frequency-dependent noise effects.
- Autonomous Harmonic Balance analysis. The `.HBOSC` command invokes the multitone, oscillator-capable Harmonic Balance algorithm for periodic steady state analysis.
- Perturbation analysis for Oscillator Phase Noise. The `.HBAC` command invokes phase periodic AC noise for oscillators circuits operating in a large-signal steady-state.
- Oscillator phase noise analysis, including both a nonlinear perturbation method and a PAC method, and includes stationary, cyclostationary, frequency-dependent, and correlated noise effects.
- Frequency translation S parameter and noise figure extraction with the `.HBLIN` command.
- Envelope analysis. The `.ENV` command: invokes standard envelope simulation. The `.ENVOSC` command invokes envelope startup simulation. The `.ENVFFT` command invokes envelope Fast Fourier Transform simulation.
- `.OPTION HBTRANINIT`, `HBTRANPTS`, and `HBTRANSTEP` for transient analysis of ring oscillators.
- Convolution for transient analysis of S parameter data models (S element).
- Calculation of the transfer function from an arbitrary source and harmonic in the circuit to a designated output with the `.HBXF` command.
- Reading encrypted netlists.

- `.OPTION SIM_ACCURACY` provides simplified accuracy control for all simulations while `.OPTION SIM_ORDER` and `SIM_TRAP` improve transient analysis simulation controls.
- DSPF Flow for fast analysis using parasitic data from layout.
- `.OPTION SIM_LA` provides linear acceleration for RC network reduction for faster simulation.
- Saving `.PRINT` simulation output to a separate file.
- `HERTZ` variable for frequency-dependent equations.
- `IC=OFF` in element statements, IC parameter (initial conditions).

HSPICE RF also adds the following measurement capabilities to HSPICE:

- Small-signal scattering parameters.
- Small-signal two-port noise parameters.
- 1 dB compression point.
- Intercept points (for example, IP2, IP3).
- Mixer conversion gain and noise figure.
- VCO output spectrum.
- Oscillator phase noise.

Options simplify specifying levels of accuracy. As a result, HSPICE RF provides effective simulation solutions for RF, high-speed, and PCB signal integrity circuit challenges.

HSPICE and HSPICE RF Differences

The following tables give an overview of which features (Table 1) and device models (Table 2 on page 7) in HSPICE are not supported in HSPICE RF.

Table 1 HSPICE Features Not in HSPICE RF

Feature	**See**
Read hspice.ini file.	*HSPICE Simulation and Analysis User Guide*
Short names for internal sub-circuits, such as 10:M1.	*HSPICE Simulation and Analysis User Guide*
.MODEL types: AMP and PLOT for graphs	*HSPICE and HSPICE RF Command Reference*
Parameter definition (.PARAM) for Monte Carlo statistical functions	*HSPICE and HSPICE RF Command Reference*
.PLOT simulation output	*HSPICE and HSPICE RF Command Reference*
.GRAPH simulation output (uses PLOT model type)	*HSPICE Simulation and Analysis User Guide* *HSPICE and HSPICE RF Command Reference*
.WIDTH, and .OPTION CO	*HSPICE Simulation and Analysis User Guide* *HSPICE and HSPICE RF Command Reference*
.OPTION ACCT	*HSPICE Simulation and Analysis User Guide* *HSPICE and HSPICE RF Command Reference*
Element template output	*HSPICE Simulation and Analysis User Guide*
Group time delay parameters in AC analysis output	*HSPICE Simulation and Analysis User Guide*
.DISTO distortion analysis and associated output commands	*HSPICE Simulation and Analysis User Guide*
.SAVE and .LOAD	*HSPICE and HSPICE RF Command Reference*

Table 1 HSPICE Features Not in HSPICE RF (Continued)

Feature	**See**
Options that activate unsupported features in HSPICE RF: FAST GSHDC GSHUNT LIMPTS OFF RESMIN TIMERES All version options	*HSPICE and HSPICE RF Command Reference*
Options ignored by HSPICE RF, because they are not needed since they are replaced by automated algorithms: ABSH ABSV ABSVAR BELV BKPSIZ CHGTOL CONVERGE CSHDC CVTOL DCFOR DCHOLD DCON DCSTEP DI DV DVDT FAST FS FT GMAX GRAMP GSHDC GSHUNT ICSWEEP IMAX IMIN ITL3 ITL5 ITLPZ LIMPTS LVLTIM MAXAMP MBYPASS NEWTOL RELH RELI RELQ RELV RELVAR TRTOL All matrix options	
All error options	*HSPICE and HSPICE RF Command Reference*
Some Transient/AC input/output (I/O) options. HSPICE RF *does* support POST and PROBE options.	
Sub-circuit cross-listing in a .pa file	*HSPICE Simulation and Analysis User Guide*, Chapter 3
-r command-line argument for a remote host	*HSPICE Simulation and Analysis User Guide*
.OP supports node voltage for any time, but supports element values *only* for t=0.	*HSPICE and HSPICE RF Command Reference*
Sensitivity analysis (.SENS)	*HSPICE Simulation and Analysis User Guide* *HSPICE and HSPICE RF Command Reference*

Table 1 HSPICE Features Not in HSPICE RF (Continued)

Feature	See
DC mismatch analysis (.DCMATCH)	*HSPICE Simulation and Analysis User Guide* *HSPICE and HSPICE RF Command Reference*

Table 2 Device Models Not in HSPICE RF

Model	See
B element: IBIS buffer— Bname n1 n2 [...] parameters	*HSPICE Signal Integrity Guide*
data-driven I element (current source)	*HSPICE Elements and Device Models Manual*
data-driven V element (voltage source)	*HSPICE Elements and Device Models Manual*
BJT LEVEL=10 (MODELLA)	*HSPICE Elements and Device Models Manual*, Chapter 5
MOSFET Levels 4-8.	*HSPICE MOSFET Models Manual*
Common Model Interface (CMI)	*HSPICE MOSFET Models Manual*

2
Getting Started

Describes how to set up your environment, invoke HSPICE RF, customize your simulation, redirect input and output, and use the CosmosScope waveform display tool.

Before you run HSPICE RF, you need to set up several environment variables. You can also create a configuration file to customize your simulation run.

HSPICE RF accepts a netlist file from standard input and delivers the ASCII text simulation results to HTML or to standard output. Error and warning messages are forwarded to standard error output.

Running HSPICE RF Simulations

Use the following syntax to invoke HSPICE RF:

```
hspicerf [-a] inputfile [outputfile] [-h] [-v]
```

For a description of the `hspicerf` command syntax and arguments, see section HSPICE RF Command Syntax in the *HSPICE and HSPICE RF Command Reference*.

Netlist Overview

The circuit description syntax for HSPICE RF is compatible with the SPICE and HSPICE input netlist format. For a description of an input netlist file and methods of entering data, see chapter Input Netlist and Data Entry in the *HSPICE Simulation and Analysis User Guide*.

Parametric Analysis Extensions

All major HSPICE RF analyses (`.TRAN`, `.AC`, `.DC`, and `.HB`) support the following parameter sweeps with the same syntax as standard HSPICE:

- LIN
- DEC
- OCT
- DATA
- POI

You can also use the `MONTE` keyword for a Monte Carlo analysis or the `OPTIMIZE` keyword for optimization.

Generating Output Files

HSPICE RF generates a table of simulation outputs.

- If the output is text (the default), the text is put into a .lis file.
- If you specify `.OPTION POST`, then HSPICE RF generates simulation output in a format suitable for a waveform display tool.
- The default output format for transient analysis in HSPICE RF is the same as in HSPICE: the .tr0 file format. For additional information, see Standard Output Files in the *HSPICE Simulation and Analysis User Guide*.

The Synopsys interactive waveform display tool, CosmosScope, can display both the text simulation results and binary output within the X-window environment.

All output functions (`.PRINT`, `.PROBE`, `.MEASURE`, and so on) can use power output variables in the form p(*devicename*), just as in HSPICE. You can also use the “power” keyword.

Larger output files from multi-million transistor simulations might not be readable by some waveform viewers. Options are available that enable you to limit the output file size. See Limiting Output Data Size on page 369 for more information.

HSPICE RF Output File Types

Table 3 shows the output file extensions that HSPICE RF analyses produce. The base file name of each output file is the same as the input netlist file's base name. The # at the end of each file extension represents the `.ALTER` run from which the file came.

In general, text output from `.PRINT` commands is intended to be read by humans, while binary output from `.PROBE` or `.OPTION POST` is intended to be read by the CosmosScope waveform display tool.

Table 3 HSPICE RF Output File Types

Command	Text Output	Output for CosmosScope
AC analysis (.AC)	.printac#	.ac#
AC noise analysis (.NOISE)	.printac#	.ac#
DC sweep (.DC)	.printsw#	.sw#
Envelope analysis (.ENV)	.printev#	.ev#
Envelope FFT (.ENVFFT)	.printev#	.ev#
Harmonic Balance (.HB)	.printhb#	.hb#
Harmonic Balance AC (.HBAC)	.printhb#	.hb#
.HBLIN analysis	.PRINT output: .printhl# S-param output: .SnP	.PROBE output: .hl# S-paramr output: .SnP
.HBLSP large-signal	.PRINT output: .printls# S-param output: .p2d#	.PROBE output: .ls# S-param output: .p2d#
.HBLSP small-signal	.PRINT output: .printss# S/noise output: .S2P#	.PROBE output: .ss# S/noise output: .S2P#
HBAC noise (.HBNOISE)	.printpn#	.pn#
Harmonic Balance OSC (.HBOSC)	.printhb#	.hb#

Table 3 HSPICE RF Output File Types

Command	**Text Output**	**Output for CosmosScope**
Harmonic Balance TRAN (.HBTRAN)	.printhr#	.hr#
Transfer Functions (.HBXF)	.printxf#	.xf#
Oscillator startup (.ENVOSC)	.printev#	.ev#
.LIN analysis	.PRINT output: .printac#; S/noise output: .sc#, .SnP, .citi#	.PROBE output: .ac#; S/noise output: .sc#, .SnP, .citi#
Phase Noise (.PHASENOISE)	.printpn#	.pn#
.SN analysis	.printsn#	.sn#
Transient analysis (.TRAN)	.printtr#	.tr#

Using the CosmosScope Waveform Display

CosmosScope has been enhanced to support viewing and processing of HSPICE RF output files. This section presents a basic overview of how to use CosmosScope to view HSPICE RF output.

- Type **cscope** on the UNIX command line to start the CosmosScope tool.
- Choose File > Open > Plotfiles (or just press CTRL-O) to open the Open Plotfiles dialog. Use the Files of Type filter to find the HSPICE RF output file that you want to open. Table 3 on page 11 lists the HSPICE RF file types. When you open a file, its contents appear in the Signal Manager window.
- The Signal Manager lists all open plot files. If you double-click a plot file name, a new window appears, showing the contents of that plot file. To plot one of the signals listed here in the active chart, double click on the signal label.
- To create a new chart, use the File > New menu. Select either XY Graph, Smith Chart, or Polar Chart. You can also use the first three icons in the toolbar to create new chart windows.

- To display the Signal Menu, right-click a signal label in a chart. Using this menu, you can change how signals look, delete signals, or move signals from one chart panel to another.
  - Use the Attributes menu item to control how the signal looks.
  - Use the Stack Region menu to move signals. You can move a signal to a new panel or an existing panel. The existing panels are named “Analog 0”, “Analog 1”, and so on; “Analog 0” is the bottom panel on a chart.
  - Use the To Time Domain command to convert a histogram plot (for example, from a .hb0 file) to a time domain signal.
- Right-click a horizontal or vertical axis to control an axis. Using the Axis Attributes dialog, you can use the Axis Menu to configure the axis precisely.
  - Use the Range submenu to zoom in or out.
  - Use the Scale submenu to switch between linear and logarithmic scales.
  - Lock Out New Signals creates an independent axis when you create a new panel.
  - Display Range Slider displays a region next to the axis. Click in that region to pan the display right, left, up, or down.
- To zoom in and out, use the Axis Attributes dialog, the zoom buttons on the tool bar, or the mouse directly on the chart window.
- To attach a marker to a signal, click on a signal label, then click the Vertical Marker or Horizontal Marker icons in the tool bar. You can use the mouse to drag the marker along the signal to see the signal’s precise value at different points.
- Choose Tools > Calculator to open the Waveform Calculator tool. This tool can be used to generate new waveforms from existing ones. It is described in detail in the *CosmosScope User Guide*. The waveform calculator has no RF-specific features.
- Tools>Measurement opens the Measurement Tool. Three RF measurements have been added, under the RF submenu of the measurement selection menu:
  - 1db compression point (1DB CP).
  - IIP3/OIP3.

    - Spurious free dynamic range (SFDR).

- Tools>RF Tool opens the RF Tool, which generates contour plots on Smith or Polar charts. In HSPICE RF, the plotfile must be a file with a .sc# extension that a `.LIN` command generates. HSPICE RF automatically finds the S parameter and noise parameter data in the .sc# file, and uses it to generate noise, gain, and stability circles.

3
HSPICE RF Tutorial

Provides a quick-start tutorial for users new to HSPICE RF.

This tutorial assumes you are familiar with HSPICE and general HSPICE syntax, but new to RF analysis features. The most basic RF analysis features are presented here, using simple examples.

Example 1: Low Noise Amplifier

The `.LIN` command simplifies the calculation of linear multi-port transfer parameters and noise parameters. In the LIN analysis, Port (P) elements are used to specify port numbers and their characteristic impedances. The analysis automatically computes the frequency-dependent complex transfer coefficients between ports. The result is a convenient means to get scattering parameters, noise parameters, stability parameters, and gain coefficients. The `.LIN` command essentially obsoletes the `.NET` command. The output from the `.LIN` command is saved in the *.sc0 file format that can, in turn, be referenced as a model file for the new S parameter element.

To set up a linear transfer parameter analysis, the HSPICE input netlist must contain:

- Use the `.AC` command to activate small-signal AC analysis, and to specify a frequency sweep. Also, use the `.AC` command to specify any other parameter sweeps of interest.
- Use the `.LIN` command with the `.AC` command to activate small-signal linear transfer analysis. The `.AC` command specifies the base frequency sweep for the LIN analysis. The LIN analysis automatically performs multiple AC and NOISE analyses, as needed to compute all complex signal transfer parameters.
- The necessary number of port (P) elements, numbered sequentially beginning with one to define the terminals of the multi-port network. For example, a two-port circuit must contain two port elements with one listed as port=1 and the other as port=2. The port elements define the ordering for the output quantities from the `.LIN` command (for example, the terminals for port=1 are used for S11, Y11, and Z11 measurements).

Much of the LIN analysis is automated so the HSPICE input netlist often does not require the following:

- AC signal sources. The `.LIN` command computes transfer parameters between the ports with no additional AC sources needed.
- DC sources. You can analyze a purely passive circuit without adding sources of any kind.

The following tutorial example shows how to set up a LIN analysis for an NMOS low noise amplifier circuit. This netlist is shipped with the HSPICE RF distribution as gsmlna.sp and is available in directory $<installdir>/demo/hspicerf/examples.

```
** NMOS 0.25um Cascode LNA for GSM applications
** setup for s-parameter and noise parameter measurements
.temp 27
.options post=2
.param   Vdd=2.3
.global gnd
**
** Cascode LNA tuned for operation near 1 GHz
**
M1 _n4 _n3 _n5 _n5 CMOSN l=0.25u w=7.5u as=15p ad=15p
+ ps=19u pd=19u m=80
M2 _n6 _n1 _n4 _n4 CMOSN l=0.25u w=7.5u as=15p ad=15p
+ ps=19u pd=19u m=80
```

```
M3 rfo _n6 gnd gnd CMOSN l=0.25u w=7.5u as=15p ad=15p
+ s=19u pd=19u m=40
r1 _vdd _n6 400
l1 _n5 gnd l=0.9nH
l2 rfin _n3 l=13nH
vvb _n1 gnd   dc=1.19 $ bias for common base device
vvdd _vdd gnd dc=Vdd
rfb rfo _n6 120 $ feedback
**
** 50 Ohm input port (incl. bias), 255 Ohm output port.
**
P1 rfin gnd port=1 z0=50 dc = 0.595 $ input port includes DC bias
P2 rfo _vdd port=2 z0=255 $ port doubles as pull-up resistor
**
** Measure s-parameters and noise parameters
**
.AC DEC 50 100MEG 5G
.LIN noisecalc=1 sparcalc=1
.PRINT S11(DB) S21(DB) S12(DB) S22(DB) NFMIN
**
** Approximate parameters for TSMC 0.25 Process (MOSIS run T17B)
**
.MODEL CMOSN NMOS             LEVEL   = 49
+VERSION   = 3.1   TNOM   = 27   TOX   = 5.8E-9
+XJ   = 1E-7   NCH   = 2.3549E17   VTH0   = 0.3819327
+K1   = 0.477867   K2   = 2.422759E-3   K3   = 1E-3
+K3B   = 2.1606637   W0   = 1E-7   NLX   = 1.57986E-7
+DVT0W   = 0   DVT1W   = 0   DVT2W   = 0
+DVT0   = 0.5334651   DVT1   = 0.7186877   DVT2   = -0.5
+U0   = 289.1720829   UA   = -1.300598E-9   UB   = 2.3082E-18
+UC   = 2.841618E-11   VSAT   = 1.482651E5   A0   = 1.6856991
+AGS   = 0.2874763   B0   = -1.833193E-8   B1   = -1E-7
+KETA   = -2.395348E-3   A1   = 0   A2   = 0.4177975
+RDSW   = 178.7751373   PRWG   = 0.3774172   PRWB   = -0.2
+WR   = 1   WINT   = 0   LINT   = 1.88839E-8
+XL   = 3E-8   XW   = -4E-8   DWG   = -1.2139E-8
+DWB   = 4.613042E-9   VOFF   = -0.0981658   NFACTOR   = 1.2032376
+CIT   = 0   CDSC   = 2.4E-4   CDSCD   = 0
+CDSCB   = 0   ETA0   = 5.128492E-3   ETAB   = 6.18609E-4
+DSUB   = 0.0463218   PCLM   = 1.91946   PDIBLC1   = 1
+PDIBLC2   = 4.422611E-3   PDIBLCB   = -0.1   DROUT   = 0.9817908
+PSCBE1   = 7.982649E10   PSCBE2   = 5.200359E-10   PVAG   = 9.31443E-3
+DELTA   = 0.01   RSH   = 3.7   MOBMOD   = 1
+PRT   = 0   UTE   = -1.5   KT1   = -0.11
+KT1L   = 0   KT2   = 0.022   UA1   = 4.31E-9
```

```
+UB1   = -7.61E-18   UC1   = -5.6E-11   AT   = 3.3E4
+WL   = 0   WLN   = 1   WW    = 0
+WWN   = 1   WWL   = 0   LL   = 0
+LLN   = 1   LW   = 0   LWN   = 1
+LWL   = 0   CAPMOD   = 2   XPART   = 0.5
+CGDO   = 5.62E-10   CGSO   = 5.62E-10   CGBO    = 1E-12
+CJ   = 1.641005E-3   PB   = 0.99   MJ   = 0.4453094
+CJSW   = 4.179682E-10   PBSW   = 0.99   MJSW   = 0.3413857
+CJSWG   = 3.29E-10   PBSWG   = 0.99   MJSWG   = 0.3413857
+CF   = 0   PVTH0   = -8.385037E-3   PRDSW   = -10
+PK2   = 2.650965E-3   WKETA   = 7.293869E-3    LKETA   = -6.070E-3)
*
.END
```

A LIN analysis also includes the following:

- `.LIN` command:

  ```
  .LIN noisecalc=1 sparcalc=1
  ```

  This invokes a LIN analysis and activates noise calculations and S parameter output files.

- Two port elements:

  ```
  P1 rfin gnd port=1 z0=50 dc=0.595
  ```

  Specifies that an input port is assumed between terminals `rfin` and ground, that it is has a 50 ohm termination, and it has a built-in DC bias of 0.595 V. The output (second) port is:

  ```
  P2 rfo _vdd port=2 z0=255
  ```

  This syntax specifies that the output port is between terminals `rfo` and `_vdd`, and is being used as a pull up resistor with impedance of 255 ohms.

- A `.PRINT` command for plotting the output S parameters in dB and the noise figure minimum.

To run this netlist, type the following command:

```
hspicerf gsmlna.sp
```

This produces two output files, named gsmlna.sc0 and gsmlna.printac0, containing the S parameter and noise parameter results, and the requested PRINT data.

To view the output:

1. Type **cscope** to invoke CosmosScope.
2. Open gsmlna.sc0 in the File>Open>Plotfiles dialog. (Be sure to change the "Files of Type…" filter to find the sc0 file.)
3. To open a blank Smith chart, click the Smith chart icon, on the left side of the upper toolbar.
4. Using the signal manager, select the S(1,1) and S(2,2) signals under the S-Par heading from the gsmlna.sc0 file. You should see them plotted on the Smith chart.
5. To open a blank Polar chart, click the Polar chart icon on the left side of the upper toolbar. Now use the signal manager to select the S(2,1) signal under the S-Par heading to plot the complex gain of the LNA.
6. Open a blank X-Y plot. Use the signal manager to plot K (the Rollett stability factor) and Gas (the associated gain) under the Gain-Par heading, and NFMIN (the noise figure minimum) under the Noise-Par heading.

Example 2: Power Amplifier

The `.HB` command computes periodic steady-state solutions of circuits. This analysis uses the Harmonic Balance (HB) technique for computing such solutions in the frequency domain. The circuit can be driven by a voltage, power, or current source, or it may be an autonomous oscillator. The HB algorithm represents the circuit's voltage and current waveforms as a Fourier series, that is, a series of sinusoidal waveforms.

To set up a periodic steady-state analysis, the HSPICE input netlist must contain:

- A `.HB` command to activate the analysis. The `.HB` command specifies the base frequency (or frequencies, also called tones) for the analysis, and the number of harmonics to use for each tone. The `.HB` command can specify base tones so that the circuit solution is represented as a multi-dimensional Fourier series. The number of terms in the series are determined by the number of harmonics; more harmonics result in higher accuracy, but also longer simulation times and higher memory usage.
- One or more signal sources for driving the circuit in HB analysis, if the circuit is driven. In the case of autonomous oscillator analysis, no signal source is required. Signal sources are specified using the HB keyword on the voltage

or current source syntax. Power sources are specified by setting the power switch on voltage/current sources to 1; in this case, the source value is treated as a power value in Watts instead of a voltage or current.

Optionally, the netlist can also contain a set of control option for optimizing HB analysis performance.

The following example shows how to set up a Harmonic Balance analysis on an NMOS Class C Power Amplifier. The example compares transient analysis results to Harmonic Balance results.

The following netlist performs both a transient and a Harmonic Balance analysis of the amplifier driven by a sinusoidal input waveform. The `accurate` option is set to ensure sufficient number of time points for comparison with HB. This example is included with the HSPICE RF distribution as pa.sp and is available in directory $<installdir>/demo/hspicerf/examples.

```
.options POST accurate
.param f0=950e6 PI=3.1415926 Ld=2e-9 Rload=5 Vin=3.0
.param Lin=0.1n Vdd=2 Cd='1.0/(4*PI*PI*f0*f0*Ld)'
M1 drain gt 0 0 CMOSN L=0.35u W=50u AS=100p AD=100p
PS=104u PD=104u M=80
Ls in gt   Lin $ gate tuning
Ld drain vdd Ld $ drain tuning
Cd drain 0    Cd
Cb drain out   INFINITY $ DC block
Rload out   0   Rload
Vdd vdd 0   DC    Vdd
Vrf1 in   0   DC 'Vin/2.0'
+ SIN ('Vin/2' 'Vin/2' 'f0' 0 0 90)
+ HB 'Vin/2' 0.0 1 1
.hb tones=f0 nharms=10
.tran 10p 10n
.probe hb p(Rload)
.probe tran p(Rload)
.include cmos49_model.inc
.end
```

An HB analysis uses the following:

- An `.HB` command:

  ```
  .hb tones=f0 nharms=10
  ```

  This invokes a single tone HB analysis with base frequency 950 mHz and 10 harmonics.

- The HB source in Vrf1:

  ```
  HB 'Vin/2' 0.0 1 1.
  ```

  This creates a sinusoidal waveform matching the transient analysis one. The amplitude is Vin/2=1.5 V, and it applies to the first harmonic of the first tone, 950 MHz.

- A `.PROBE` command for plotting the output power:

  ```
  .probe hb p(Rload)
  ```

To run this netlist, type the following command:

```
hspicerf pa.sp
```

This produces two output files named pa.tr0 and pa.hb0, containing the transient and HB output, respectively. To view and compare the output:

1. Type **cscope** to invoke CosmosScope.
2. To open both files, use the File > Open > Plotfiles dialog. (Be sure to change the “Files of Type…” filter to find the hb0 file.)
3. Using the signal manager, view the v(out) signals from the pa.tr0 file.

   A time domain waveform appears.
4. View the v(out) signal from the pa.hb0 file.

   This should be a histogram with lines at 950MHz, and multiples thereof, up to 9.5GHz.
5. Right-click on the waveform label for v(out) from the pa.hb0 file, and choose To Time-Domain.
6. Change the X-End(sec) value to 10n.
7. Click OK to accept the default interval value.

   You should now see a new waveform called timedomain(v(out)).
8. Left-click on the timedomain(v(out)) label, hold, and drag the signal to the plot containing v(out).

   This should overlay the v(out) and timedomain(v(out)) signals on the same panel. Zoom into the transitions to see the slight differences between the waveforms.

Example 3: Amplifier IP3

This example takes the LNA circuit of Example 1 and performs a simulation using two closely spaced steady-state tones to study the compression and third order distortion properties of the amplifier. The example file is located at: /<install_dir>/demo/hspicerf/examples/gsmlnaIP3.sp

```
**
** NMOS 0.25um Cascode LNA for GSM applications
** Test bench setup for two-tone power sweep in dBm
** to extract IP3.
**
.temp 27
.options post=2
.param   Vdd=2.3
.global  gnd
.param Pin:dBm=-30.0
.param Pin=Pin:dBm
.param Pin:W='1.0e-3*pwr(10.0,Pin/10.0)'   $ Change to Watts for sources
**
** Cascode LNA tuned for operation near 1 GHz
**
M1 _n4 _n3 _n5 _n5 CMOSN l=0.25u w=7.5u as=15p ad=15p ps=19u pd=19u m=80
M2 _n6 _n1 _n4 _n4 CMOSN l=0.25u w=7.5u as=15p ad=15p ps=19u pd=19u m=80
M3  rfo _n6 gnd gnd CMOSN l=0.25u w=7.5u as=15p ad=15p ps=19u pd=19u m=40
r1 _vdd _n6 400
l1 _n5  gnd  l=0.9nH
l2 rfin _n3  l=13nH  $ 0.65n
vvb _n1 gnd   dc=1.19 $ bias for common base device
vinb rfinb gnd dc=0.595
lchk rfin rfinb INFINITY  $ Choke
cblk rfin rfind INFINITY  $ DC block
vvdd _vdd gnd dc=Vdd
rfb  rfo _n6 120      $ feedback
**
**
** Two-tone input source (DC blocked at this point)
**
Vin rfind gnd dc=0 power=1 z0=50  $ 50 Ohm src
+ HB Pin:W 0 1 1  $ tone 1
+ HB Pin:W 0 1 2  $ tone 2
Rload rfo _vdd R=255
**
** HB test bench to measure IP3 and IP2
```

```
**
.HB tones=900MEG,910MEG nharms=11 11 intmodmax=7
+ SWEEP Pin:dBm -50.0 0.0 2.0
.print HB P(Rload) P(Rload)[1,0] P(Rload)[2,0] P(Rload)[2,-1]
.probe HB P(Rload) P(Rload)[1,0] P(Rload)[2,0] P(Rload)[2,-1]
**
** Approximate parameters for MOSIS 0.25um process (run T17B)
**
.MODEL CMOSN NMOS(              LEVEL    = 49
+VERSION    = 3.1    TNOM    = 27    TOX    = 5.8E-9
+XJ         = 1E-7    NCH        = 2.3549E17    VTH0    = 0.3819327
+K1    = 0.477867    K2         = 2.422759E-3   K3    = 1E-3
+K3B    = 2.1606637    W0         = 1E-7    NLX    = 1.579864E-7
+DVT0W    = 0    DVT1W      = 0    DVT2W    = 0
+DVT0    = 0.5334651    DVT1       = 0.7186877    DVT2    = -0.5
+U0    = 289.1720829    UA         = -1.300598E-9   UB    = 2.308197E-18
+UC    = 2.841618E-11   VSAT       = 1.482651E5    A0    = 1.6856991
+AGS    = 0.2874763    B0    = -1.833193E-8    B1    = -1E-7
+KETA    = -2.395348E-3   A1    = 0    A2    = 0.4177975
+RDSW    = 178.7751373    PRWG    = 0.3774172    PRWB    = -0.2
+WR    = 1    WINT    = 0    LINT    = 1.888394E-8
+XL    = 3E-8    XW    = -4E-8    DWG    = -1.213938E-8
+DWB    = 4.613042E-9    VOFF    = -0.0981658    NFACTOR   = 1.2032376
+CIT    = 0    CDSC    = 2.4E-4    CDSCD    = 0
+CDSCB    = 0    ETA0    = 5.128492E-3    ETAB    = 6.18609E-4
+DSUB    = 0.0463218    PCLM    = 1.91946    PDIBLC1   = 1
+PDIBLC2   = 4.422611E-3    PDIBLCB   = -0.1    DROUT    = 0.9817908
+PSCBE1   = 7.982649E10   PSCBE2    = 5.200359E-10   PVAG   = 9.314435E-3
+DELTA    = 0.01    RSH    = 3.7    MOBMOD    = 1
+PRT    = 0    UTE    = -1.5    KT1    = -0.11
+KT1L    = 0    KT2    = 0.022    UA1    = 4.31E-9
+UB1    = -7.61E-18    UC1    = -5.6E-11    AT    = 3.3E4
+WL    = 0    WLN    = 1    WW    = 0
+WWN    = 1    WWL    = 0    LL    = 0
+LLN    = 1    LW    = 0    LWN    = 1
+LWL    = 0    CAPMOD    = 2    XPART    = 0.5
+CGDO    = 5.62E-10    CGSO    = 5.62E-10    CGBO    = 1E-12
+CJ    = 1.641005E-3    PB    = 0.99    MJ    = 0.4453094
+CJSW    = 4.179682E-10   PBSW    = 0.99    MJSW    = 0.3413857
+CJSWG    = 3.29E-10    PBSWG    = 0.99    MJSWG    = 0.3413857
+CF    = 0    PVTH0    = -8.385037E-3   PRDSW    = -10
+PK2   = 2.650965E-3   WKETA   = 7.293869E-3   LKETA   = -6.070221E-3   )
*
.END
```

First, notice that we have defined variables that allow power to be swept in dBm units.

```
.param Pin:dBm=-30.0
.param Pin=Pin:dBm
.param Pin:W='1.0e-3*pwr(10.0,Pin/10.0)'
```

References to sources must use SI units in conjunction with the previous equation to convert from dBm to Watts. The colon (:) is used as a labeling convenience.

Second, a voltage source element is used as a two-tone power source by setting the power flag and a source impedance of 50 ohms is specified. The HB keyword is used to identify the amplitude (interpreted in Watts with the power flag set), phase, harmonic index, and tone index for each tone.

```
Vin rfind gnd dc=0 power=1 z0=50 $ 50 Ohm src
+ HB Pin:W 0 1 1   $ tone 1
+ HB Pin:W 0 1 2   $ tone 2
```

Third, the `.HB` command designates the frequencies of the two tones and establishes the power sweep using the dBm power variable. The `intmodmax` parameter has been set to 7 to include intermodulation harmonic content up to 7th order effects.

```
.HB tones=900MEG,910MEG nharms=11 intmodmax=7

+ SWEEP Pin:dBm -50.0 0.0 2.0
```

Last, the HSPICE RF ability to specify specific harmonic terms is used in the `.PRINT` and `.PROBE` statements to pull out the signals of particular interest. Notice the three different formats:

```
.PRINT HB P(Rload)
```

This reference dumps a complete spectrum in RMS Watts for the power across resistor `Rload`.

```
.PRINT HB P(Rload)[1,0]
```

This reference selectively dumps the power in resistor `Rload` at the first harmonic of the 1st tone.

```
.PRINT HB P(Rload)[2,-1]
```

This reference selectively dumps the power in resistor `Rload` at the 3rd intermodulation product frequency (890 MHz).

To run this simulation, type the following line at the command line:

```
hspicerf gsmlnaIP3.sp
```

Viewing Results using CosmoScope

For this analysis, the .print statement will generate a<design_name>.printhb0 file. Assume you want to find out the output power through the load resistor at the first tone when the input power is 0.1mW

To view the file:

1. Click the 4. Analysis button and then click on the Print tab.
2. Click the 3. Simulation button.
3. Invoke CosmosScope by clicking on the Waveform button.
4. Choose File > Open > Plotfiles to open the <design_name>.hb0 file. (Be sure to select HSPICERF (*.hb*, *.pn*, *.hr*, *.jt*) from the Files of type pulldown to find the <design_name>.hb0 file.)
5. Plot the signals Pr(rload) [1,0], Pr(rload) [2,0] and Pr(rload) [2 -1] on top of each other. The X-axis will be the input power and the Y-axis will be the output power.

   Result: CosmosScope will display the input and output power in dBm. But, there will be a (W) or (Watt) after the dBm label, this is incorrect.
6. To measure the 1dB compression point of the amplifier, open the measurement tool by clicking on the caliper icon at the bottom tool bar. Use the down arrow at the end of the Measurement field and select RF and P1dB. The PowerOut field should contain the Pr(rload):(1,0) trace.
7. Select a PowerIn value from the list.(The power value should be as large as possible, but still well within the linear range of the amplifier.) Try -25dbm.
8. Click the Apply button.

   Result: CosmoScope will show the linear gain of the amplifier and the 1dBcompression point.
9. The 3rd order intercept point is also measured by using the measurement tool. Use the down arrow at the end of the Measurement field and select RF and IP3/SFDR. The PowerOut1 field should contain the Pr(rload):(1,0) trace and the PowerOut3 field should contain the Pr(rload):(2, -1) trace.
10. Select a PowerIn value from the list. (The power value should be a value that is as large as possible but, still well within the linear range of the amplifier.) Try -25dbm.

11. Click Apply.

    Result: CosmosScope will show the 3rd order intercept point of the amplifier.

Example 4: Colpitts Oscillator

This section demonstrates HSPICE RF oscillator analysis using a single transistor oscillator circuit. Oscillator analysis is an extension of Harmonic Balance in which the base frequency itself is an unknown to be solved for. In oscillator analysis, the user supplies a guess at the base frequency, and no voltage or current source stimulus is needed.

To activate oscillator analysis, include a `.HBOSC` command with:

- The `TONE` parameter set to a guess of the oscillation frequency.
- The `PROBENODE` parameter set to identify an oscillating node or pair of nodes. Always specify a pair of nodes; if only one node oscillates, specify ground as the second node. To speed up the simulation, also supply a guess at the magnitude of the oscillating voltage across these nodes.
- The `FSPTS` parameter set to a frequency range and number of search points. When you set `FSPTS`, HSPICE RF precedes the HBOSC analysis with a frequency search in the specified range to obtain an optimal initial guess for the oscillation frequency. This can accelerate the HB oscillator convergence.

In conjunction with oscillator analysis, HSPICE RF can perform phase noise analysis. Phase noise analysis measures the effect of transistor noise on the oscillator frequency. Phase noise analysis is activated using the `.HBNOISE` command; this command sets a set of frequency points for phase noise analysis. The `.PRINT` and `.PROBE` commands can be used to output phase noise values.

The following netlist, osc.sp, simulates an oscillator, and performs phase noise analysis. This example is included with the HSPICE RF distribution as pa.sp and is available in directory $<installdir>/demo/hspicerf/examples.

Use the `.HBOSC` command with the `PROBENODE` and `FSPTS` parameters set.

```
PROBENODE=emitter,0,4.27
```

Identifies the emitter node as an oscillating node, and provides a guess value of 4.27 volts for the oscillation amplitude at the emitter node.

```
FSPTS=40,9e6,1.1e7
```

Causes an initial frequency search using 40 equally-spaced points between 9 and 11 MHz.

In the `.PHASENOISE`, `.PRINT`, and `.PROBE` commands:

```
.PHASENOISE V(emitter) dec 10 10k 1meg
```

Runs phase noise analysis at the specified offset frequencies, measured from the oscillation carrier frequency. The frequency points specified here are on a logarithmic scale, 10 points per decade, 10 kHz to 1 MHz.

- `.PROBE PHASENOISE PHNOISE` and the similar `.PRINT` command instruct HSPICE RF to output phase noise results to the osc.pn0 and osc.printpn0 files.

```
**
** Uses emitter resistor limiting to keep output sinusoidal.
** Output can be taken at the emitter (eml node).
**
*----------------------------------------------------------
* Options for Oscillator Harmonic Balance Analysis...
*
.OPTIONS post sim_accuracy=100 hbsolver=0
*----------------------------------------------------------
* Bias NPN transistor for 5V Vce, 10mA Ic
* Emitter follower Colpitts design
Vcc collector 0      9V
Q1 collector base emitter emitter RF_WB_NPN
Re1   emitter   eml     100
RLoad eml        0      300
Rb1   collector base 4300
Rb2   base       0     5600
*
*----------------------------------------------------------
* Capacitive feedback network
Ce    0    eml      100pF
Cfb base eml       100pF
Cbb base bb        470pF
Lb bb     0      6uH
*----------------------------------------------------------
* Simulation control for automated oscillator analysis
*
.HBOSC tones=1.0e7 nharms=15
+PROBENODE=emitter,0,4.27
+FSPTS=40,9.e6,1.1e7
*
.PHASENOISE V(emitter) DEC 10 10K 1MEG
+METHOD=0 CARRIERINDEX=1
*
.print hbosc vm(eml) vp(eml) vr(emitter) vi(emitter)
.print hbosc vm(emitter) vp(emitter) P(Rload)
.print phasenoise phnoise
.probe phasenoise phnoise
```

```
.probe hbosc v(emitter) v(eml)
.include bjt.inc
.END
```

After you run this netlist, examine the osc.printhb0 file.

- At the top is the oscillator frequency (about 10.14 MHz) and the `.PRINT HBOSC` output.
- The first 2 lines show that the eml node oscillates around 3V with an amplitude of about 2.85V.
- The emitter node oscillates around 4V with an amplitude of about 4.27V.

Also examine the osc.printpn0 file, which contains the phase noise results in text form.

You can view the osc.hb0 and osc.pn0 files in CosmosScope.

1. To start CosmosScope, type **cscope**.
2. Use the File>Open>Plotfiles dialog to open osc.hb0.

   Remember to set the file type filter to HSPICE RF HB (*.hb*).
3. From the signal manager, double click on v(emitter) to see that node's spectrum.
4. Right-click on the v(emitter) label in the chart, and choose "To Time Domain" to create a time domain waveform.
5. To accept the defaults for range and interval, click OK.

   You should see an oscillating time domain waveform.

To run a transient simulation for comparison:

1. Use the `.TRAN 1n 10u` command.
2. Add `ic=10n` to the `Lb` inductor.

   The resulting waveforms should be the same as those from HB oscillator analysis.

Example 5: CMOS GPS VCO

This second oscillator analysis example involves two negative resistance oscillators coupled at 90 degrees. MOS capacitors are used as varactors. This VCO topology is common for GPS applications and produces quadrature LO outputs near 1550 MHz. The purpose of this example is to generate the VCO tuning curve (output level and frequency as a function of tuning voltage) as well as its phase noise characteristics as a function of tuning voltage.

As in previous examples, the oscillator analysis is activated using the `.HBOSC` command:

- The `TONE` parameter sets an approximate oscillation frequency (near 1550 MHz).
- The `NHARMS` parameter sets the harmonic content to 11th order.
- The `PROBENODE` parameters identify the drain pins across the first oscillator section as the pair of oscillating nodes. This is a differential oscillator, and the approximate value for this differential amplitude is 6.1 V.
- The `FSPTS` parameters set the search frequency range between 1500 and 1600 MHz.
- The `SWEEP` parameters set a tuning voltage sweep from 2.0 to 3.2 V.

The following example is based on demonstration netlist gpsvco.sp, which is available in directory $<installdir>/demo/hspicerf/examples. This netlist simulates the oscillator schematic shown in Figure 1 and performs phase noise analysis.

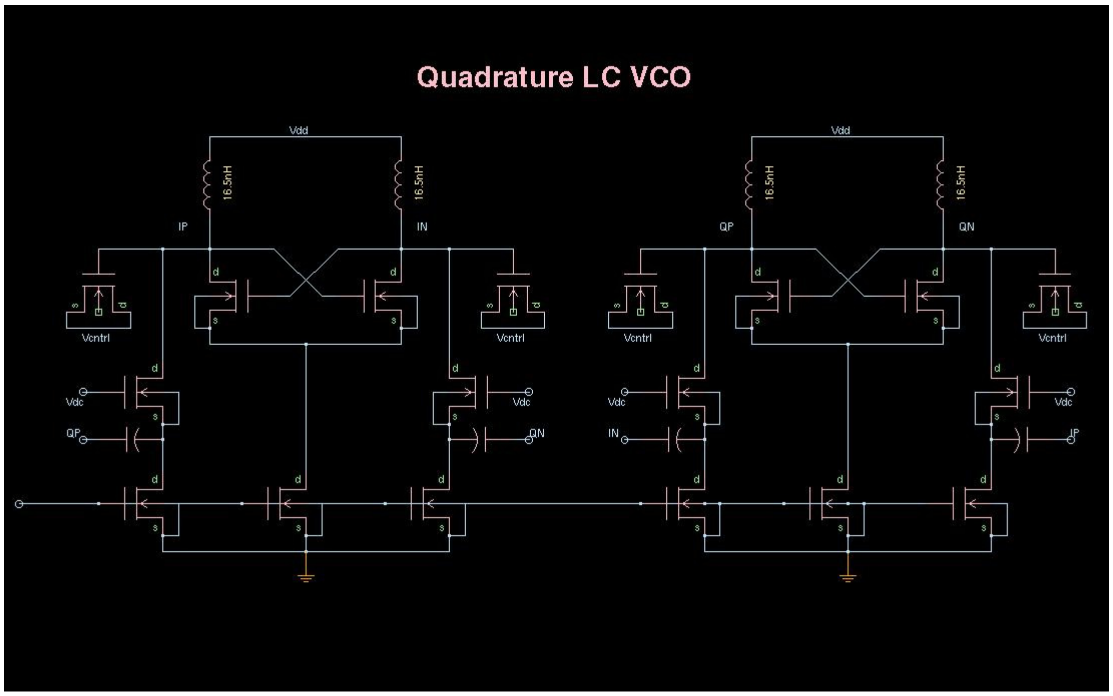
```
**
** NMOS IC Quadrature VCO circuit for GPS local oscillator
**
** Twin differential negative resistance VCOs using NMOS
** transistors for varactors, coupled to produce quadrature
** resonances.
** Design based on 0.35um CMOS process.
**
** References:
**  >P. Vancorenland and M.S.J. Steyaert, "A 1.57-GHz fully
**    integrated very low-phase-noise quadrature VCO,"
**    IEEE Trans. Solid-State Circuits, May 2002, pp.653-656.
**  >J. van der Tang, P. van de Ven, D. Kasperkovitz, and A.
Roermund,
**   "Analysis and design of an optimally coupled 5-GHz quadrature
**   LC oscillator,"  IEEE Trans. Solid-State Circuits, May 2002,
**    pp.657-661.
** >F. Behbahani, H. Firouzkouhi, R. Chokkalingam, S. Delshadpour,
**   A. Kheirkhani, M. Nariman, M. Conta, and S. Bhatia,
**   "A fully integrated low-IF CMOS GPS radio with on-chip analog
**  image rejection," IEEE Trans. Solid-State Circuits, Dec. 2002,
**   pp. 1721-1727.
**
** Setup for Harmonic Balance Analysis
**
```

```
** Oscillation Frequency: ~ 1575 MHz (GPS L1 frequency)
** Amplitude:  ~5 Volts peak-to-peak (zero to 5V)
** Vdd: 2.5 V
**
** HSPICE Simulation Options:
*.option delmax=1n ACCURATE LIST NODE
**
** HSPICE RF Simulation Options :
.option sim_accuracy=10
**
*.option savehb='a.hbs' loadhb='a.hbs'
.option POST
.param Vtune=2.0  $ Failures: vtune=1
.param Cval=0.2p
*--------------------------------
Vtune vc gnd  DC Vtune
Vdd vdd gnd 2.5
*--------------------------------
* First oscillator section
** Low-Q resonator with Vdd at center tap of inductors
R1a IP ri 100k  $ These R's set the Q
R1b ri IN 100k
L1 IP vdd 16.5nH
L2 vdd IN 16.5nH
Cc1 IP gnd Cval $ I to Q
Cc2 IN gnd Cval $ -I to Q
** Differential fets
M1 IP IN cs gnd NMOS l=0.35u w=15u
M2 IN IP cs gnd NMOS l=0.35u w=15u
** Bias fet - bias at Vdd -- too high?
Mb cs  vdd gnd gnd NMOS l=0.35u w=15u
** fets used as varactors
Mt1 vc IP vc gnd NMOS l=0.35u w=2u M=50
Mt2 vc IN vc gnd NMOS l=0.35u w=2u M=50
*--------------------------------
** Second oscillator section
** Low-Q resonator with Vdd at center tap of inductors
R1a_b QP ri_b 100k  $ These R's set the Q
R1b_b ri_b QN 100k
L1_b QP vdd 16.5nH
L2_b vdd QN 16.5nH
Cc1_b QP gnd Cval $ -Q to -I
Cc2_b QN gnd Cval $ -Q to I
** Differential fets
M1_b QP QN cs_b gnd NMOS l=0.35u w=15u
M2_b QN QP cs_b gnd NMOS l=0.35u w=15u
** Bias fet - bias at Vdd -- too high? 2nd in parallel
Mb_b cs_b  vdd gnd gnd NMOS l=0.35u w=15u
```

```
** fets used as varactors
Mt1_b vc QP vc gnd NMOS l=0.35u w=2u M=50
Mt2_b vc QN vc gnd NMOS l=0.35u w=2u M=50
*
*------------------------------
* Differentiators Coupling transistors for quadrature
*
.param Cdiff=0.14p difMsize=50u
vidiff  dbias gnd 1.25
viqdiff vdcdif gnd 1.75
Midiff1 dQP dbias gnd gnd NMOS l=0.35u w=difMsize
Midiff2 dQN dbias gnd gnd NMOS l=0.35u w=difMsize
Midiff3 dIN dbias gnd gnd NMOS l=0.35u w=difMsize
Midiff4 dIP dbias gnd gnd NMOS l=0.35u w=difMsize
Cdiff1  dQP QP Cdiff
Cdiff2  dQN QN Cdiff
Cdiff3  dIN IN   Cdiff
Cdiff4  dIP IP   Cdiff
Mc_QP1 IP vdcdif dQP gnd NMOS l=0.35u w=difMsize
Mc_QN2 IN vdcdif dQN gnd NMOS l=0.35u w=difMsize
Mc_QN3 QP vdcdif dIN gnd NMOS l=0.35u w=difMsize
Mc_QP4 QN vdcdif dIP gnd NMOS l=0.35u w=difMsize
*------------------------------
* Transient Analysis Test Bench
*
* stimulate oscillation with 2mA pulse
*iosc IP IN PULSE ( 0 2m .01n .01n .01n 10n 1u )
*.probe tran v(IP) v(IN)
*.print tran v(IP) v(IN)
*.TRAN .01n 10n
*-----------------------------
* Harmonic Balance Test Bench
*
.sweepblock vtune_sweep
+ 0 5 0.2
+ 2 3 0.1
.HBOSC tones=1550e6 nharms=12
+ PROBENODE=IP,QN,4
+ sweep Vtune sweepblock=vtune_sweep
**
.phasenoise dec 10 100 1e7
.print phasenoise phnz
.probe phasenoise phnz
.print hb v(IP,IN) v(IP,IN)[1] v(QP,QN) v(QP,QN)[1]
.probe hb v(IP,IN) v(IP,IN)[1] v(QP,QN) v(QP,QN)[1]
.probe hb hertz[1][1]
*
* NMOS Device from MOSIS 0.35um Process
```

```
*
* BSIM3 VERSION 3.1 PARAMETERS
*
* DATE: Mar  8/00
* LOT: n9co                  WAF: 07
* Temperature_parameters=Default
*
.MODEL NMOS NMOS (                                 LEVEL   = 49
+VERSION = 3.1            TNOM    = 27            TOX     = 7.9E-9
+XJ      = 1.5E-7        NCH     = 1.7E17        VTH0    = 0.5047781
+K1      = 0.5719698     K2      = 0.0197928     K3      = 33.4446099
+K3B     = -3.1667861    W0      = 1E-5         NLX     = 2.455237E-7
+DVT0W   = 0              DVT1W   = 0              DVT2W   = 0
+DVT0    = 2.8937881     DVT1    = 0.6610934     DVT2    = -0.0446083
+U0     = 421.8714618   UA      = -1.18967E-10  UB      = 1.621684E-18
+UC      = 3.422111E-11  VSAT    = 1.145012E5    A0      = 1.119634
+AGS      = 0.1918651      B0       = 1.800933E-6    B1       = 5E-6
+KETA     = 3.313177E-3    A1       = 0              A2       = 1
+RDSW   = 984.149934    PRWG    = -1.133763E-3  PRWB    = -7.19717E-3
+WR      = 1            WINT    = 9.590106E-8   LINT    = 1.719803E-8
+XL      = -5E-8         XW      = 0            DWG     = -2.019736E-9
+DWB      = 6.217095E-9    VOFF     = -0.1076921     NFACTOR = 0
+CIT      = 0              CDSC     = 2.4E-4         CDSCD    = 0
+CDSCB   = 0            ETA0    = 0.0147171     ETAB    = -7.256296E-3
+DSUB   = 0.3377074     PCLM    = 1.1535622     PDIBLC1 = 2.946624E-4
+PDIBLC2 = 4.171891E-3   PDIBLCB = 0.0497942     DROUT   = 0.0799917
+PSCBE1  = 3.380501E9    PSCBE2  = 1.69587E-9    PVAG    = 0.4105571
+DELTA    = 0.01           MOBMOD   = 1              PRT      = 0
+UTE      = -1.5           KT1      = -0.11          KT1L     = 0
+KT2      = 0.022         UA1      = 4.31E-9       UB1      = -7.61E-18
+UC1      = -5.6E-11       AT       = 3.3E4          WL       = 0
+WLN      = 1             WW       = -1.22182E-15   WWN      = 1.1657
+WWL      = 0              LL       = 0              LLN      = 1
+LW       = 0              LWN      = 1              LWL      = 0
+CAPMOD  = 2              XPART   = 0.4           CGDO    = 3.73E-10
+CGSO    = 3.73E-10      CGBO    = 1E-11        CJ      = 8.988141E-4
+PB     = 0.8616985     MJ      = 0.3906381     CJSW    = 2.463277E-10
+PBSW   = 0.5072799     MJSW    = 0.1331717     PVTH0   = -0.0143809
+PRDSW  = -81.683425    WRDSW  = -107.8071189  PK2     = 1.210197E-3
+WKETA  = -1.00008E-3   LKETA   = -6.1699E-3    PAGS    = 0.24968
+AF       = 1.0            KF       = 1.0E-30      )
*
.END
```

Figure 1 VCO Schematic



The results of the analysis are displayed in Figure 2 on page 35, Figure 3 on page 36, and Figure 4 on page 37 using CosmosScope for VCO waveforms, tuning curves, and phase noise response.

Figure 2 VCO Waveforms Output in CosmosScope

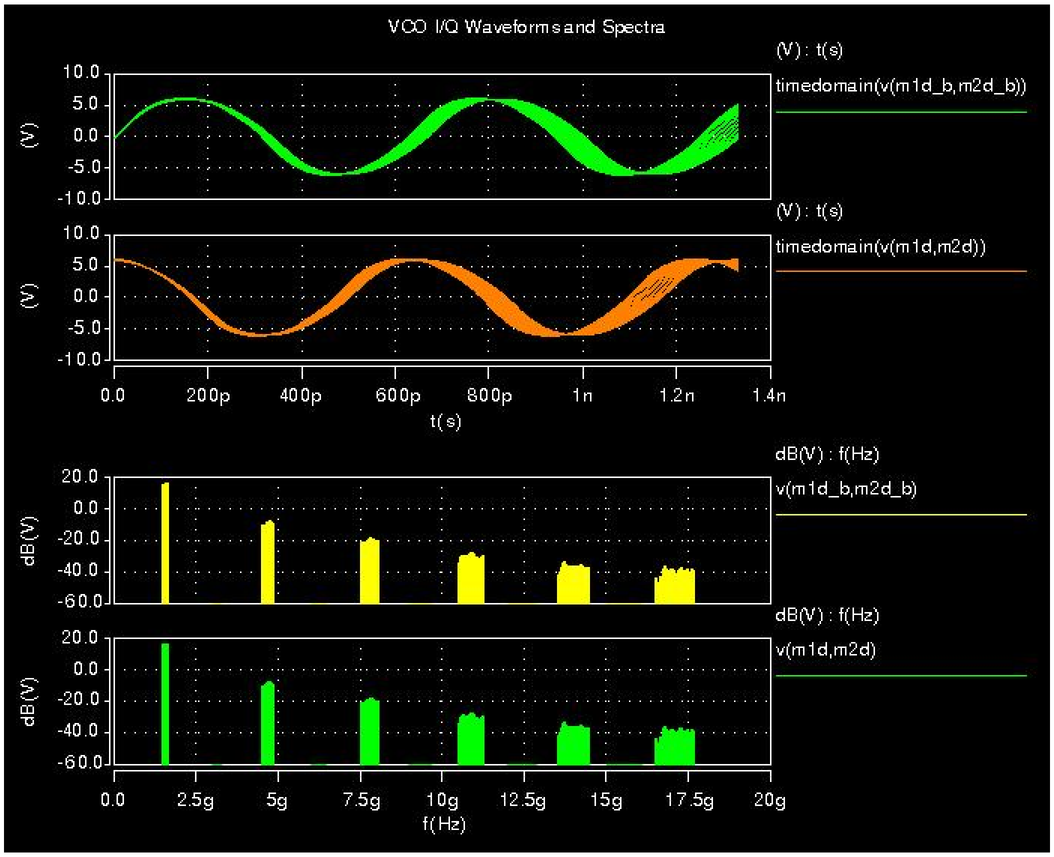


Figure 3 VCO Tuning Curves Output in CosmosScope

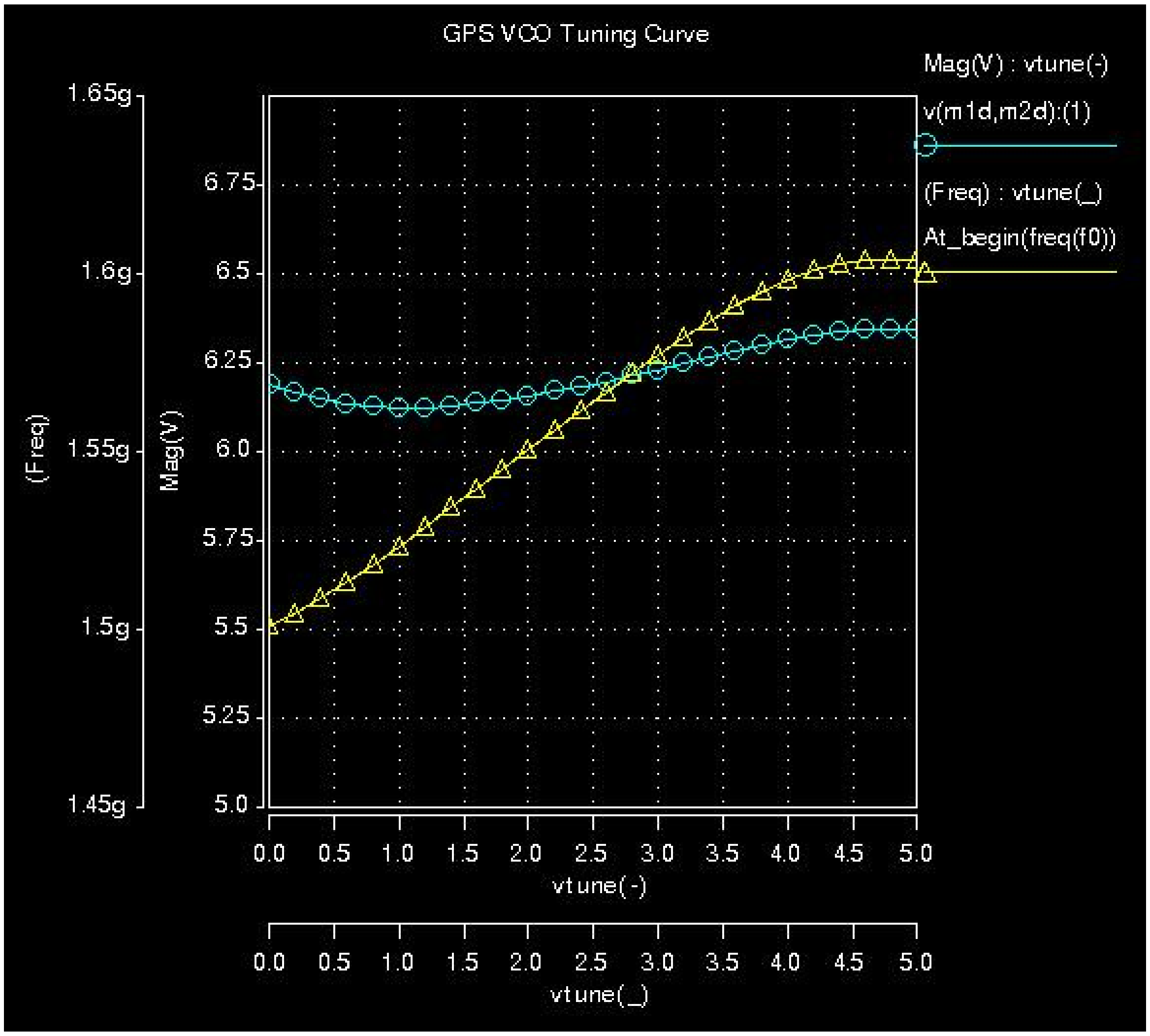
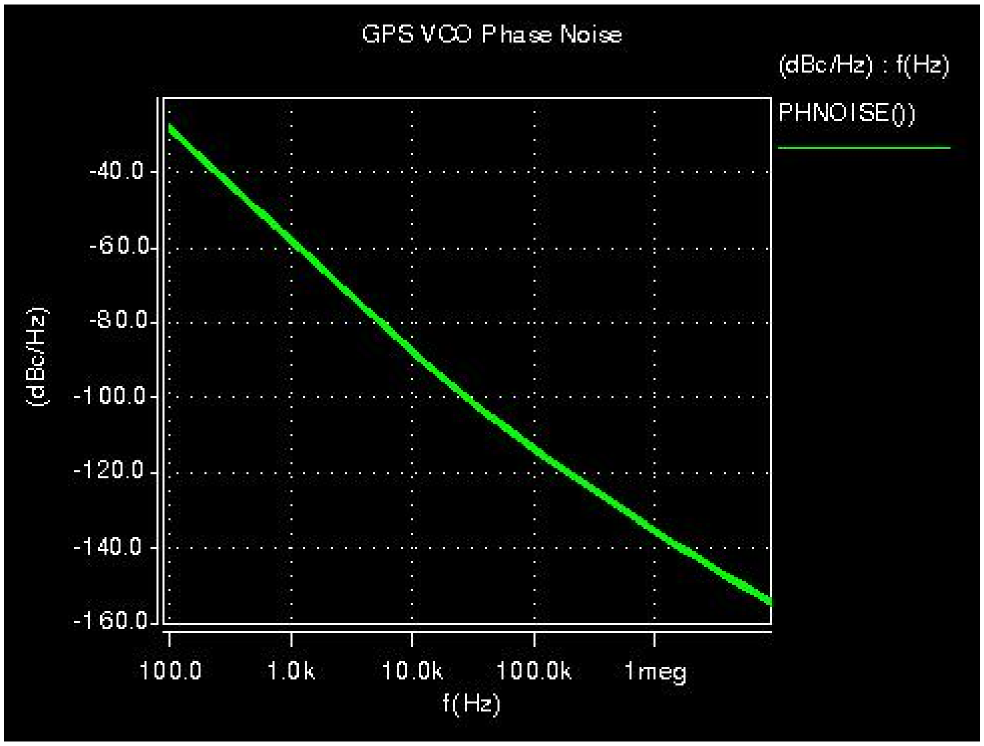


Figure 4 VCO Phase Noise Response in CosmosScope



Example 6: Mixer

The example in this section shows how to use HSPICE RF to analyze a circuit driven by multiple input stimuli with different frequencies. Mixer circuits provide a typical example of this scenario: in this case, there might be two input signals (LO and RF), which are mixed to produce an IF output signal. In this case, HSPICE RF offers two options:

- Multi-tone HB analysis: specify the `LO` and `RF` base frequencies as two separate tones on the `.HB` command.
- Periodic AC analysis (HBAC): if one of the inputs is a small-signal, you can use a faster linear analysis to analyze its effect. For example, if a mixer's `LO` is a large signal, but `RF` is a small signal, a single-tone HB analysis using the `LO` frequency can be combined with HBAC in place of a 2-tone HB analysis.

To demonstrate both techniques, this example analyzes an ideal mixer built using behavioral elements. It is based on demonstration netlist mix_tran.sp, which is available in directory $<installdir>/demo/hspicerf/examples.

```
* Ideal mixer example: transient analysis
.OPTIONS POST
vlo lo 0 1.0 sin (1.0 0.5 1.0g 0 0 90)
rrf1 rf1 rf 1.0
g1 0 if cur='1.0*v(lo)*v(rf)' $ mixer element
c1 0 if q='1.0e-9*v(lo)*v(rf)' $ mixer element
rout if ifg 1.0
vctrl ifg 0 0.0
h1 out 0 vctrl 1.0 $ convert I to V
rh1 out 0 1.0
vrf rf1 0 sin (0 0.001 0.8GHz 0 0 114)
.tran 10p 10n
.opt sim_accuracy=100
.end
```

This example uses behavioral controlled current and charge sources to simulate a mixer. The `LO` signal is driven by a 0.5 Volt sinusoid at 1 GHz, and `RF` is driven by a 10mV signal at 800 MHz. The mixer output is the voltage at node out, v(out).

Two-tone HB Approach

To analyze this circuit using 2-tone HB, add:

- HB source for `LO`: add `HB 0.5 0 1 1` to the LO voltage source; this sets the amplitude to 0.5, no phase shift for the first harmonic of the first tone, which is 1 GHz.
- HB source for `RF`: add `HB 0.001 24 1 2` to the RF voltage source; this sets the amplitude to 0.001, 24 degrees phase shift for the first harmonic of the second tone (0.8 GHz).
- An `.HB` command specifying both tones: .hb tones=1g 0.8g nharms=6 3; only a small number of harmonics is required to resolve the signals.

The complete mix_hb.sp netlist for 2-tone HB analysis is then:

```
* Ideal mixer example: 2-tone HB analysis
.OPTIONS POST
vlo lo 0 1.0 sin (1.0 0.5 1.0g 0 0 90) HB 0.5 0 1 1
rrf1 rf1 rf 1.0
g1 0 if cur='1.0*v(lo)*v(rf)' $ mixer element
c1 0 if q='1.0e-9*v(lo)*v(rf)' $ mixer element
```

```
rout if ifg 1.0
vctrl ifg 0 0.0
h1 out 0 vctrl 1.0 $ convert I to V
rh1 out 0 1.0
vrf rf1 0 sin (0 0.001 0.8GHz 0 0 114) HB 0.001 24 1 2
.opt sim_accuracy=100
.hb tones=1g 0.8g nharms=6 3
.end
```

This example is available in directory $<installdir>/demo/hspicerf/examples.

HBAC Approach

To analyze this circuit using HBAC, start with the 2-tone HB analysis setup, and modify it as follows:

- Replace the `RF` HB signal with an HBAC signal: change `HB 0.001 24 1 2` to HBAC 0.001 24; this deactivates the source for HB and activates it for HBAC with the same magnitude and phase.
- Specify the frequency in the `.HBAC` command.
- Change the `.HB` command to single tone:

  ```
  .HB tones=1g nharms=6
  ```

  HBAC takes care of the second tone.
- Add a `.HBAC` command

  ```
  .HBAC lin 1 0.8g 0.8g
  ```

  This command runs an analysis at a single frequency point, 0.8 GHz. In general, HBAC analysis can sweep the RF frequency over a range of values.

The following is the complete mix_hbac.sp netlist for HBAC analysis of this simple mixer. This netlist also contains commands for performing periodic noise analysis. It is available in directory $<installdir>/demo/hspicerf/examples.

```
* Ideal mixer example: HBAC analysis
.OPTIONS POST
vlo lo 0 1.0 sin (1.0 0.5 1.0g 0 0 90)
+ HB 0.5 0 1 1
rrf1 rf1 rf 1.0
g1 0 if cur='1.0*v(lo)*v(rf)' $ mixer element
c1 0 if q='1.0e-9*v(lo)*v(rf)' $ mixer element
rout if ifg 1.0
vctrl ifg 0 0.0
h1 out 0 vctrl 1.0 $ convert I to V
```

```
rh1 out 0 1.0
vrf rf1 0 sin (0 0.001 0.8GHz 0 0 114)
+ HBAC 0.001 24
.opt sim_accuracy=100
.hb tones=1g nharms=6
.hbac lin 1 0.8g 0.8g
* Noise analysis
.hbnoise v(out) rrf1 lin 40 0.1g 4g
.print hbnoise onoise nf
.probe hbnoise onoise nf
.end
```

Comparing Results

After running all three netlists above, you will have generated 3 output files:

- mix_tran.tr0
- mix_hb.hb0
- mix_hbac.hb0

You can compare the results of the 3 analyses in CosmosScope.

1. To run the netlists and start CosmosScope, type:

   ```
   hspicerf mix_tran.sp
   hspicerf mix_hb.sp
   hspicerf mix_hbac.sp
   cscope &
   ```

2. Open the mix_tran.tr0 file: choose File>Open>Plotfiles and select mix_tran.tr0.
3. To plot v(out), double-click v(out) in the signal manager.
4. Open the mix_hb.hb0 file: choose File>Open>Plotfiles and select mix_hb.hb0.

   You might need to change the “Files of Type…” filter to “HSPICERF HB (*.hb*)”.
5. Plot v(out) by double clicking v(out) in the signal manager.

   A histogram displays.
6. Open the mix_hbac.hb0 file: choose File>Open>Plotfiles and select mix_hbac.hb0.

   You might need to change the “Files of Type…” filter to “HSPICERF HBAC (*.hb*)”.

7. Plot v(out) by double clicking v(out) in the signal manager.

   You should see a histogram similar to the one from mix_hb.hb0.

8. Convert the HB and HBAC histograms to time domain. For each of the two v(out) histogram signals, right-click on the v(out) label and choose To Time Domain. Accept the default range and interval settings.

   Two new time domain waveforms should appear.

9. Overlay the three time domain plots. Right click on each "timedomain(v(out))" label, and choose Stack Region/Analog 0.

   The bottom panel should now display all three time domain signals. All three are almost indistinguishable from each other.

You can also use HBAC to perform noise analysis on RF circuits by using the `.HBNOISE` command, which is included in the mix_hbac.sp netlist.

- The `.HBNOISE` command invokes noise analysis, identifying an output node where the noise is measured, an input noise source (in this case, rrf1) which serves as a reference for noise figure computation, and a frequency sweep for the noise analysis.
- The `.PRINT` and `.PROBE hbnoise` commands instruct HSPICE RF to save the output noise and noise figure at each frequency in the mix_hbac.printpn0 and mix_hbac.pn0 output files.

This ideal mixer is noiseless, except for the resistors at the input and output.

The mix_hbac.lis file contains detailed data on the individual noise source contributions of the resistors. You can view mix_hbac.printpn0 to see the output noise and noise figure at each frequency. In CosmosScope, you can view mix_hbac.pn0 to plot the output noise and noise figure data as a function of frequency.

Device Model Cards

The following is an NMOS model in cmos49_model.inc file used in the power amplifier example. It is available in directory $<installdir>/demo/hspicerf/examples.

```
.MODEL CMOSN NMOS (LEVEL   = 49
+VERSION = 3.1   TNOM   = 27   TOX   = 7.9E-9
+XJ     = 1.5E-7   NCH   = 1.7E17   VTH0   = 0.5047781
+K1     = 0.5719698   K2   = 0.0197928   K3   = 33.4446099
+K3B    = -3.1667861   W0   = 1E-5   NLX   = 2.455237E-7
+DVT0W   = 0   DVT1W    = 0   DVT2W    = 0
+DVT0    = 2.8937881   DVT1    = 0.6610934   DVT2    = -0.0446083
+U0      = 421.8714618   UA    = -1.18967E-10   UB   = 1.621684E-18
+UC      = 3.422111E-11   VSAT    = 1.145012E5   A0    = 1.119634
+AGS     = 0.1918651   B0    = 1.800933E-6   B1    = 5E-6
+KETA    = 3.313177E-3   A1    = 0   A2    = 1
+RDSW    = 984.149934   PRWG   = -1.133763E-3  PRWB   = -7.19717E-3
+WR      = 1   WINT    = 9.590106E-8   LINT    = 1.719803E-8
+XL      = -5E-8   XW    = 0   DWG    = -2.019736E-9
+DWB     = 6.217095E-9   VOFF    = -0.1076921   NFACTOR    = 0
+CIT     = 0   CDSC    = 2.4E-4   CDSCD    = 0
+CDSCB   = 0   ETA0    = 0.0147171   ETAB    = -7.256296E-3
+DSUB    = 0.3377074   PCLM   = 1.1535622   PDIBLC1   = 2.946624E-4
+PDIBLC2= 4.171891E-3  PDIBLCB  = 0.0497942   DROUT   = 0.0799917
+PSCBE1 = 3.380501E9   PSCBE2    = 1.69587E-9   PVAG   = 0.4105571
+DELTA   = 0.01   MOBMOD    = 1   PRT    = 0
+UTE     = -1.5   KT1    = -0.11   KT1L    = 0
+KT2     = 0.022   UA1    = 4.31E-9   UB1    = -7.61E-18
+UC1     = -5.6E-11   AT    = 3.3E4   WL    = 0
+WLN     = 1   WW    = -1.22182E-15   WWN    = 1.1657
+WWL     = 0   LL    = 0   LLN    = 1
+LW      = 0   LWN    = 1   LWL    = 0
+CAPMOD = 2   XPART    = 0.4   CGDO    = 3.73E-10
+CGSO    = 3.73E-10    CGBO    = 1E-11   CJ    = 8.988141E-4
+PB      = 0.8616985   MJ    = 0.3906381   CJSW    = 2.463277E-10
+PBSW    = 0.5072799   MJSW    = 0.1331717   PVTH0    = -0.0143809
+PRDSW   = -81.683425   WRDSW = -107.8071189   PK2   = 1.210197E-3
+WKETA   = -1.00008E-3   LKETA    = -6.1699E-3   PAGS    = 0.24968)
```

The following is the BJT model file, bjt.inc used in oscillator example. It is available in directory $<installdir>/demo/hspicerf/examples.

```
* RF Wideband NPN Transistor die SPICE MODEL
.MODEL RF_WB_NPN   NPN
+ IS     = 1.32873E-015   BF     = 1.02000E+002
+ NF     = 1.00025E+000   VAF    = 5.19033E+001
+ EG     = 1.11000E+000   XTI    = 3.00000E+000
+ CJE    = 2.03216E-012   VJE    = 6.00000E-001
+ MJE    = 2.90076E-001   TF     = 6.55790E-012
+ XTF    = 3.89752E+001   VTF    = 1.09308E+001
+ ITF    = 5.21078E-001   CJC    = 1.00353E-012
+ VJC    = 3.40808E-001   MJC    = 1.94223E-001
```

4

Input Netlist and Data Entry

Describes the input netlist file and methods of entering data.

For descriptions of individual HSPICE commands referenced in this chapter, see Chapter 3, RF Netlist Commands, in the *HSPICE and HSPICE RF Command Reference*.

Input Netlist File Guidelines

HSPICE RF operates on an input netlist file, and store results in either an output listing file or a graph data file. An input file, with the name *<design>.sp,* contains the following:

- Design netlist (subcircuits, macros, power supplies, and so on).
- Statement naming the library to use (optional).
- Specifies the type of analysis to run (optional).
- Specifies the type of output desired (optional).

An input filename can be up to 1024 characters long. The input netlist file cannot be in a packed or compressed format.

To generate input netlist and library input files, HSPICE or HSPICE RF uses either a schematic netlister or a text editor.

Statements in the input netlist file can be in any order, except that the first line is a title line, and the last `.ALTER` submodule must appear at the end of the file and before the `.END` statement.

Note:

If you do not place an `.END` statement at the end of the input netlist file, HSPICE RF issues an error message.

Netlist input processing is case insensitive, except for file names and their paths. HSPICE RF does not limit the identifier length, line length, or file size.

Input Line Format

- The input reader can accept an input token, such as:
  - a statement name.
  - a node name.
  - a parameter name or value.

    Any valid string of characters between two token delimiters is a token. You can not use a character string as a parameter value in HSPICE RF. See Delimiters on page 46.
- An input statement, or equation can be up to 1024 characters long.
- HSPICE RF ignores differences between upper and lower case in input lines, except in quoted filenames.
- To continue a statement on the next line, enter a plus (`+`) sign as the first non-numeric, non-blank character in the next line.
- To indicate "to the power of" in your netlist, use two asterisks (`**`). For example, `2**5` represents two to the fifth power (2^5)
- To continue all HSPICE RF statements, including quoted strings (such as paths and algebraics), use a backslash (`\`) or a double backslash (`\\`) at the end of the line that you want to continue.
  - A single backslash preserves white space.
- Names must begin with an alphabetic character, but thereafter can contain numbers and the following characters:

  `! # $ % * + / < > [ ] _ { } : ; ? | .`

  - When you use an asterisk (`*`) or a question mark (`?`) with a `.PRINT`, `.PROBE`, `.LPRINT` (HSPICE RF), or `.CHECK` (HSPICE RF) statement, HSPICE or HSPICE RF uses the character as a wildcard. For additional information, see Using Wildcards on Node Names on page 59.
  - When you use curly brackets (`{ }`), HSPICE converts them to square brackets (`[ ]`) automatically.

- Names are input tokens. Token delimiters must precede and follow names. See “Delimiters” below.
- Names can be up to 1024 characters long and are not case-sensitive.
- Do not use any of the time keywords as a parameter name or node name in your netlist.
- The following symbols are reserved operator keywords: , () = “ ‘

  Do not use these symbols as part of any parameter or node name that you define. Using any of these reserved operator keywords as names causes a syntax error, and HSPICE RF stops immediately.

First Character

The first character in every line specifies how HSPICE RF interprets the remaining line. Table 4 lists and describes the valid characters.

Table 4 First Character Descriptions

Line	If the First Character is...	Indicates
First line of a netlist	Any character	Title or comment line. The first line of an included file is a normal line and not a comment.
Subsequent lines of netlist, and all lines of included files	. (period)	Netlist keyword. For example, .TRAN 0.5ns 20ns
	`c, C, d, D, e, E, f, F, g, G, h, H, i, I, j, J, k, K, l, L, m, M, q, Q, r, R, s, S, v, V, w, W`	Element instantiation
	* (asterisk) # (number)	Comment line (HSPICE) Comment line (HSPICE RF)
	+ (plus)	Continues previous line

Delimiters

- An input token is any item in the input file that HSPICE RF recognizes. Input token delimiters are: tab, blank, comma (,), equal sign (=), and parentheses ( ).
- Single (‘) or double quotes (“) delimit expressions and filenames.
- Colons (:) delimit element attributes (for example, `M1:VGS`).
- Periods (.) indicate hierarchy. For example, `X1.X2.n1` is the n1 node on the X2 subcircuit of the X1 circuit.

Node Identifiers

Node identifiers can be up to 1024 characters long, including periods and extensions. Node identifiers are used for node numbers and node names.

- Node numbers are valid in the range of 0 through 9999999999999999 (1-1e16).
- Leading zeros in node numbers are ignored.
- Trailing characters in node numbers are ignored. For example, `node 1A` is the same as `node 1`.
- A node name can begin with any of these characters:

  ```
  ! # % * / < > _ ? | . &
  ```

  For additional information, see Node Naming Conventions on page 58.
- To make node names global across all subcircuits, use a `.GLOBAL` statement.
- The `0`, `GND`, `GND!`, and `GROUND` node names all refer to the global HSPICE RF ground. Simulation treats nodes with any of these names as a ground node, and produces v(0) into the output files.

Instance Names

The names of element instances begin with the element key letter (see Table 5), except in subcircuits where instance names begin with X. (Subcircuits are sometimes called macros or modules.) Instance names can be up to 1024 characters long.

Table 5 Element Identifiers

Letter (First Char)	Element	Example Line
`B`	IBIS buffer	`b_io_0 nd_pu0 nd_pd0 nd_out nd_in0 nd_en0 nd_outofin0 nd_pc0 nd_gc0`
`C`	Capacitor	`Cbypass 1 0 10pf`
`D`	Diode	`D7 3 9 D1`
`E`	Voltage-controlled voltage source	`Ea 1 2 3 4 K`
`F`	Current-controlled current source	`Fsub n1 n2 vin 2.0`
`G`	Voltage-controlled current source	`G12 4 0 3 0 10`
`H`	Current-controlled voltage source	`H3 4 5 Vout 2.0`
`I`	Current source	`I A 2 6 1e-6`
`J`	JFET or MESFET	`J1 7 2 3 GAASFET`
`K`	Linear mutual inductor (general form)	`K1 L1 L2 1`
`L`	Linear inductor	`LX a b 1e-9`
`M`	MOS transistor	`M834 1 2 3 4 N1`
`P`	Port	`P1 in gnd port=1 z0=50`
`Q`	Bipolar transistor	`Q5 3 6 7 8 pnp1`
`R`	Resistor	`R10 21 10 1000`
`S`	S parameter element	`S1 nd1 nd2 s_model2`
`V`	Voltage source	`V1 8 0 5`

Table 5 Element Identifiers (Continued)

Letter (First Char)	Element	Example Line
`W, T, U`	Transmission Line	`W1 in1 0 out1 0 N=1 L=1`
`X`	Subcircuit call	`X1 2 4 17 31 MULTI WN=100 LN=5`

Hierarchy Paths

- A period (.) indicates path hierarchy.
- Paths can be up to 1024 characters long.
- Path numbers compress the hierarchy for post-processing and listing files.
- The `.OPTION PATHNUM` controls whether the list files show full path names or path numbers.

Numbers

You can enter numbers as integer, floating point, floating point with an integer exponent, or integer or floating point with one of the scale factors listed in Table 6.

Table 6 Scale Factors

Scale Factor	Prefix	Symbol	Multiplying Factor
T	tera	T	1e+12
G	giga	G	1e+9
MEG or X	mega	M	1e+6
K	kilo	k	1e+3
M	milli	m	1e-3
U	micro	μ	1e-6

Table 6 Scale Factors (Continued)

Scale Factor	Prefix	Symbol	Multiplying Factor
N	nano	n	1e-9
P	pico	p	1e-12
F	femto	f	1e-15
A	atto	a	1e-18

Note:

Scale factor A is not a scale factor in a character string that contains amps. For example, HSPICE interprets the 20amps string as 20e-18mps (20^{-18}amps), but it correctly interprets 20amps as 20 amperes of current, not as 20e-18mps (20^{-18}amps).

- Numbers can use exponential format or engineering key letter format, but not both (1e-12 or 1p, but not 1e-6u).
- To designate exponents, use D or E.
- The `.OPTION EXPMAX` limits the exponent size.
- Trailing alphabetic characters are interpreted as units comments.
- Units comments are not checked.
- The `.OPTION INGOLD` controls the format of numbers in printouts.
- The `.OPTION NUMDGT=x` controls the listing printout accuracy.
- The `.OPTION MEASDGT=x` controls the measure file printout accuracy.
- The `.OPTION VFLOOR=x` specifies the smallest voltage for which HSPICE or HSPICE RF prints the value. Smaller voltages print as 0.

Parameters and Expressions

- Parameter names in HSPICE RF use HSPICE name syntax rules, except that names must begin with an alphabetic character. The other characters must be either a number, or one of these characters:

```
! # $ % [ ] _
```

- To define parameter hierarchy overrides and defaults, use the `.OPTION PARHIER=global | local` statement.
- If you create multiple definitions for the same parameter or option, HSPICE RF uses the last parameter definition or `.OPTION` statement, even if that definition occurs later in the input than a reference to the parameter or option. HSPICE RF does not warn you when you redefine a parameter.
- You must define a parameter before you use that parameter to define another parameter.
- When you select design parameter names, be careful to avoid conflicts with parameterized libraries.
- To delimit expressions, use single or double quotes.
- Expressions cannot exceed 1024 characters.
- For improved readability, use a double slash (\\) at end of a line, to continue the line.
- You can nest functions up to three levels.
- Any function that you define can contain up to two arguments.
- Use the `PAR` (expression or parameter) function to evaluate expressions in output statements.

Input Netlist File Structure

An input netlist file should consist of one main program and can contain one or more optional submodules. HSPICE RF uses a submodule (preceded by an `.ALTER` statement) to automatically change an input netlist file; then rerun the simulation with different options, netlist, analysis statements, and test vectors.

You can use several high-level call statements (`.INCLUDE`,and `.LIB`) to structure the input netlist file modules. These statements can call netlists, model parameters, test vectors, analysis, and option macros into a file, from library files or other files. The input netlist file also can call an external data file, which contains parameterized data for element sources and models. You must enclose the names of included or internally-specified files in single or double quotation when they begin with a number (0-9).

Schematic Netlists

HSPICE RF typically use netlisters to generate circuits from schematics, and accept either hierarchical or flat netlists.

The process of creating a schematic involves:

- Symbol creation with a symbol editor.
- Circuit encapsulation.
- Property creation.
- Symbol placement.
- Symbol property definition.
- Wire routing and definition

Table 7 Input Netlist File Sections

Sections	Examples	Definition
Title	.TITLE	The first line in the netlist is the title of the input netlist file (optional in HSPICE RF).
Set-up	.OPTION .IC or .NODESET, .PARAM, .GLOBAL	Sets conditions for simulation. Initial values in circuit and subcircuit. Set parameter values in the netlist. Set node name globally in netlist.
Sources	Sources and digital inputs	Sets input stimuli (I or V element).
Netlist	Circuit elements .SUBKCT, .ENDS, or .MACRO, .EOM	Circuit for simulation. Subcircuit definitions.
Analysis	.DC, .TRAN, .AC, and so on. .SAVE and .LOAD .DATA, .TEMP	Statements to perform analyses. Save and load operating point information. Create table for data-driven analysis. Set temperature analysis.
Output	.PRINT, .PROBE, .MEASURE	Statements to output variables. Statement to evaluate and report user-defined functions of a circuit.

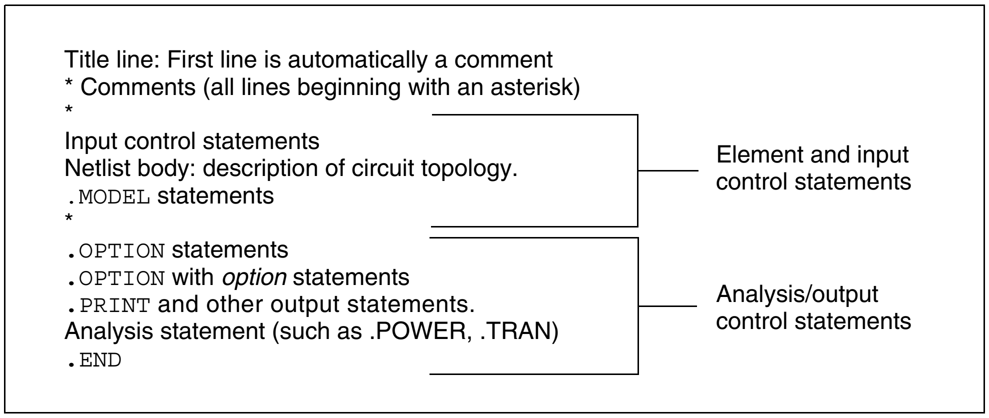
Table 7 Input Netlist File Sections (Continued)

Sections	Examples	Definition
Library, Model and File Inclusion	.INCLUDE	General include files.
	.MODEL	Element model descriptions.
	.LIB	Library.
End of netlist	.END	Required statement; end of netlist.

Input Netlist File Composition

The HSPICE RF circuit description syntax is compatible with the SPICE input netlist format. Figure 5 shows the basic structure of an input netlist.

Figure 5 Basic Netlist Structure


Element and input control statements
Analysis/output control statements

```
Title line: First line is automatically a comment
* Comments (all lines beginning with an asterisk)
*
Input control statements
Netlist body: description of circuit topology.
.MODEL statements
*
.OPTION statements
.OPTION with option statements
.PRINT and other output statements.
Analysis statement (such as .POWER, .TRAN)
.END
```

The following is an example of a simple netlist file, called inv_ckt.in. It shows a small inverter test case that measures the timing behavior of the inverter.

To create the circuit:

1. Define the MOSFET models for the PMOS and NMOS transistors of the inverter.
2. Insert the power supplies for both VDD and GND power rails.

Insert the pulse source to the inverter input.

This circuit uses transient analysis and produces output graphical waveform data for the input and output ports of the inverter circuit.

```
* Sample inverter circuit
* **** MOS models *****
.MODEL n1 NMOS LEVEL=3 THETA=0.4 ...
.MODEL p1 PMOS LEVEL=3 ...
* ***** Define power supplies and sources *****
VDD VDD 0 5
VPULSE VIN 0 PULSE 0 5 2N 2N 2N 98N 200N
VGND GND 0 0
* ***** Actual circuit topology *****
M1 VOUT VIN VDD VDD p1
M2 VOUT VIN GND GND n1
* ***** Analysis statement *****
.TRAN 1n 300n
* ***** Output control statements *****
.OPTION POST PROBE
.PROBE V(VIN) V(VOUT)
.END
```

For a description of individual commands used in HSPICE RF netlists, see Chapter 3, RF Netlist Commands, in the *HSPICE and HSPICE RF Command Reference*.

Title of Simulation

You set the simulation title in the first line of the input file. HSPICE or HSPICE RF always reads this line, and uses it as the title of the simulation, regardless of the line's contents. The simulation prints the title verbatim, in each section heading of the output listing file.

To set the title, you can place a `.TITLE` statement on the first line of the netlist. However, HSPICE or HSPICE RF does not require the `.TITLE` syntax.

The first line of the input file is always the implicit title. If any statement appears as the first line in a file, simulation interprets it as a title, and does not execute it.

An `.ALTER` statement does not support use the `.TITLE` statement. To change a title for a `.ALTER` statement, place the title content in the `.ALTER` statement itself.

Comments and Line Continuation

The first line of a netlist is always a comment, regardless of its first character; comments that are not the first line of the netlist require an asterisk (`*`) as the first character in a line or a dollar sign (`$`) directly in front of the comment anywhere on the line. For example,

```
* <comment_on_a_line_by_itself>
-or-
<HSPICE_statement> $ <comment_following_HSPICE_input>
```

You can place comment statements anywhere in the circuit description.

The dollar sign must be used for comments that do *not* begin in the first character position on a line (for example, for comments that follow simulator input on the same line). If it is not the first nonblank character, then the dollar sign must be preceded by either:

- Whitespace
- Comma (,)
- Valid numeric expression.

You can also place the dollar sign within node or element names. For example,

```
* RF=1K GAIN SHOULD BE 100
$ MAY THE FORCE BE WITH MY CIRCUIT
VIN 1 0 PL 0 0 5V 5NS $ 10v 50ns
R12 1 0 1MEG $ FEED BACK
.PARAM a=1w$comment a=1, w treated as a space and ignored
.PARAM a=1k$comment a=1e3, k is a scale factor
```

A dollar sign is the preferred way to indicate comments, because of the flexibility of its placement within the code.

Line continuations require a plus sign (+) as the first character in the line that follows. Here is an example of comments and line continuation in a netlist file:

```
.ABC Title Line (HSPICE or HSPICE RF ignores the netlist keyword
* on this line, because the first line is always a comment)

* This is a comment line
.MODEL n1 NMOS $ this is an example of an inline comment
* This is a comment line and the following line is a continuation
+ LEVEL=3
```

Element and Source Statements

Element statements describe the netlists of devices and sources. Use nodes to connect elements to one another. Nodes can be either numbers or names. Element statements specify:

- Type of device.
- Nodes to which the device is connected.
- Operating electrical characteristics of the device.

Element statements can also reference model statements that define the electrical parameters of the element.

Table 8 lists the parameters of an element statements.

Table 8 Element Parameters

Parameter	Description
elname	Element name that cannot exceed 1023 characters, and must begin with a specific letter for each element type: C Capacitor D Diode E,F,G,H Dependent current and voltage sources I Current (inductance) source J JFET or MESFET K Mutual inductor L Inductor model or magnetic core mutual inductor model M MOSFET Q BJT P Port R Resistor S S-parameter model T, U, W Transmission line V Voltage source X Subcircuit call
node1 ...	Node names identify the nodes that connect to the element. The node name begins with a letter and can contain a maximum of 1023 characters. You cannot use the following characters in node names:= ( ) , ' <space>
mname	HSPICE or HSPICE RF requires a model reference name for all elements, except passive devices.
pname1 ...	An element parameter name identifies the parameter value that follows this name.
expression	Any mathematical expression containing values or parameters, such as param1 * val2
val1 ...	Value of the *pname1* parameter, or of the corresponding model node. The value can be a number or an algebraic expression.
M=val	Element multiplier. Replicates *val* element times, in parallel. Do not assign a negative value or zero as the M value.

For descriptions of element statements for the various types of supported elements, see the chapters about individual types of elements in this user guide.

Example 1

```
Q1234567  4000  5000 6000 SUBSTRATE BJTMODEL AREA=1.0
```

The preceding example specifies a bipolar junction transistor, with its collector connected to node 4000, its base connected to node 5000, its emitter connected to node 6000, and its substrate connected to the `SUBSTRATE` node. The `BJTMODEL` name references the model statement, which describes the transistor parameters.

```
M1 ADDR SIG1 GND SBS N1 10U 100U
```

The preceding example specifies a MOSFET named `M1`, where:

- drain node=`ADDR`
- gate node=`SIG1`
- source node=`GND`
- substrate nodes=`SBS`

The preceding element statement calls an associated model statement, `N1`. The MOSFET dimensions are width=`100` microns and length=`10` microns.

Example 2

```
M1 ADDR SIG1 GND SBS N1 w1+w l1+l
```

The preceding example specifies a MOSFET named `M1`, where:

- drain node=`ADDR`
- gate node=`SIG1`
- source node=`GND`
- substrate nodes=`SBS`

The preceding element statement calls an associated model statement, `N1`. MOSFET dimensions are algebraic expressions (width=`w1+w`, and length=`l1+l`).

Defining Subcircuits

You can create a subcircuit description for a commonly-used circuit, and include one or more references to the subcircuit in your netlist.

- Use `.SUBCKT` and `.MACRO` statements to define subcircuits within your HSPICE netlist or HSPICE RF.
- Use the `.ENDS` statement to terminate a `.SUBCKT` statement.
- Use the `.EOM` statement to terminate a `.MACRO` statement.
- Use `X<subcircuit_name>` (the subcircuit call statement) to call a subcircuit that you previously defined in a `.MACRO` or `.SUBCKT` command in your netlist, where <*subcircuit_name*> is the element name of the subcircuit that you are calling. This subcircuit element name can be up to 15 characters long.
- Use the `.INCLUDE` statement to include another netlist as a subcircuit in the current netlist.

Node Naming Conventions

Nodes are the points of connection between elements in the input netlist. You can use either names or numbers to designate nodes. Node numbers can be from 1 to 999999999999999; node number 0 is always ground. HSPICE or HSPICE RF ignores letters that follow numbers in node names. When the node name begins with a letter or a valid special character, the node name can contain a maximum of 1024 characters.

In addition to letters and digits, node names can include the following characters:

```
+, -, *, /, $, #, [], !, <>, _, %
```

Node names that begin with one or more numerical digits cannot contain brackets; for example, 123[r55]. Whereas, node names that begin with alphabetic character may contain brackets; for example, n123[r55].

If you use braces { } in node names, HSPICE or HSPICE RF changes them to brackets [ ].

You cannot use the following characters in node names: `() ,=‘ <blank>`

You should avoid using the dollar sign ($) after a numerical digit in a node name, because HSPICE assumes whatever follows the “$” symbol is an in-line comment (see Comments and Line Continuation on page 54 for additional information). It can cause error and warning messages depending on where the node containing the “$” is located. For example, HSPICE generates an error indicating that a resistor node is missing:

```
R1 1$ 2 1k
```

Also, in this example, HSPICE issues a warning indicating that the value of resistor R1 is limited to 1e-5 and interprets the line as “`R1 2 1`“ without a defined value:

```
R1 2 1$ 1k
```

The period (.) is reserved for use as a separator between a subcircuit name and a node name: *subcircuitName.nodeName*. If a node name contains a period, the node will be considered a top level node unless there is a valid match to a subcircuit name and node name in the hierarchy.

The sorting order for operating point nodes is:

```
a-z, !, #, $, %, *, +, -, /
```

Using Wildcards on Node Names

You can use wildcards to match node names.

- `?` wildcard matches any single character. For example, `9?` matches `92`, `9a`, `9A`, and `9%`.
- `*` wildcard matches any string of zero or more characters. For example:
  - If your netlist includes a resistor named `r1` and a voltage source named `vin`, then `.PRINT i(*)` prints the current for both of these elements: `i(r1)` and i(vin).
  - And `.PRINT v(o*)` prints the voltages for all nodes whose names start with `o`; if your netlist contains nodes named `in` and `out`, this example prints only the `v(out)` voltage.
- `[ ]` matches any character tht appears within the brackets. For example, `[123]` matches `1`, `2`, or `3`. A hyphen inside the brackets indicates a character range. For example, `[0-9]` is the same as `[0123456789]`, and matches any digit.

For example, the following prints the results of a transient analysis for the voltage at the matched node name.

```
.PRINT TRAN V(9?t*u)
```

Wildcards must begin with a letter or a number; for example,

```
.PROBE v(*)                  $ correct format
.PROBE *                     $ incorrect format
.PROBE x*                    $ correct format
```

Here are some practical applications for these wildcards:

- If your netlist includes a resistor named `r1` and a voltage source named `vin`, then `.PRINT i(*)` prints the current for both elements `i(r1)` and `i(vin)`.
- The statement `.PRINT v(o*)` prints the voltages for all nodes whose names start with o; if your netlist contains nodes named `in` and `out`, this example prints only the `v(out)` voltage.
- If your netlist contains nodes named `0`, `1`, 2, and `3`, then `.PRINT v(0,*)` or `.PRINT v(0 *)` prints the voltage between node `0` and each of the other nodes: `v(0,1)`, `v(0,2)`, and `v(0,3)`.

Examples

The following examples use wildcards with `.PRINT`, `.PROBE`, and `.LPRINT` statements.

- Probe node voltages for nodes at all levels.

  ```
  .PROBE v(*)
  ```

- Probe all nodes whose names start with “a”. For example: `a1`, `a2`, `a3`, `a00`, `ayz`.

  ```
  .PROBE v(a*)
  ```

- Print node voltages for nodes at the first level and all levels below the first level, where zero-level are top-level nodes. For example: `X1.A`, `X4.554`, `Xab.abc123`.

  ```
  .PRINT v(*.*)
  ```

- Probe node voltages for all nodes whose name start with “x” at the first level and all levels below the first level, where zero-level are top-level nodes. For example: `x1.A`, `x4.554`, `xab.abc123`.

  ```
  .PROBE v(x*.*)
  ```

- Print node voltages for nodes whose names start with “x” at the second-level and all levels below the second level. For example: `x1.x2.a`, `xab.xdff.in`.

  ```
  .PRINT v(x*.*.*)
  ```

- Match all first-level nodes with names that are exactly two characters long. For example: `x1.in`, `x4.12`.

  ```
  .PRINT v(x*.*.*)
  ```

- In HSPICE RF, print the logic state of all top-level nodes, whose names start with `b`. For example: `b1`, `b2`, `b3`, `b56`, `bac`.

  ```
  .LPRINT (1,4) b*
  ```

Element, Instance, and Subcircuit Naming Conventions

Instances and subcircuits are elements and as such, follow the naming conventions for elements.

Element names in HSPICE or HSPICE RF begin with a letter designating the element type, followed by up to 1023 alphanumeric characters. Element type letters are R for resistor, C for capacitor, M for a MOSFET device, and so on (see Element and Source Statements on page 55).

Subcircuit Node Names

HSPICE assigns two subcircuit node names.

- To assign the first name, HSPICE or HSPICE RF uses the (`.`) extension to concatenate the circuit path name with the node name—for example, `X1.XBIAS.M5`.

  Node designations that start with the same number, followed by any letter, are the same node. For example, `1c` and `1d` are the same node.

- The second subcircuit node name is a unique number that HSPICE automatically assigns to an input netlist subcircuit. The (`:`) extension concatenates this number with the internal node name, to form the entire subcircuit's node name (for example, `10:M5`). The output listing file cross-references the node name.

  Note:

  HSPICE RF does not support short names for internal subcircuits, such as `10:M5`.

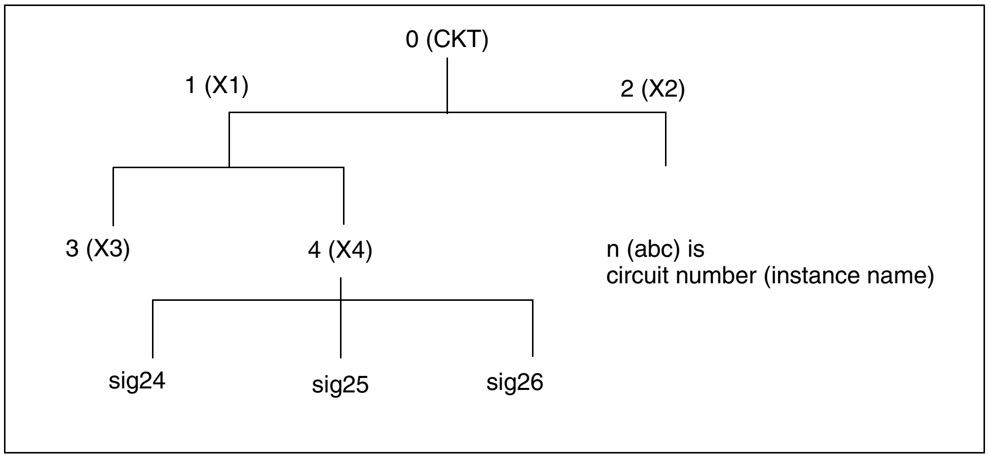
To indicate the ground node, use either the number `0`, the name `GND`, or `!GND`. Every node should have at least two connections, except for transmission line nodes (unterminated transmission lines are permitted) and MOSFET substrate nodes (which have two internal connections). Floating power supply nodes are terminated with a 1Megohm resistor and a warning message.

Path Names of Subcircuit Nodes

A path name consists of a sequence of subcircuit names, starting at the highest-level subcircuit call, and ending at an element or bottom-level node. Periods separate the subcircuit names in the path name. The maximum length of the path name, including the node name, is 1024 characters.

You can use path names in `.PRINT`, `.PLOT`, `.NODESET`, and `.IC` statements, as another way to reference internal nodes (nodes not appearing on the parameter list). You can use the path name to reference any node, including any internal node. Subcircuit node and element names follow the rules shown in Figure 6 on page 62.

Figure 6 Subcircuit Calling Tree, with Circuit Numbers and Instance Names



In Figure 6, the path name of the `sig25` node in the `X4` subcircuit is `X1.X4.sig25`. You can use this path in HSPICE or HSPICE RF statements, such as:

```
.PRINT v(X1.X4.sig25)
```

Abbreviated Subcircuit Node Names

In HSPICE, you can use circuit numbers as an alternative to path names, to reference nodes or elements in `.PRINT`, `.NODESET`, or `.IC` statements.

Compiling the circuit assigns a circuit number to all subcircuits, creating an abbreviated path name:

`<subckt-num>:<name>`

Note:

HSPICE RF does not recognize this type of abbreviated subcircuit name.

The subcircuit name and a colon precede every occurrence of a node or element in the output listing file. For example, `4:INTNODE1` is a node named `INTNODE1`, in a subcircuit assigned the number `4`.

Any node not in a subcircuit has a 0: prefix (0 references the main circuit). To identify nodes and subcircuits in the output listing file, HSPICE uses a circuit number that references the subcircuit where the node or element appears.

Abbreviated path names let you use DC operating point node voltage output, as input in a `.NODESET` statement for a later run.

You can copy the part of the output listing titled *Operating Point Information* or you can type it directly into the input file, preceded by a `.NODESET` statement. This eliminates recomputing the DC operating point in the second simulation.

Automatic Node Name Generation

HSPICE or HSPICE RF can automatically assign internal node names. To check both nodal voltages and branch currents, you can use the assigned node name when you print or plot. HSPICE or HSPICE RF supports several special cases for node assignment—for example, simulation automatically assigns node 0 as a ground node.

For CSOS (CMOS Silicon on Sapphire), if you assign a value of -1 to the bulk node, the name of the bulk node is B#. Use this name to print the voltage at the bulk node. When printing or plotting current—for example `.PLOT I(R1)`—HSPICE inserts a zero-valued voltage source. This source inserts an extra node in the circuit named V*nn*, where *nn* is a number that HSPICE (or HSPICE RF) automatically generates; this number appears in the output listing file.

Global Node Names

The `.GLOBAL` statement globally assigns a node name, in HSPICE or HSPICE RF. This means that all references to a global node name, used at any level of the hierarchy in the circuit, connect to the same node.

The most common use of a `.GLOBAL` statement is if your netlist file includes subcircuits. This statement assigns a common node name to subcircuit nodes. Another common use of `.GLOBAL` statements is to assign power supply connections of all subcircuits. For example, `.GLOBAL VCC` connects all subcircuits with the internal node name `VCC`.

Ordinarily, in a subcircuit, the node name consists of the circuit number, concatenated to the node name. When you use a `.GLOBAL` statement, HSPICE or HSPICE RF does not concatenate the node name with the circuit number, and assigns only the global name. You can then exclude the power node name in the subcircuit or macro call.

Circuit Temperature

To specify the circuit temperature for a HSPICE or HSPICE RF simulation, use the `.TEMP` statement, or the `TEMP` parameter in the `.DC`, `.AC`, and `.TRAN` statements. HSPICE compares the circuit simulation temperature against the reference temperature in the `TNOM` control option. HSPICE or HSPICE RF uses the difference between the circuit simulation temperature and the `TNOM` reference temperature to define derating factors for component values.

In HSPICE RF, you can use multiple `.TEMP` statements to specify multiple temperatures for different portions of the circuit. HSPICE permits only one temperature for the entire circuit. Multiple `.TEMP` statements in a circuit behave as a sweep function.

Data-Driven Analysis

In data-driven analysis, you can modify any number of parameters, then use the new parameter values to perform an operating point, DC, AC, or transient analysis. An array of parameter values can be either inline (in the simulation input file) or stored as an external ASCII file. The `.DATA` statement associates a list of parameter names with corresponding values in the array.

HSPICE supports the entire functionality of the `.DATA` statement. However, HSPICE RF supports `.DATA` only for*:*

- Data-driven analysis.
- Inline or external data files.

Library Calls and Definitions

To create and read from libraries of commonly-used commands, device models, subcircuit analysis, and statements in library files, use the `.LIB` call statement. As HSPICE RF encounters each `.LIB` call name in the main data file, it reads the corresponding entry from the designated library file, until it finds an `.ENDL` statement.

You can also place a `.LIB` call statement in an `.ALTER` block.

Library Building Rules

- A library cannot contain `.ALTER` statements.
- A library can contain nested `.LIB` calls to itself or to other libraries. If you use a relative path in a nested `.LIB` call, the path starts from the directory of the parent library, not from the work directory. If the path starts from the work directory, HSPICE can also find the library, but it prints a warning. The depth of nested calls is limited only by the constraints of your system configuration.
- A library cannot contain a call to a library of its own entry name, within the same library file.
- A HSPICE RF library cannot contain the `.END` statement.
- `.ALTER` processing cannot change `.LIB` statements, within a file that an `.INCLUDE` statement calls.

Defining Parameters

The `.PARAM` statement defines parameters. Parameters in HSPICE or HSPICE RF are names that have associated numeric values. You can also use either of the following specialized methods to define parameters:

- Predefined Analysis
- Measurement Parameters

Predefined Analysis

HSPICE RF provides several specialized analysis types, which require a way to control the analysis. For the syntax used in these `.PARAM` commands, see the description of the .PARAM command in the *HSPICE and HSPICE RF Command Reference*.

HSPICE RF supports the following predefined analysis parameters:

- Temperature functions (*fn*)
- Optimization guess/range
- Monte Carlo functions

HSPICE RF does not support:

- frequency
- time

Measurement Parameters

A `.MEASURE` statement produces a measurement parameter. In general, the rules for measurement parameters are the same as those for standard parameters. However, measurement parameters are not defined in a `.PARAM` statement, but directly in the `.MEASURE` statement.

Altering Design Variables and Subcircuits

The following rules apply when you use an `.ALTER` block to alter design variables and subcircuits in HSPICE. This section does not apply to HSPICE RF.

- If the name of a new element, `.MODEL` statement, or subcircuit definition is identical to the name of an original statement of the same type, then the new statement replaces the old. Add new statements in the input netlist file.
- You can alter element and `.MODEL` statements within a subcircuit definition. You can also add a new element or `.MODEL` statement to a subcircuit definition. To modify the topology in subcircuit definitions, put the element into libraries. To add a library, use `.LIB`; to delete, use `.DEL LIB`.
- If a parameter name in a new `.PARAM` statement in the `.ALTER` module is identical to a previous parameter name, then the new assigned value replaces the old value.
- If you used parameter (variable) values for elements (or model parameter values) when you used `.ALTER`, use the `.PARAM` statement to change these parameter values. Do not use numerical values to redescribe elements or model parameters.
- If you used an `.OPTION` statement (in an original input file or a `.ALTER` block) to turn on an option, you can turn that option off.

- Each `.ALTER` simulation run prints only the actual altered input. A special `.ALTER` title identifies the run.
- `.ALTER` processing cannot revise `.LIB` statements within a file that an `.INCLUDE` statement calls. However, `.ALTER` processing can accept `.INCLUDE` statements, within a file that a `.LIB` statement calls.

Using Multiple .ALTER Blocks

- For the first simulation run, HSPICE reads the input file, up to the first `.ALTER` statement, and performs the analyses up to that `.ALTER` statement.
- After it completes the first simulation, HSPICE reads the input between the first `.ALTER` statement, and either the next `.ALTER` statement or the `.END` statement.
- HSPICE RF then uses these statements to modify the input netlist file.
- HSPICE RF then resimulates the circuit.
- For each additional `.ALTER` statement, HSPICE RF performs the simulation that precedes the first `.ALTER` statement.
- HSPICE RF then performs another simulation, using the input between the current `.ALTER` statement, and either the next `.ALTER` statement or the `.END` statement.

If you do not want to rerun the simulation that precedes the first `.ALTER` statement, every time you run an `.ALTER` simulation, then do the following:

1. Put the statements that precede the first `.ALTER` statement, into a library.
2. Use the `.LIB` statement in the main input file.
3. Put a `.DEL LIB` statement in the `.ALTER` section, to delete that library for the `.ALTER` simulation run.

Altering Design Variables and Subcircuits

The following rules apply when you use an `.ALTER` block to alter design variables and subcircuits in HSPICE. This section does not apply to HSPICE RF.

- If the name of a new element, `.MODEL` statement, or subcircuit definition is identical to the name of an original statement of the same type, then the new statement replaces the old. Add new statements in the input netlist file.
- You can alter element and `.MODEL` statements within a subcircuit definition. You can also add a new element or `.MODEL` statement to a subcircuit definition. To modify the topology in subcircuit definitions, put the element into libraries. To add a library, use `.LIB`; to delete, use `.DEL LIB`.
- If a parameter name in a new `.PARAM` statement in the `.ALTER` module is identical to a previous parameter name, then the new assigned value replaces the old value.
- If you used parameter (variable) values for elements (or model parameter values) when you used `.ALTER`, use the `.PARAM` statement to change these parameter values. Do not use numerical values to redescribe elements or model parameters.
- If you used an `.OPTION` statement (in an original input file or a `.ALTER` block) to turn on an option, you can turn that option off.
- Each `.ALTER` simulation run prints only the actual altered input. A special `.ALTER` title identifies the run.
- `.ALTER` processing cannot revise `.LIB` statements within a file that an `.INCLUDE` statement calls. However, `.ALTER` processing can accept `.INCLUDE` statements, within a file that a `.LIB` statement calls.

Using Multiple .ALTER Blocks

This section does not apply to HSPICE RF.

- For the first simulation run, HSPICE reads the input file, up to the first `.ALTER` statement, and performs the analyses up to that `.ALTER` statement.
- After it completes the first simulation, HSPICE reads the input between the first `.ALTER` statement, and either the next `.ALTER` statement or the `.END` statement.
- HSPICE then uses these statements to modify the input netlist file.
- HSPICE then resimulates the circuit.
- For each additional `.ALTER` statement, HSPICE performs the simulation that precedes the first `.ALTER` statement.
- HSPICE then performs another simulation, using the input between the current `.ALTER` statement, and either the next `.ALTER` statement or the `.END` statement.

If you do not want to rerun the simulation that precedes the first `.ALTER` statement, every time you run an `.ALTER` simulation, then do the following:

1. Put the statements that precede the first `.ALTER` statement, into a library.
2. Use the `.LIB` statement in the main input file.
3. Put a `.DEL LIB` statement in the `.ALTER` section, to delete that library for the `.ALTER` simulation run.

Connecting Nodes

Use a `.CONNECT` statement to connect two nodes in your HSPICE netlist, so that simulation evaluates two nodes as only one node. Both nodes must be at the same level in the circuit design that you are simulating: you cannot connect nodes that belong to different subcircuits. You also cannot use this statement in HSPICE RF.

Deleting a Library

Use a `.DEL LIB` statement to remove library data from memory. The next time you run a simulation, the `.DEL LIB` statement removes the `.LIB` call statement, with the same library number and entry name, from memory. You can then use a `.LIB` statement to replace the deleted library.

You can use a `.DEL LIB` statement with a `.ALTER` statement. HSPICE RF does not support the `.ALTER` statement.

Ending a Netlist

An `.END` statement must be the last statement in the input netlist file. Text that follows the `.END` statement is a comment, and has no effect on the simulation.

An input file that contains more than one simulation run must include an `.END` statement for each simulation run. You can concatenate several simulations into a single file.

Condition-Controlled Netlists (IF-ELSE)

You can use the IF-ELSE structure to change the circuit topology, expand the circuit, set parameter values for each device instance, select different model cards, reference subcircuits, or define subcircuits in each IF-ELSE block.

```
.if (condition1)
   <statement_block1>

# The following statement block in {braces} is
# optional, and you can repeat it multiple times:
{ .elseif (condition2)
   <statement_block2>
}

# The following statement block in [brackets]
# is optional, and you cannot repeat it:
[ .else
   <statement_block3>
]
.endif
```

- In an `.IF`, `.ELSEIF`, or `.ELSE` condition statement, complex Boolean expressions must not be ambiguous. For example, change `(a==b && c>=d)` to `( (a==b) && (c>=d) )`.
- In an `IF`, `ELSEIF`, or `ELSE` statement block, you can include most valid HSPICE or HSPICE RF analysis and output statements. The exceptions are:
  - `.END`, `.ALTER`, `.GLOBAL`, `.DEL LIB`, `.MALIAS`, `.ALIAS`, `.LIST`, `.NOLIST`, and `.CONNECT` statements.

  - `search`, `d_ibis`, `d_imic`, `d_lv56`, `biasfi`, `modsrh`, `cmiflag`, `nxx`, and `brief` options.

- You can include `IF`-`ELSEIF`-`ELSE` statements in subcircuits and subcircuits in `IF`-`ELSEIF`-`ELSE` statements.
- You can use IF-ELSEIF-ELSE blocks to select different submodules to structure the netlist (using `.INC`, `.LIB`, and `.VEC` statements).
- If two or more models in an IF-ELSE block have the same model name and model type, they must also be the same revision level.
- Parameters in an IF-ELSE block do not affect the parameter value within the condition expression. HSPICE or HSPICE RF updates the parameter value only after it selects the IF-ELSE block.
- You can nest IF-ELSE blocks.
- You can include `.SUBCKT` and `.MACRO` statements within an IF-ELSE block.
- You can include an unlimited number of `ELSEIF` statements within an IF-ELSE block.
- You cannot include sweep parameters or simulation results within an IF-ELSE block.
- You cannot use an IF-ELSE block within another statement. In the following example, HSPICE or HSPICE RF does not recognize the IF-ELSE block as part of the resistor definition:

```
r 1 0
   .if (r_val>10k)
   + 10k
   .else
   + r_val
   .endif
```

Using Subcircuits

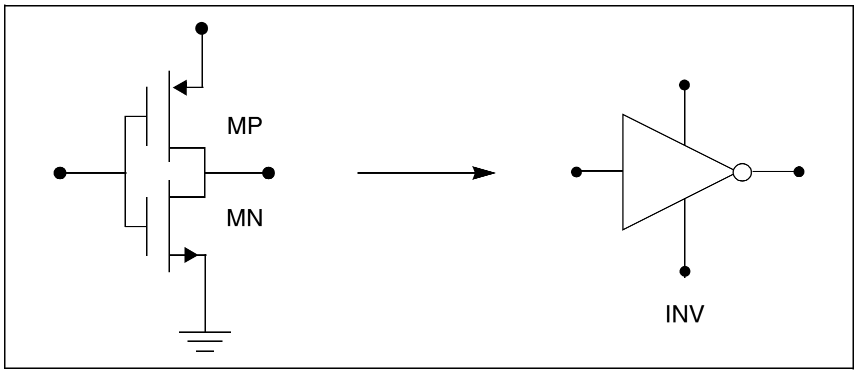
Reusable cells are the key to saving labor in any CAD system. This also applies to circuit simulation, in HSPICE or HSPICE RF.

- To create and simulate a reusable circuit, construct it as a subcircuit.
- Use parameters to expand the utility of a subcircuit.

Traditional SPICE includes the basic subcircuit, but does not provide a way to consistently name nodes. However, HSPICE or HSPICE RF provides a simple method for naming subcircuit nodes and elements: use the subcircuit call name as a prefix to the node or element name.

In HSPICE RF, you cannot replicate output commands within subcircuit (subckt) definitions.

Figure 7 Subcircuit Representation



The following input creates an instance named X1 of the INV cell macro, which consists of two MOSFETs, named MN and MP:

```
X1 IN OUT VD_LOCAL VS_LOCAL inv W=20
.MACRO INV IN OUT VDD VSS W=10 L=1 DJUNC=0
MP OUT IN VDD VDD PCH W=W L=L DTEMP=DJUNC
MN OUT IN VSS VSS NCH W='W/2' L=L DTEMP=DJUNC
.EOM
```

Note:

> To access the name of the MOSFET, inside of the `INV` subcircuit that `X1` calls, the names are `X1.MP` and `X1.MN`. So to print the current that flows through the MOSFETs, use `.PRINT I (X1.MP).`

Hierarchical Parameters

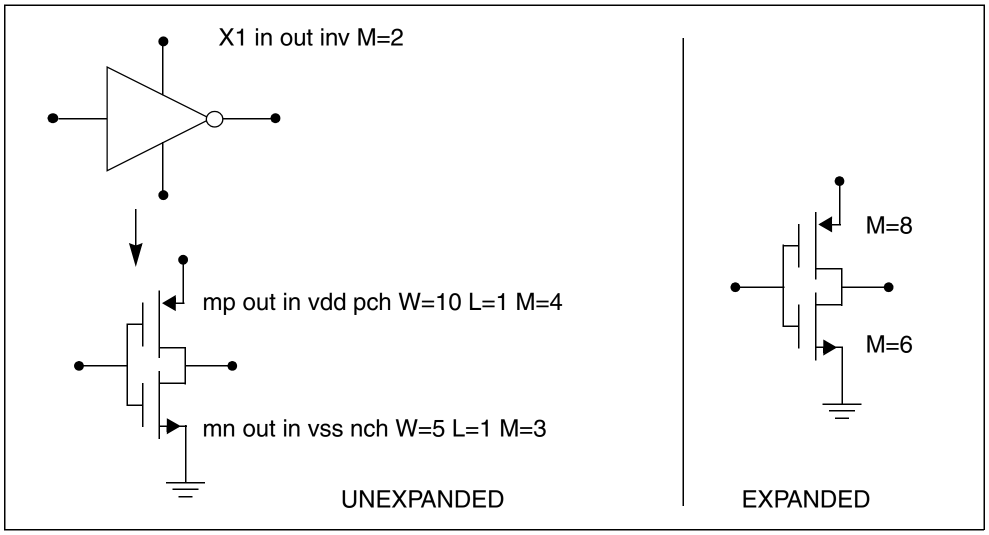
You can use two hierarchical parameters, the `M` (multiply) parameter and the `S` (scale) parameter.

M (Multiply) Parameter

The most basic HSPICE RF subcircuit parameter is the M (multiply) parameter. This keyword is common to all elements, including subcircuits, except for voltage sources. The M parameter multiplies the internal component values, which, in effect, creates parallel copies of the element. To simulate 32 output buffers switching simultaneously, you need to place only one subcircuit; for example,

```
X1 in out buffer M=32
```

Figure 8 How Hierarchical Multiply Works



Multiply works hierarchically. For a subcircuit within a subcircuit, HSPICE RF multiplies the product of both levels. Do not assign a negative value or zero as the `M` value.

S (Scale) Parameter

To scale a subcircuit, use the S (local scale) parameter. This parameter behaves in much the same way as the `M` parameter in the preceding section.

```
.OPTION hier_scale=value
.OPTION scale=value
X1 node1 node2 subname S=valueM parameter
```

The `OPTION HIER_SCALE` statement defines how HSPICE RF interprets the S parameter, where value is either:

- 0 (the default), indicating a user-defined parameter, or
- 1, indicating a scale parameter.

The `.OPTION SCALE` statement defines the original (default) scale of the subcircuit. The specified S scale is relative to this default scale of the subcircuit.

The scale in the `subname` subcircuit is value*scale. Subcircuits can originate from multiple sources, so scaling is multiplicative (cumulative) throughout your design hierarchy.

```
x1 a y inv S=1u
subckt inv in out
x2 a b kk S=1m
.ends
```

In this example:

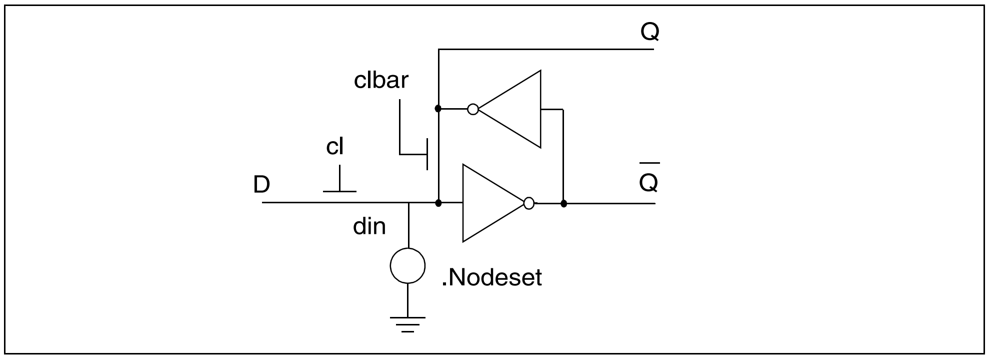
- HSPICE RF scales the `X1` subcircuit by the first `S` scaling value, `1u`*scale.
- Because scaling is cumulative, `X2` (a subcircuit of `X1`) is then scaled, in effect, by the S scaling values of both X1 and X2: `1m*1u*`scale.

Using Hierarchical Parameters to Simplify Simulation

You can use the hierarchical parameter to simplify simulations. An example is shown in the following listing and Figure 9 on page 75.

```
X1 D Q Qbar CL CLBAR dlatch flip=0
.macro dlatch
+ D Q Qbar CL CLBAR flip=vcc
.nodeset v(din)=flip
xinv1 din qbar inv
xinv2 Qbar Q inv
m1 q CLBAR din nch w=5 l=1
m2 D CL din nch w=5 l=1
.eom
```

Figure 9 D Latch with Nodeset



HSPICE does not limit the size or complexity of subcircuits; they can contain subcircuit references, and any model or element statement. However, in HSPICE RF, you cannot replicate output commands within subcircuit definitions. To specify subcircuit nodes in `.PRINT` statements, specify the full subcircuit path and node name.

DDL Library Access

To include a DDL library component in a data file, use the `X` subcircuit call statement with the `DDL` element call. The `DDL` element statement includes the model name, which the actual DDL library file uses.

For example, the following element statement creates an instance of the 1N4004 diode model:

```
X1 2 1 D1N4004
```

Where `D1N4004` is the model name.

See Element and Source Statements on page 55 and the *HSPICE Elements and Device Models Manual* for descriptions of element statements.

Optional parameter fields in the element statement can override the internal specification of the model. For example, for op-amp devices, you can override the offset voltage, and the gain and offset current. Because the DDL library devices are based on HSPICE circuit-level models, simulation automatically compensates for the effects of supply voltage, loading, and temperature.

HSPICE or HSPICE RF accesses DDL models in several ways:

- The installation script creates an hspice.ini initialization file.
- HSPICE or HSPICE RF writes the search path for the DDL and vendor libraries into a `.OPTION SEARCH='<lib_path>'` statement.

  This provides immediate access to all libraries for all users. It also automatically includes the models in the input netlist. If the input netlist references a model or subcircuit, HSPICE or HSPICE RF searches the directory to which the `DDLPATH` environment variable points for a file with the same name as the reference name. This file is an include file so its filename suffix is .inc. HSPICE installation sets the `DDLPATH` variable in the meta.cfg configuration file.
- Set `.OPTION SEARCH='<lib_path>'` in the input netlist.

  Use this method to list the personal libraries to search. HSPICE first searches the default libraries referenced in the hspice.ini file, then searches libraries in the order listed in the input file.
- Directly include a specific model, using the `.INCLUDE` statement. For example, to use a model named T2N2211, store the model in a file named T2N2211.inc, and put the following statement in the input file:

  ```
  .INCLUDE <path>/T2N2211.inc
  ```

  This method requires you to store each model in its own .inc file, so it is not generally useful. However, you can use it to debug new models, when you test only a small number of models.

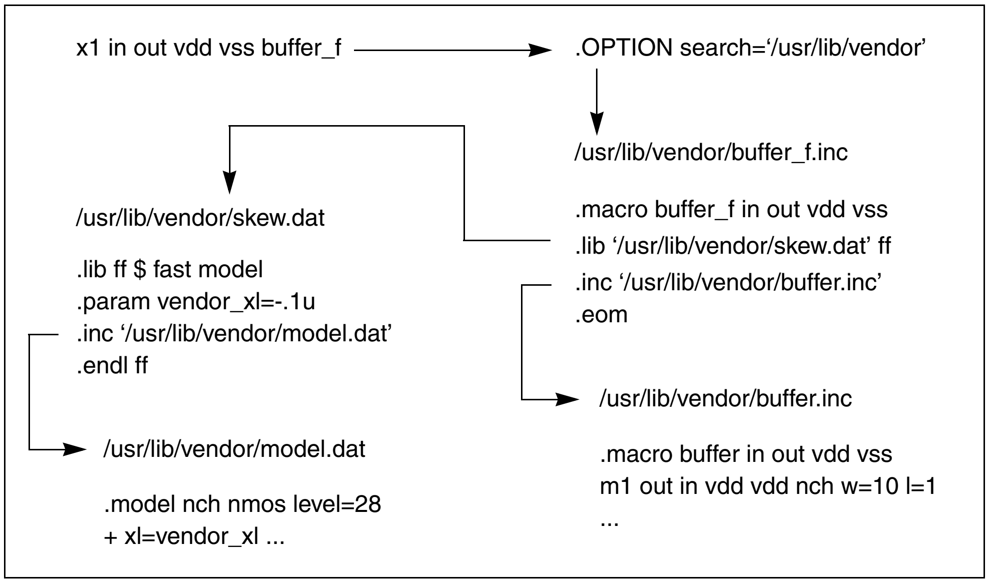
Vendor Libraries

The vendor library is the interface between commercial parts and circuit or system simulation.

- ASIC vendors provide comprehensive cells, corresponding to inverters, gates, latches, and output buffers.
- Memory and microprocessor vendors supply input and output buffers.
- Interface vendors supply complete cells for simple functions and output buffers, to use in generic family output.
- Analog vendors supply behavioral models.

To avoid name and parameter conflicts, models in vendor cell libraries should be within the subcircuit definitions.

Figure 10 Vendor Library Usage


x1 in out vdd vss buffer_f
.OPTION search='/usr/lib/vendor'
/usr/lib/vendor/buffer_f.inc
.macro buffer_f in out vdd vss
.lib '/usr/lib/vendor/skew.dat' ff
.inc '/usr/lib/vendor/buffer.inc'
.eom
/usr/lib/vendor/skew.dat
.lib ff $ fast model
.param vendor_xl=-.1u
.inc '/usr/lib/vendor/model.dat'
.endl ff
/usr/lib/vendor/model.dat
.model nch nmos level=28
+ xl=vendor_xl ...
/usr/lib/vendor/buffer.inc
.macro buffer in out vdd vss
m1 out in vdd vdd nch w=10 l=1
...

Subcircuit Library Structure

Your library structure must adhere to the `.INCLUDE` statement specification in the implicit subcircuit. You can use this statement to specify the directory that contains the <subname>.inc subcircuit file, and then reference the *<subname>* in each subcircuit call.

The component naming conventions for each subcircuit is:

`<subname>.inc`

Store the subcircuit in a directory that is accessible by a `.OPTION SEARCH='<lib_path>'` statement.

Create subcircuit libraries in a hierarchy. Typically, the top-level subcircuit fully describes the input/output buffer; any hierarchy is buried inside. The buried hierarchy can include model statements, lower-level components, and parameter assignments. Your library cannot use `.LIB` or `.INCLUDE` statements anywhere in the hierarchy.

5 Elements

Describes the syntax for the basic elements of a circuit netlist in HSPICE or HSPICE RF.

Elements are local and sometimes customized instances of a device model specified in your design netlist.

For descriptions of the standard device models on which elements (instances) are based, see the *HSPICE Elements and Device Models Manual* and the *HSPICE MOSFET Models Manual*.

Passive Elements

This section describes the passive elements: resistors, capacitors, and inductors.

Values for Elements

HSPICE RF accepts equation-based resistors and capacitors. You can specify the value of a resistor or capacitor as an arbitrary equation, involving node voltages or variable parameters. Unlike HSPICE, you cannot use parameters to indirectly reference node voltages in HSPICE RF.

Resistor Elements in a HSPICE or HSPICE RF Netlist

```
Rxxx n1 n2 <mname> Rval <TC1 <TC2><TC>> <SCALE=val> <M=val>
+ <AC=val> <DTEMP=val> <L=val> <W=val> <C=val>
+ <NOISE=val>

Rxxx n1 n2 <mname> <R=>resistance <<TC1=>val>
+ <<TC2=>val> <<TC=>val> <SCALE=val> <M=val>
+ <AC=val> <DTEMP=val> <L=val> <W=val>
+ <C=val> <NOISE=val>
Rxxx n1 n2 R='equation' ...
```

Parameter	Description
Rxxx	Resistor element name. Must begin with R, followed by up to 1023 alphanumeric characters.
n1	Positive terminal node name.
n2	Negative terminal node name.
mname	Resistor model name. Use this name in elements, to reference a resistor model.
TC	TC1 alias. The current definition overrides the previous definition.
TC1	First-order temperature coefficient for the resistor. See the “Passive Device Models” chapter in the *HSPICE Elements and Device Models Manual* for temperature-dependent relations.
TC2	Second-order temperature coefficient for the resistor.
SCALE	Element scale factor; scales resistance and capacitance by its value. Default=1.0.
R= resistance	Resistance value at room temperature. This can be: ■ a numeric value in ohms ■ a parameter in ohms ■ a function of any node voltages ■ a function of branch currents ■ any independent variables such as `time`, `hertz`, and `temper`

Parameter	Description
M	Multiplier to simulate parallel resistors. For example, for two parallel instances of a resistor, set M=2, to multiply the number of resistors by 2. Default=1.0.
AC	Resistance for AC analysis. Default=Reff.
DTEMP	Temperature difference between the element and the circuit, in degrees Celsius. Default=0.0.
L	Resistor length in meters. Default=0.0, if you did not specify L in a resistor model.
W	Resistor width. Default=0.0, if you did not specify W in the model.
C	Capacitance connected from node n2 to bulk. Default=0.0, if you did not specify C in a resistor model.
user-defined equation	Can be a function of any node voltages, element currents, temperature, frequency, or time
NOISE	■ NOISE=0, do not evaluate resistor noise. ■ NOISE=1, evaluate resistor noise (default).

Resistance can be a value (in units of ohms) or an equation. Required parameters are the two nodes, and the resistance or model name. If you specify other parameters, the node and model name must precede those parameters. Other parameters can follow in any order. If you specify a resistor model (see the “Passive Device Models” chapter in the *HSPICE Elements and Device Models Manual*), the resistance value is optional.

HSPICE RF Examples

Some basic examples for HSPICE RF include:

- `R1` is a resistor whose resistance follows the voltage at node `c`.

  ```
  R1 1 0 ‘v(c)’
  ```

- `R2` is a resistor whose resistance is the sum of the absolute values of nodes `c` and `d`.

  ```
  R2 1 0 ‘abs(v(c)) + abs(v(d))’
  ```

- `R3` is a resistor whose resistance is the sum of the `rconst` parameter, and 100 times `tx1` for a total of 1100 ohms.

```
.PARAM rconst=100 tx1=10
R3 4 5 ‘rconst + tx1 * 100’
```

Linear Resistors

R*xxx node1 node2* < *modelname* > < R = > *value* < TC1=*val* >
+ < TC2=*val* > < W=*val* > < L=*val* > < M=*val* >
+ < C=*val* > < DTEMP=*val* > < SCALE=*val* >

Parameter	Description
Rxxx	Name of a resistor.
node1 and node2	Names or numbers of the connecting nodes.
modelname	Name of the resistor model.
value	Nominal resistance value, in ohms.
R	Resistance, in ohms, at room temperature.
TC1, TC2	Temperature coefficient.
W	Resistor width.
L	Resistor length.
M	Parallel multiplier.
C	Parasitic capacitance between node2 and the substrate.
DTEMP	Temperature difference between element and circuit.
SCALE	Scaling factor.

Example

```
R1 1 2 10.0
Rload 1 GND RVAL

.param rx=100
R3 2 3 RX TC1=0.001 TC2=0
RP X1.A X2.X5.B .5
.MODEL RVAL R
```

In the example above, `R1` is a simple 10Ω linear resistor and `Rload` calls a resistor model named `RVAL`, which is defined later in the netlist.

Note:

If a resistor calls a model, then you do not need to specify a constant resistance, as you do with `R1`.

- `R3` takes its value from the `RX` parameter, and uses the `TC1` and `TC2` temperature coefficients, which become 0.001 and 0, respectively.
- `RP` spans across different circuit hierarchies, and is 0.5Ω.

Behavioral Resistors in HSPICE or HSPICE RF

```
Rxxx n1 n2 . . . <R=> 'equation' . . .
```

Note:

The equation can be a function of any node voltage or branch current, and any independent variables such as `time`, `hertz`, or `temper`.

Example

```
R1 A B R=‘V(A) + I(VDD)’
```

Frequency-Dependent Resistors

```
Rxxx n1 n2 R=equation <CONVOLUTION=[0|1|2] <FBASE=value>
+ <FMAX=value>>
```

Parameter	Description
CONVOLUTION	Indicates which method is used. ▪ 0 : Acts the same as the conventional method. This is the default. ▪ 1 : Applies recursive convolution, and if the rational function is not accurate enough, it switches to linear convolution. ▪ 2 : Applies linear convolution.
FBASE	Specifies the lower bound of the transient analysis frequency. For CONVOLUTION=1 mode, HSPICE starts sampling at this frequency. For CONVOLUTION=2 mode, HSPICE uses this value as the base frequency point for Inverse Fourier Transformation. For recursive convolution, the default value is 0Hz, and for linear convolution, HSPICE uses the reciprocal of the transient period.
FMAX	Specifies the possible maximum frequency of interest. The default value is the frequency point where the function reaches close enough to infinity value, assuming that the monotonous function is approaching the infinity value and that it is taken at 10THz. The equation should be a function of HERTZ. If CONVOLUTION is turned on when a HERTZ keyword is not used in the equation, it is automatically be turned off to let the resistor behave as conventional.The equation can be a function of temperature, but it cannot be node voltage or branch current and time.

The equation can only be a function of time-independent variables such as hertz, and temperature.

Example

```
R1 1 2 r='1.0 + 1e-5*sqrt(HERTZ)' CONVOLUTION=1
```

Skin Effect Resistors

```
Rxxx n1 n2 R=value Rs=value
```

The `Rs` indicates the skin effect coefficient of the resistor.

The complex impedance of the resistor can be expressed as the following equation:

```
R(f)=Ro + (1+j)*Rs*sqrt(f)
```

The `Ro`, `j`, and `f` are DC resistance, imaginably unit (j^2=-1) and frequency, respectively.

Capacitors

```
Cxxx n1 n2 <mname> <C=>capacitance <<TC1=>val>
+ <<TC2=>val> <SCALE=val> <IC=val> <M=val>
+ <W=val> <L=val> <DTEMP=val>
Cxxx n1 n2 <C=>'equation' <CTYPE=0|1>
+ <above_options...>
```

Polynomial form:

```
Cxxx n1 n2 POLY c0 c1... <above_options...>
```

Parameter	Description
Cxxx	Capacitor element name. Must begin with C, followed by up to 1023 alphanumeric characters.
n1	Positive terminal node name.
n2	Negative terminal node name.
mname	Capacitance model name. Elements use this name to reference a capacitor.
C=capacitance	Capacitance at room temperature—a numeric value or a parameter in farads.
TC1	First-order temperature coefficient for the capacitor. See the “Passive Device Models” chapter in the *HSPICE Elements and Device Models Manual* for temperature-dependent relations.
TC2	Second-order temperature coefficient for the capacitor.

Parameter	Description
SCALE	Element scale parameter, scales capacitance by its value. Default=1.0.
IC	Initial voltage across the capacitor, in volts. If you specify UIC in the .TRAN statement, HSPICE or HSPICE RF uses this value as the DC operating point voltage. The .IC statement overrides it.
M	Multiplier, used to simulate multiple parallel capacitors. Default=1.0
W	Capacitor width, in meters. Default=0.0, if you did not specify W in a capacitor model.
L	Capacitor length, in meters. Default=0.0, if you did not specify L in a capacitor model.
DTEMP	Element temperature difference from the circuit temperature, in degrees Celsius. Default=0.0.
C='equation'	Capacitance at room temperature, specified as a function of: ■ any node voltages ■ any branch currents ■ any independent variables such as `time`, `hertz`, and `temper`
CTYPE	Determines capacitance charge calculation for elements with capacitance equations. If the C capacitance is a function of V(n1<,n2>), set CTYPE=0. Use this setting correctly, to ensure proper capacitance calculations, and correct simulation results. Default=0.
POLY	Keyword, to specify capacitance as a non-linear polynomial.
c0 c1...	Coefficients of a polynomial, described as a function of the voltage across the capacitor. c0 represents the magnitude of the 0th order term, `c1` represents the magnitude of the 1st order term, and so on. You cannot use parameters as coefficient values.

You can specify capacitance as a numeric value, in units of farads, as an equation, or as a polynomial of the voltage. The only required fields are the two nodes, and the capacitance or model name.

- If you use the parameter labels, the nodes and model name must precede the labels. Other arguments can follow in any order.
- If you specify a capacitor model (see the "Passive Device Models" chapter in the *HSPICE Elements and Device Models Manual*), the capacitance value is optional.

If you use an equation to specify capacitance, the `CTYPE` parameter determines how HSPICE calculates the capacitance charge. The calculation is different, depending on whether the equation uses a self-referential voltage (that is, the voltage across the capacitor, whose capacitance is determined by the equation).

To avoid syntax conflicts, if a capacitor model has the same name as a capacitance parameter, HSPICE or HSPICE RF uses the model name.

Example 1

In the following example, C1 assumes its capacitance value from the model, not the parameter.

```
.PARAMETER CAPXX=1
C1 1 2 CAPXX
.MODEL CAPXX C CAP=1
```

Example 2

In the following example, the C1 capacitors connect from node 1 to node 2, with a capacitance of 20 picofarads:

```
C1 1 2 20p
```

In this next example, Cshunt refers to three capacitors in parallel, connected from the node output to ground, each with a capacitance of 100 femtofarads.

```
Cshunt output gnd C=100f M=3
```

The Cload capacitor connects from the driver node to the output node. The capacitance is determined by the voltage on the capcontrol node, times 1E-6. The initial voltage across the capacitor is 0 volts.

```
Cload driver output C='1u*v(capcontrol)' CTYPE=1 IC=0v
```

The C99 capacitor connects from the in node to the out node. The capacitance is determined by the polynomial C=c0 + c1*v + c2*v*v, where v is the voltage across the capacitor.

```
C99 in out POLY 2.0 0.5 0.01
```

Linear Capacitors

```
Cxxx node1 node2 < modelname > < C=> value < TC1=val >
+ < TC2=val > <W=val > < L=val > < DTEMP=val >
+ < M=val > < SCALE=val > < IC=val >
```

Parameter	Description
Cxxx	Name of a capacitor. Must begin with C, followed by up to 1023 alphanumeric characters.
node1 and node2	Names or numbers of connecting nodes.
value	Nominal capacitance value, in Farads.
modelname	Name of the capacitor model.
C	Capacitance, in Farads, at room temperature.
TC1, TC2	Specifies the temperature coefficient.
W	Capacitor width.
L	Capacitor length.
M	Multiplier to simulate multiple parallel capacitors.
DTEMP	Temperature difference between element and circuit.
SCALE	Scaling factor.
IC	Initial capacitor voltage.

Example

```
Cbypass 1 0 10PF
C1 2 3 CBX
.MODEL CBX C
CB B 0 10P IC=4V
CP X1.XA.1 0 0.1P
```

In this example:

- Cbypass is a straightforward, 10-picofarad (PF) capacitor.
- C1, which calls the CBX model, does not have a constant capacitance.

- CB is a 10 PF capacitor, with an initial voltage of 4V across it.
- CP is a 0.1 PF capacitor.

Frequency-Dependent Capacitors

You can specify frequency-dependent capacitors using the `C='equation'` with the `HERTZ` keyword. The `HERTZ` keyword represents the operating frequency. In time domain analyses, an expression with the `HERTZ` keyword behaves differently according to the value assigned to the `CONVOLUTION` keyword.

Syntax

```
Cxxx n1 n2 C='equation' <CONVOLUTION=[0|1|2]
+ <FBASE=val> <FMAX=val>>
```

Parameter	Description
n1 n2	Names or numbers of connecting nodes.
equation	Expressed as a function of HERTZ. If CONVOLUTION=1 or 2 and HERTZ is not used in the equation, CONVOLUTION is turned off and the capacitor behaves conventionally. The equation can be a function of temperature, but it does not support variables of node voltage, branch current, or time. If these variables exist in the expression and CONVOLUTION=1 or 2, then only their values at the operating point are considered in calculation.
CONVOLUTION	Specifies the method used. ■ 0 (default): HERTZ=0 in time domain analysis. ■ 1 or 2: performs Inverse Fast Fourier Transformation (IFFT) linear convolution.
FBASE	Base frequency to use for transient analysis. This value becomes the base frequency point for Inverse Fast Fourier Transformation (IFFT) when CONVOLUTION=1 or 2. If you do not set this value, the base frequency is a reciprocal value of the transient period.
FMAX	Maximum frequency to use for transient analysis. Used as the maximum frequency point for Inverse Fourier Transformation. If you do not set this value, the reciprocal value of RISETIME is taken.

Example

```
C1 1 2 C='1e-6 - HERTZ/1e16' CONVOLUTION=1 fbase=10
+ fmax=30meg
```

Behavioral Capacitors in HSPICE or HSPICE RF

```
    Cxxx n1 n2 . . . C='equation' CTYPE=0 or 1
```

Parameter	Description
CTYPE	Determines the calculation mode for elements that use capacitance equations. Set this parameter carefully, to ensure correct simulation results. HSPICE RF extends the definition and values of CTYPE, relative to HSPICE: ▪ CTYPE=0, if C depends only on its own terminal voltages—that is, a function of V(n1<, n2>). ▪ CTYPE=1, if C depends only on outside voltages or currents. ▪ CTYPE=2, if C depends on both its own terminal and outside voltages. This is the default for HSPICE RF. HSPICE does not support CTYPE=2.

You can specify the capacitor value as a function of any node voltage or branch current, and any independent variables such as `time`, `hertz`, and `temper`.

Example

```
C1 1 0 C='1e-9*V(10)' CTYPE=1
V10 10 0 PWL(0,1v t1,1v t2,4v)
```

DC Block Capacitors

```
Cxxx node1 node2 <C=> INFINITY  <IC=val>
```

When the capacitance of a capacitor is infinity, this element is called a “DC block.” In HSPICE, you specify an `INFINITY` value for such capacitors.

HPSICE does not support any other capacitor parameters for DC block elements, because HSPICE assumes that an infinite capacitor value is independent of any scaling factors.

The DC block acts as an open circuit for all DC analyses. HSPICE calculates the DC voltage across the nodes of the circuit. In all other (non-DC) analyses, a DC voltage source of this value represents the DC block—HSPICE does not allow `dv/dt` variations.

Charge-Conserved Capacitors

```
Cxxx node1 node2 q='expression'
```

HSPICE supports AC, DC, TRAN, and PZ analyses for charge-conserved capacitors.

The `expression` supports the following parameters and variables:

- Parameters
  - node voltages
  - branch currents
- Variables
  - `time`
  - `temper`
  - `hertz`

  Note:

  The `hertz` variable is not supported in transient analyses.

Parameters must be used directly in an equation. HSPICE does not support parameters that represent an equation containing variables.

Error Handling If you use an unsupported parameter in an expression, HSPICE issues an error message and aborts the simulation. HSPICE ignores unsupported analysis types and then issues warning a message.

Limitations The following syntax does not support charge-conserving capacitors:

```
Cxx node1 node2 C='expression'
```

Capacitor equations are not implicitly converted to charge equations.

Example 1: Capacitance-based Capacitor

```
C1 a b C='Co*(1+alpha*V(a,b)' ctype=0
```

You can obtain Q by integrating ‘C’ w.r.t V(a,b)

Example 2: Charge-based Capacitor

```
C1 a b Q='Co*V(a,b)(1+0.5*alpha*V(a,b))
```

Example 3: Capacitance-based Capacitor

```
.option list node post
r1 1 2 100
r2 3 0 200
Vin 1 0 pulse(0 5v 1ns 2ns 2ns 10ns 20ns)
C1 2 3 c='cos(v(2,3)) + v(1,2)' ctype=2
.tran 1ns 100ns
.print tran  i(c1)
.end
```

Example 4: Charge-based Capacitor

```
.option list node post
r1 1 2 100
r2 3 0 200
Vin 1 0 pulse(0 5v 1ns 2ns 2ns 10ns 20ns)
C1 2 3 q='sin(v(2,3)) + v(2,3)*v(1,2)'
.tran 1ns 100ns
.print tran  i(c1)
.end
```

Inductors

General form:

```
Lxxx n1 n2 <L=>inductance <mname> <<TC1=>val>
+ <<TC2=>val> <SCALE=val> <IC=val> <M=val>
+ <DTEMP=val> <R=val>
Lxxx n1 n2 L='equation' <LTYPE=val> <above_options...>
```

Polynomial form:

```
Lxxx n1 n2 POLY c0 c1... <above_options...>
```

Magnetic winding form:

```
Lxxx n1 n2 NT=turns <above_options...>
```

Parameter	Description
Lxxx	Inductor element name. Must begin with L, followed by up to 1023 alphanumeric characters.
n1	Positive terminal node name.
n2	Negative terminal node name.

Parameter	Description
TC1	First-order temperature coefficient for the inductor. See the "Passive Device Models" chapter in the *HSPICE Elements and Device Models Manual* for temperature-dependent relations.
TC2	Second-order temperature coefficient for the inductor.
SCALE	Element scale parameter; scales inductance by its value. Default=1.0.
IC	Initial current through the inductor, in amperes. HSPICE or HSPICE RF uses this value as the DC operating point voltage, when you specify UIC in the .TRAN statement. The .IC statement overrides it.
L=inductance	Inductance value. This can be: ■ a numeric value, in henries ■ a parameter in henries ■ a function of any node voltages ■ a function of branch currents ■ any independent variables such as `time`, `hertz`, and `temper`
M	Multiplier, used to simulate parallel inductors. Default=1.0.
DTEMP	Temperature difference between the element and the circuit, in degrees Celsius. Default=0.0.
R	Resistance of the inductor, in ohms. Default=0.0.
L='equation'	Inductance at room temperature, specified as: ■ a function of any node voltages ■ a function of branch currents ■ any independent variables such as `time`, `hertz`, and `temper`
LTYPE	Calculates inductance flux for elements, using inductance equations. If the L inductance is a function of I(Lxxx), then set LTYPE=0. Otherwise, set LTYPE=1. Use this setting correctly, to ensure proper inductance calculations, and correct simulation results. Default=0.

Parameter	Description
POLY	Keyword that specifies the inductance, calculated by a polynomial.
c0 c1...	Coefficients of a polynomial in the current, describing the inductor value. c0 is the magnitude of the 0th order term, c1 is the magnitude of the 1st order term, and so on.
NT=turns	Number of turns of an inductive magnetic winding.
mname	Saturable core model name. See the “Passive Device Models” chapter in the *HSPICE Elements and Device Models Manual* for model information.

In this syntax, the inductance can be either a value (in units of henries), an equation, a polynomial of the current, or a magnetic winding. Required fields are the two nodes, and the inductance or model name.

- If you specify parameters, the nodes and model name must be first. Other parameters can be in any order.
- If you specify an inductor model (see the “Passive Device Models” chapter in the *HSPICE Elements and Device Models Manual*), the inductance value is optional.

Example 1

In the following example, the L1 inductor connects from the coilin node to the coilout node, with an inductance of 100 nanohenries.

```
L1 coilin coilout 100n
```

Example 2

The Lloop inductor connects from node 12 to node 17. Its inductance is 1 microhenry, and its temperature coefficients are 0.001 and 0.

```
Lloop 12 17 L=1u TC1=0.001 TC2=0
```

Example 3

The Lcoil inductor connects from the input node to ground. Its inductance is determined by the product of the current through the inductor, and 1E-6.

```
Lcoil input gnd L='1u*i(input)' LTYPE=0
```

Example 4

The L99 inductor connects from the in node to the out node. Its inductance is determined by the polynomial L=c0 + c1*i + c2*i*i, where i is the current through the inductor. The inductor also has a specified DC resistance of 10 ohms.

```
L99 in out POLY 4.0 0.35 0.01 R=10
```

Example 5

The `L` inductor connects from node 1 to node, as a magnetic winding element, with 10 turns of wire.

```
L 1 2 NT=10
```

Mutual Inductors

General form:

K*xxx* L*yyy* L*zzz* <K=*coupling* | *coupling*>

Mutual core form:

K*aaa* L*bbb* <L*ccc* ... <L*ddd*>> *mname* <MAG=*magnetization*>

Parameter	**Description**
Kxxx	Mutual inductor element name. Must begin with K, followed by up to 1023 alphanumeric characters.
Lyyy	Name of the first of two coupled inductors.
Lzzz	Name of the second of two coupled inductors.
K=coupling	Coefficient of mutual coupling. K is a unitless number, with magnitude > 0 and < 1. If K is negative, the direction of coupling reverses. This is equivalent to reversing the polarity of either of the coupled inductors. Use the K=coupling syntax when using a parameter value or an equation, and the keyword “k=” can be omitted.
Kaaa	Saturable core element name. Must begin with K, followed by up to 1023 alphanumeric characters.

Parameter	Description
Lbbb, Lccc, Lddd	Names of the windings about the Kaaa core. One winding element is required, and each winding element must use the magnetic winding syntax. All winding elements with the same magnetic core model should be written in one mutual inductor statement in the netlist.
mname	Saturable core model name. (See the "Passive Device Models" chapter in the *HSPICE Elements and Device Models Manual* for more information.)
MAG= magnetization	Initial magnetization of the saturable core. You can set this to +1, 0, or -1, where +/- 1 refer to positive and negative values of the BS model parameter. (See the "Passive Device Models" chapter in the *HSPICE Elements and Device Models Manual* for more information.)

In this syntax, *coupling* is a unitless value, from zero to one, representing the coupling strength. If you use parameter labels, the nodes and model name must be first. Other arguments can be in any order. If you specify an inductor model (see the "Passive Device Models" chapter in the *HSPICE Elements and Device Models Manual*), the inductance value is optional.

You can determine the coupling coefficient, based on geometric and spatial information. To determine the final coupling inductance, HSPICE or HSPICE RF divides the coupling coefficient by the square-root of the product of the self-inductances.

When using the mutual inductor element to calculate the coupling between more than two inductors, HSPICE or HSPICE RF can automatically calculate an approximate second-order coupling. See the third example below for a specific situation.

Note:

> The automatic inductance calculation is an estimation, and is accurate for a subset of geometries. The second-order coupling coefficient is the product of the two first-order coefficients, which is not correct for many geometries.

Example 1

The Lin and Lout inductors are coupled, with a coefficient of 0.9.

```
K1 Lin Lout 0.9
```

Example 2

The Lhigh and Llow inductors are coupled, with a coefficient equal to the value of the `COUPLE` parameter.

```
Kxfmr Lhigh Llow K=COUPLE
```

- The K1 mutual inductor couples L1 and L2.
- The K2 mutual inductor couples L2 and L3.

Example 3

The coupling coefficients are 0.98 and 0.87. HSPICE or HSPICE RF automatically calculates the mutual inductance between L1 and L3, with a coefficient of 0.98*0.87=0.853.

```
K1 L1 L2 0.98
K2 L2 L3 0.87
```

Ideal Transformer

```
Kxxx Li Lj <k=IDEAL | IDEAL>
```

Ideal transformers use the `IDEAL` keyword with the K element to designate ideal K transformer coupling.

This keyword activates the following equation set for non-DC values, which is presented here with multiple coupled inductors. Ij is the current into the first terminal of `Lj`.

```
V1/sqrt(L1)=V2/sqrt(L2)=V3/sqrt(L3)=V4/sqrt(L4)=...
(I1*sqrt(L1) + (I2*sqrt(L2) + (I3*sqrt(L3) + (I4*sqrt(L4) +
     ...=0
```

HSPICE can solve any I or V in terms of `L` ratios. DC is treated as expected—inductors are treated as short circuits. Mutual coupling is ignored for DC.

Inductors that use the `INFINITY` keyword can be coupled with `IDEAL` K elements. In this situation, all inductors involved must have the `INFINITY` value, and for `K=IDEAL`, the ratio of all `L` values is unity. Then, for two `L` values:

```
v2= v1
i2 + i1=0
```

Example 1

This example is a standard 5-pin ideal balun transformer subcircuit. Two pins are grounded for standard operation. With all `K` values being `IDEAL`, the absolute `L` values are not crucial—only their ratios are important.

```
**
**   all K's ideal  -----o out1
**                  Lo1=.25
**   o----in-       -----o 0
**         Lin=1    Lo2=.25
** 0 o-------       -----o out2
**
.subckt BALUN1  in  out1  out2
Lin    in    gnd   L=1
Lo1    out1  gnd   L=0.25
Lo2    gnd   out2  L=0.25
K12    Lin  Lo1    IDEAL
K13    Lin  Lo2    IDEAL
K23    Lo1  Lo2    IDEAL
.ends
```

Example 2

This example is a 2-pin ideal 4:1 step-up balun transformer subcircuit with shared DC path (no DC isolation). Input and output have a common pin, and both inductors have the same value. Note that Rload=4*Rin.

```
**
**   all K's ideal
**in o-------------------o out=in
**                  L1=1
**                  -----o 0
**                  L2=1
**                  -----o out2
**
** With all K's ideal, the actual L's values are
** not important -- only their ratio to each other.
.subckt BALUN2 in  out2
L1     in   gnd   L=1
L2     gnd  out2  L=1
K12    L1   L2   IDEAL
.ends
```

Example 3

This example is a 3-pin ideal balun transformer with shared DC path (no DC isolation). All inductors have the same value (here set to unity).

```
**
**   all K's ideal  -----o out1
**                  Lo2=1
**                  -----o 0
**                  Lo1=1
**                  -----o out2
**    in            Lin=1
**   o-------------------o in
**
.subckt BALUN3 in  out1  out2
Lo2    gnd  out1  L=1
Lo1    out2 gnd   L=1
Lin    in   out2  L=1
K12    Lin  Lo1  IDEAL
K13    Lin  Lo2  IDEAL
K23    Lo1  Lo2  IDEAL
.ends
```

Linear Inductors

L*xxx* *node1* *node2* <L => *inductance* <TC1=*val*> <TC2=*val*>
+ <M=*val*> <DTEMP=*val*> <IC=*val*>

Parameter	Description
Lxxx	Name of an inductor.
node1 and node2	Names or numbers of the connecting nodes.
inductance	Nominal inductance value, in Henries.
L	Inductance, in Henries, at room temperature.
TC1, TC2	Temperature coefficient.
M	Multiplier for parallel inductors.
DTEMP	Temperature difference between the element and the circuit.
IC	Initial inductor current.

Example:

```
LX A B 1E-9
LR 1 0 1u IC=10mA
```

- `LX` is a 1 nH inductor.
- `LR` is a 1 uH inductor, with an initial current of 10 mA.

Frequency-Dependent Inductors

You can specify frequency-dependent inductors using the `L='equation'` with the `HERTZ` keyword. The `HERTZ` keyword represents the operating frequency. In time domain analyses, an expression with the `HERTZ` keyword behaves differently according to the value assigned to the `CONVOLUTION` keyword.

Syntax

```
Lxxx n1 n2 L='equation' <CONVOLUTION=[0|1|2] <FBASE=value>
+ <FMAX=value>>
```

Parameter	Description
Lxxx	Inductor element name. Must begin with L, followed by up to 1023 alphanumeric characters
n1 n2	Positive and negative terminal node names.
equation	The equation should be a function of HERTZ. If CONVOLUTION is turned on when a HERTZ keyword is not used in the equation, CONVOLUTION is automatically be turned off and the inductor behaves conventionally.The equation can be a function of temperature, but it does not support variables of node voltage, branch current, or time. If these variables exist in the equation with CONVOLUTION turned on, only their values at the operating point are considered in the calculation.
CONVOLUTION	Indicates which method is used. ■ 0 (default): Acts the same as the conventional method. ■ 1 : Applies recursive convolution, and if the rational function is not accurate enough, it switches to linear convolution. ■ 2 : Applies linear convolution.

Parameter	Description
FBASE	Specifies the lower bound of the transient analysis frequency. ■ For CONVOLUTION=1 mode, HSPICE starts sampling at this frequency. ■ For CONVOLUTION=2 mode, HSPICE uses this value as the base frequency point for Inverse Fourier Transformation. ■ For recursive convolution, the default value is 0Hz. ■ For linear convolution, HSPICE uses the reciprocal of the transient period.
FMAX	Specifies the possible maximum frequency of interest. The default value is the frequency point where the function reaches close enough to infinity value, assuming that the monotonous function is approaching the infinity value and that it is taken at 10THz.

Example

```
L1 1 2 L='0.5n + 0.5n/(1 + HERTZ/1e8)' CONVOLUTION=1 fbase=10
+ fmax=30meg
```

AC Choke Inductors

Syntax

```
Lxxx node1 node2  <L=> INFINITY  <IC=val>
```

When the inductance of an inductor is infinity, this element is called an “AC choke.” In HSPICE, you specify an `INFINITY` value for inductors.

HSPICE does not support any other inductor parameters, because it assumes that the infinite inductance value is independent of temperature and scaling factors. The AC choke acts as a short circuit for all DC analyses and HSPICE calculates the DC current through the inductor. In all other (non-DC) analyses, a DC current source of this value represents the choke—HSPICE does not allow `di/dt` variations.

To properly simulate power-line inductors with HSPICE RF, either set them to analog mode or invoke the `SIM_RAIL` option:

```
.OPTION SIM_ANALOG=“L1”
```

-or-

```
.OPTION SIM_RAIL=ON
```

Reluctors

Syntax

Reluctance Inline Form

```
Lxxx n1p n1n ... nNp nNn
+ RELUCTANCE=(r1, c1, val1, r2, c2, val2, ... , rm, cm, valm)
+ <SHORTALL=yes | no> <IGNORE_COUPLING=yes | no>
```

Reluctance External File Form

```
Lxxx n1p n1n ... nNp nNn RELUCTANCE
+ FILE="<filename1>"  [FILE="<filename2>" [...]]
+ <SHORTALL=yes | no> <IGNORE_COUPLING=yes | no>
```

Parameter	Description
Lxxx	Name of a reluctor. Must begin with L, followed by up to 1023 alphanumeric characters
n1p n1n ... nNp nNn	Names of the connecting terminal nodes. The number of terminals must be even. Each pair of ports represents the location of an inductor.
RELUCTANCE	Keyword to specify reluctance (inverse inductance).
r1, c1, val1, r2, c2, val2, ... rm, cm, valm	Reluctance matrix data. In general, K will be sparse and only non-zero values in the matrix need be given. Each matrix entry is represented by a triplet (r,c,val). The value r and c are integers referring to a pair of inductors from the list of terminal nodes. If there are 2*N terminal nodes, there will be N inductors, and the r and c values must be in the range [1,N]. The val value is a reluctance value for the (r,c) matrix location, and the unit for reluctance is the inverse Henry (H^{-1}). Only terms along and above the diagonal are specified for the reluctance_matrix. The simulator fills in the lower triangle to ensure symmetry. If you specify lower diagonal terms, the simulator converts that entry to the appropriate upper diagonal term. If multiple entries are supplied for the same (r,c) location, then only the first one is used, and a warning will be issued indicating that some entries are ignored. All diagonal entries of the reluctance matrix must be assigned a positive value. The reluctance matrix should be positive definite.

Parameter	Description
FILE="<filename1>"	For the external file format, the data files should contain three columns of data. Each row should contain an (r,c,val) triplet separated by white space. The r, c, and val values may be expressions surrounded by single quotes. Multiple files may be specified to allow the reluctance data to be spread over several files if necessary.
SHORTALL	■ SHORTALL=yes, all inductors in this model are converted to short circuits, and all reluctance matrix values are ignored. ■ SHORTALL=no (default), inductors are not converted to short circuits, and reluctance matrix values are not ignored.
IGNORE_COUPLIN G	■ IGNORE_COUPLING=yes, all off-diagonal terms are ignored (that is, set to zero). ■ IGNORE_COUPLING=no (default), off-diagonal terms are not ignored.

Example

This example has 9 segments (or ports) with 12 nodes, and can potentially generate a 9x9 reluctance matrix with 81 elements.

```
L_ThreeNets a 1 1 2 2 a_1 b 4 4 5 5 b_1 c 7 7 8 8 c_1
+ RELUCTANCE=(
+ 1  1    103e9
+ 1  4    -34.7e9
+ 1  7    -9.95e9
+ 4  4    114e9
+ 4  7    -34.7e9
+ 7  7    103e9
+ 2  2    103e9
+ 2  5    -34.7e9
+ 2  8    -9.95e9
+ 5  5    114e9
+ 5  8    -34.7e9
+ 8  8    103e9
+ 3  3    103e9
+ 3  6    -34.7e9
+ 3  9    -9.95e9
+ 6  6    114e9
+ 6  9    -34.7e9
+ 9  9    103e9 )
+ SHORTALL = no IGNORE_COUPLING = no
```

Alternatively, the same element could be specified by using:

```
L_ThreeNets a 1 1 2 2 a_1 b 4 4 5 5 b_1 c 7 7 8 8 c_1 RELUCTANCE
+ FILE="reluctance.dat" SHORTALL = no IGNORE_COUPLING = no
```

Where reluctance.dat contains:

```
+ 1  1    103e9
+ 1  4    -34.7e9
+ 1  7    -9.95e9
+ 4  4    114e9
+ 4  7    -34.7e9
+ 7  7    103e9
+ 2  2    103e9
+ 2  5    -34.7e9
+ 2  8    -9.95e9
+ 5  5    114e9
+ 5  8    -34.7e9
+ 8  8    103e9
+ 3  3    103e9
+ 3  6    -34.7e9
+ 3  9    -9.95e9
+ 6  6    114e9
+ 6  9    -34.7e9
+ 9  9    103e9
```

The following shows the mapping between the port numbers and node pairs:

Ports	1	2	3	4	5	6	7	8	9
Node pairs	(a,1)	(1,2)	(2,a_1)	(b,4)	(4,5)	(5,b_1)	(c,7)	(7,8)	(8,c_1)

Active Elements

This section describes the active elements: diodes and transistors.

Diode Element

Geometric (`LEVEL=1`) or Non-Geometric (`LEVEL=3`) form:

```
Dxxx nplus nminus mname <<AREA=>area> <<PJ=>val>
+ <WP=val> <LP=val> <WM=val> <LM=val> <OFF>
+ <IC=vd> <M=val> <DTEMP=val>

Dxxx nplus nminus mname <W=width> <L=length> <WP=val>
+ <LP=val> <WM=val> <LM=val> <OFF> <IC=vd> <M=val>
+ <DTEMP=val>
```

Fowler-Nordheim (`LEVEL=2`) form:

```
Dxxx nplus nminus mname <W=val <L=val>> <WP=val>
+ <OFF> <IC=vd> <M=val>
```

Parameter	Description
Dxxx	Diode element name. Must begin with D, followed by up to 1023 alphanumeric characters.
nplus	Positive terminal (anode) node name. The series resistor for the equivalent circuit is attached to this terminal.
nminus	Negative terminal (cathode) node name.
mname	Diode model name reference.
AREA	Area of the diode (unitless for LEVEL=1 diode, and square meters for LEVEL=3 diode). This affects saturation currents, capacitances, and resistances (diode model parameters are IK, IKR, JS, CJO, and RS). The SCALE option does not affect the area factor for the LEVEL=1 diode. Default=1.0. Overrides AREA from the diode model. If you do not specify the AREA, HSPICE or HSPICE RF calculates it from the width and length.

Parameter	Description
PJ	Periphery of junction (unitless for LEVEL=1 diode, and meters for LEVEL=3 diode). Overrides PJ from the diode model. If you do not specify PJ, HSPICE or HSPICE RF calculates it from the width and length specifications.
WP	Width of polysilicon capacitor, in meters (for LEVEL=3 diode only). Overrides WP in the diode model. Default=0.0.
LP	Length of polysilicon capacitor, in meters (for LEVEL=3 diode only). Overrides LP in the diode model. Default=0.0.
WM	Width of metal capacitor, in meters (for LEVEL=3 diode only). Overrides WM in the diode model. Default=0.0.
LM	Length of metal capacitor, in meters (for LEVEL=3 diode only). Overrides LM in the diode model. Default=0.0.
OFF	Sets the initial condition for this element to OFF, in DC analysis. Default=ON.
IC=vd	Initial voltage, across the diode element. Use this value when you specify the UIC option in the .TRAN statement. The .IC statement overrides this value.
M	Multiplier, to simulate multiple diodes in parallel. The M setting affects all currents, capacitances, and resistances. Default=1.
DTEMP	The difference between the element temperature and the circuit temperature, in degrees Celsius. Default=0.0.
W	Width of the diode, in meters (LEVEL=3 diode model only)
L	Length of the diode, in meters (LEVEL=3 diode model only)

You must specify two nodes and a model name. If you specify other parameters, the nodes and model name must be first and the other parameters can appear in any order.

Example 1

The D1 diode, with anode and cathode, connects to nodes 1 and 2. Diode1 specifies the diode model.

```
D1 1 2 diode1
```

Example 2

The Dprot diode, with anode and cathode, connects to both the output node and ground, references the *firstd* diode model, and specifies an area of 10 (unitless for `LEVEL=1` model). The initial condition has the diode OFF.

```
Dprot output gnd firstd 10 OFF
```

Example 3

The Ddrive diode, with anode and cathode, connects to the driver and output nodes. The width and length are 500 microns. This diode references the model_d diode model.

```
Ddrive driver output model_d W=5e-4 L=5e-4 IC=0.2
```

Bipolar Junction Transistor (BJT) Element

```
Qxxx nc nb ne <ns> mname <area> <OFF>
+ <IC=vbeval,vceval> <M=val> <DTEMP=val>

Qxxx nc nb ne <ns> mname <AREA=area> <AREAB=val>
+ <AREAC=val> <OFF> <VBE=vbeval> <VCE=vceval>
+ <M=val> <DTEMP=val>
```

Parameter	Description
Qxxx	BJT element name. Must begin with Q, then up to 1023 alphanumeric characters.
nc	Collector terminal node name.
nb	Base terminal node name.
ne	Emitter terminal node name.
ns	Substrate terminal node name, which is optional. You can also use the BULK parameter to set this name in the BJT model.
mname	BJT model name reference.
area, AREA=area	Emitter area multiplying factor, which affects currents, resistances, and capacitances. Default=1.0.
OFF	Sets initial condition for this element to OFF, in DC analysis. Default=ON.

Parameter	Description
IC=vbeval, vceval, VBE, VCE	Initial internal base-emitter voltage (vbeval) and collector-emitter voltage (vceval). HSPICE or HSPICE RF uses this value when the .TRAN statement includes UIC. The .IC statement overrides it.
M	Multiplier, to simulate multiple BJTs in parallel. The M setting affects all currents, capacitances, and resistances. Default=1.
DTEMP	The difference between the element temperature and the circuit temperature, in degrees Celsius. Default=0.0.
AREAB	Base area multiplying factor, which affects currents, resistances, and capacitances. Default=AREA.
AREAC	Collector area multiplying factor, which affects currents, resistances, and capacitances. Default=AREA.

The only required fields are the collector, base, and emitter nodes, and the model name. The nodes and model name must precede other fields in the netlist.

Example 1

In the Q1 BJT element below:

```
Q1 1 2 3 model_1
```

- The collector connects to node 1.
- The base connects to node 2.
- The emitter connects to node 3.
- model_1 references the BJT model.

Example 2

In the following Qopamp1 BJT element:

```
Qopamp1 c1 b3 e2 s 1stagepnp AREA=1.5 AREAB=2.5
AREAC=3.0
```

- The collector connects to the c1 node.
- The base connects to the b3 node.
- The emitter connects to the e2 node.
- The substrate connects to the s node.
- 1stagepnp references the BJT model.

- The `AREA` area factor is 1.5.
- The `AREAB` area factor is 2.5.
- The `AREAC` area factor is 3.0.

Example 3

In the Qdrive BJT element below:

```
Qdrive driver in output model_npn 0.1
```

- The collector connects to the driver node.
- The base connects to the in node.
- The emitter connects to the output node.
- model_npn references the BJT model.
- The area factor is 0.1.

JFETs and MESFETs

```
Jxxx nd ng ns <nb> mname <<<AREA>=area | <W=val>
+ <L=val>> <OFF> <IC=vdsval,vgsval> <M=val>
+ <DTEMP=val>

Jxxx nd ng ns <nb> mname <<<AREA>=area> | <W=val>
+ <L=val>> <OFF> <VDS=vdsval> <VGS=vgsval>
+ <M=val> <DTEMP=val>
```

Parameter	Description
Jxxx	JFET or MESFET element name. Must begin with J, followed by up to 1023 alphanumeric characters.
nd	Drain terminal node name
ng	Gate terminal node name
ns	Source terminal node name
nb	Bulk terminal node name, which is optional.
mname	JFET or MESFET model name reference

Parameter	Description
area, AREA=area	Area multiplying factor that affects the BETA, RD, RS, IS, CGS, and CGD model parameters. Default=1.0, in units of square meters.
W	FET gate width in meters
L	FET gate length in meters
OFF	Sets initial condition to OFF for this element, in DC analysis. Default=ON.
IC=vdsval, vgsval, VDS, VGS	Initial internal drain-source voltage (vdsval) and gate-source voltage (vgsval). Use this argument when the .TRAN statement contains UIC. The .IC statement overrides it.
M	Multiplier to simulate multiple JFETs or MESFETs in parallel. The M setting affects all currents, capacitances, and resistances. Default=1.
DTEMP	The difference between the element temperature and the circuit temperature, in degrees Celsius. Default=0.0.

Only drain, gate, and source nodes, and model name fields are required. Node and model names must precede other fields.

Example 1

In the J1 JFET element below:

```
J1 1 2 3 model_1
```

- The drain connects to node 1.
- The source connects to node 2.
- The gate connects to node 3.
- model_1 references the JFET model.

Example 2

In the following Jopamp1 JFET element:

```
Jopamp1 d1 g3 s2 b 1stage AREA=100u
```

- The drain connects to the d1 node.
- The source connects to the g3 node.
- The gate connects to the s2 node.

- 1stage references the JFET model.
- The area is 100 microns.

Example 3

In the Jdrive JFET element below:

```
Jdrive driver in output model_jfet W=10u L=10u
```

- The drain connects to the driver node.
- The source connects to the in node.
- The gate connects to the output node.
- model_jfet references the JFET model.
- The width is 10 microns.
- The length is 10 microns.

MOSFETs

```
Mxxx nd ng ns <nb> mname <<L=>length> <<W=>width>
+ <AD=val> AS=val> <PD=val> <PS=val>
+ <NRD=val> <NRS=val> <RDC=val> <RSC=val> <OFF>
+ <IC=vds,vgs,vbs> <M=val> <DTEMP=val>
+ <GEO=val> <DELVTO=val>
.OPTION WL
Mxxx nd ng ns <nb> mname <width> <length> <other_options...>
```

Parameter	Description
Mxxx	MOSFET element name. Must begin with M, followed by up to 1023 alphanumeric characters.
nd	Drain terminal node name.
ng	Gate terminal node name.
ns	Source terminal node name.
nb	Bulk terminal node name, which is optional. To set this argument in the MOSFET model, use the BULK parameter.
mname	MOSFET model name reference

Parameter	Description
L	MOSFET channel length, in meters. This parameter overrides .OPTION DEFL, with a maximum value of 0.1m. Default=DEFL.
W	MOSFET channel width, in meters. This parameter overrides .OPTION DEFW. Default=DEFW.
AD	Drain diffusion area. Overrides .OPTION DEFAD. Default=DEFAD, if you set the ACM=0 model parameter.
AS	Source diffusion area. Overrides .OPTION DEFAS. Default=DEFAS, if you set the ACM=0 model parameter.
PD	Perimeter of drain junction, including channel edge. Overrides .OPTION DEFPD. Default=DEFAD, if you set the ACM=0 or 1 model parameter. Default=0.0, if you set ACM=2 or 3.
PS	Perimeter of source junction, including channel edge. Overrides .OPTION DEFPS. Default=DEFAS, if you set the ACM=0 or 1 model parameter. Default=0.0, if you set ACM=2 or 3.
NRD	Number of squares of drain diffusion for resistance calculations. Overrides .OPTION DEFNRD. Default=DEFNRD, if you set ACM=0 or 1 model parameter. Default=0.0, if you set ACM=2 or 3.
NRS	Number of squares of source diffusion for resistance calculations. Overrides .OPTION DEFNRS. Default=DEFNRS when you set the MOSFET model parameter ACM=0 or 1. Default=0.0, when you set ACM=2 or 3.
RDC	Additional drain resistance due to contact resistance, in units of ohms. This value overrides the RDC setting in the MOSFET model specification. Default=0.0.
RSC	Additional source resistance due to contact resistance, in units of ohms. This value overrides the RSC setting in the MOSFET model specification. Default=0.0.
OFF	Sets initial condition for this element to OFF, in DC analysis. Default=ON. This command does not work for depletion devices.
IC=vds, vgs, vbs	Initial voltage across external drain and source (vds), gate and source (vgs), and bulk and source terminals (vbs). Use these arguments with `.TRAN UIC`. `.IC` statements override these values.

Parameter	Description
M	Multiplier, to simulate multiple MOSFETs in parallel. Affects all channel widths, diode leakages, capacitances, and resistances. Default=1.
DTEMP	The difference between the element temperature and the circuit temperature, in degrees Celsius. Default=0.0.
GEO	Source/drain sharing selector for a MOSFET model parameter value of ACM=3. Default=0.0.
DELVTO	Zero-bias threshold voltage shift. Default=0.0.

The only required fields are the drain, gate and source nodes, and the model name. The nodes and model name must precede other fields in the netlist. If you did not specify a label, use the second syntax with the `.OPTION WL` statement, to exchange the width and length options.

Example

In the following M1 MOSFET element:

```
M1 1 2 3 model_1
```

- The drain connects to node 1.
- The gate connects to node 2.
- The source connects to node 3.
- model_1 references the MOSFET model.

In the following Mopamp1 MOSFET element:

```
Mopamp1 d1 g3 s2 b 1stage L=2u W=10u
```

- The drain connects to the d1 node.
- The gate connects to the g3 node.
- The source connects to the s2 node.
- 1stage references the MOSFET model.
- The length of the gate is 2 microns.
- The width of the gate is 10 microns.

In the following Mdrive MOSFET element:

```
Mdrive driver in output bsim3v3 W=3u L=0.25u DTEMP=4.0
```

- The drain connects to the driver node.
- The gate connects to the in node.
- The source connects to the output node.
- bsim3v3 references the MOSFET model.
- The length of the gate is 3 microns.
- The width of the gate is 0.25 microns.
- The device temperature is 4 degrees Celsius higher than the circuit temperature.

Transmission Lines

A transmission line is a passive element that connects any two conductors, at any distance apart. One conductor sends the input signal through the transmission line, and the other conductor receives the output signal from the transmission line. The signal that is transmitted from one end of the pair to the other end, is voltage between the conductors.

Examples of transmission lines include:

- Power transmission lines
- Telephone lines
- Waveguides
- Traces on printed circuit boards and multi-chip modules (MCMs)
- Bonding wires in semiconductor IC packages
- On-chip interconnections

W Element

The W element supports five different formats to specify the transmission line properties:

- Model 1: RLGC-Model specification.
  - Internally specified in a .model statement.
  - Externally specified in a different file.

- Model 2: U-Model specification.
  - RLGC input for up to five coupled conductors.
  - Geometric input (planer, coax, twin-lead).
  - Measured-parameter input.
  - Skin effect.
- Model 3: Built-in field solver model.
- Model 4: Frequency-dependent tabular model.
- Model 5: S Parameter Model

W Element Statement

The general syntax for a lossy (W Element) transmission line element is:

RLGC file form:

```
Wxxx in1 <in2 <...inx>> refin out1 <out2 <...outx>>
+ refout <RLGCfile=filename> N=val L=val
```

U Model form:

```
Wxxx in1 <in2 <...inx>> refin out1 <out2 <...outx>>
+ refout <Umodel=modelname> N=val L=val
```

Field solver form:

```
Wxxx in1 <in2 <...inx>> refin out1 <out2 <...outx>>
+ refout <FSmodel=modelname> N=val L=val
```

The number of ports on a single transmission line are not limited. You must provide one input and output port, the ground references, a model or file reference, a number of conductors, and a length. HSPICE RF does not support the Field Solver form of the W element.

S Model form:

```
Wxxx in1 <in2 <...inx>> refin out1 <out2 <...outx>>
+ refout <Smodel=modelname> <NODEMAP=XiYj...> N=val L=val
```

Table Model form:

```
Wxxx in1 in2 <...inx>> refin out1 <out2 <...outx>>
+ refout N=val L=val TABLEMODEL=name
```

Parameter	Description
Wxxx	Lossy (W Element) transmission line element name. Must start with W, followed by up to 1023 alphanumeric characters.
inx	Signal input node for xth transmission line (in1 is required).
refin	Ground reference for input signal
outx	Signal output node for the xth transmission line (each input port must have a corresponding output port).
refout	Ground reference for output signal.
N	Number of conductors (excluding the reference conductor).
L	Physical length of the transmission line, in units of meters.
RLGCfile=filename	File name reference for the file containing the RLGC information for the transmission lines (for syntax, see “Using the W Element” in the *HSPICE Signal Integrity Guide*).
Umodel=modelname	U-model lossy transmission-line model reference name. A lossy transmission line model, used to represent the characteristics of the W-element transmission line.
FSmodel= modelname	Internal field solver model name. References the PETL internal field solver as the source of the transmission-line characteristics (for syntax, see “Using the Field Solver Model” chapter in the *HSPICE Signal Integrity Guide*).

Parameter	Description
NODEMAP	String that assigns each index of the S parameter matrix to one of the W Element terminals. This string must be an array of pairs that consists of a letter and a number, (for example, Xn), where ■ X= I, i, N, or n to indicate near end (input side) terminal of the W element ■ X= O, i, F, or f to indicate far end (output side) terminal of the W element. The default value for NODEMAP is “I1I2I3...InO1O2O3...On”
Smodel	S Model name reference, which contains the S parameters of the transmission lines (for the S Model syntax, see the *HSPICE Signal Integrity Guide*).
TABLEMODEL	Name of the frequency-dependent tabular model.

Example 1

The W1 lossy transmission line connects the in node to the out node:

```
W1 in gnd out gnd RLGCfile=cable.rlgc N=1 L=5
```

Where,

- Both signal references are grounded
- The RLGC file is named cable.rlgc
- The transmission line is 5 meters long.

Example 2

The Wcable element is a two-conductor lossy transmission line:

```
Wcable in1 in2 gnd out1 out2 gnd Umodel=umod_1 N=2
+ L=10
```

Where,

- in1 and in2 input nodes connect to the out1 and out2 output node
- Both signal references are grounded.
- umod_1 references the U-model.
- The transmission line is 10 meters long.

Example 3

The Wnet1 element is a five-conductor lossy transmission line:

```
Wnet1 i1 i2 i3 i4 i5 gnd o1 gnd o3 gnd o5 gnd
+ FSmodel=board1 N=5 L=1m
```

Where,

- The i1, i2, i3, i4 and i5 input nodes connect to the o1, o3, and o5 output nodes.
- The i5 input and three outputs (o1, o3, and o5) are all grounded.
- board1 references the Field Solver model.
- The transmission line is 1 millimeter long.

Example 4: S Model Example

```
Wnet1 i1 i2 gnd o1 o2 gnd
+ Smodel=smod_1 nodemap=i1i2o1o2
+ N=2 L=10m
```

Where,

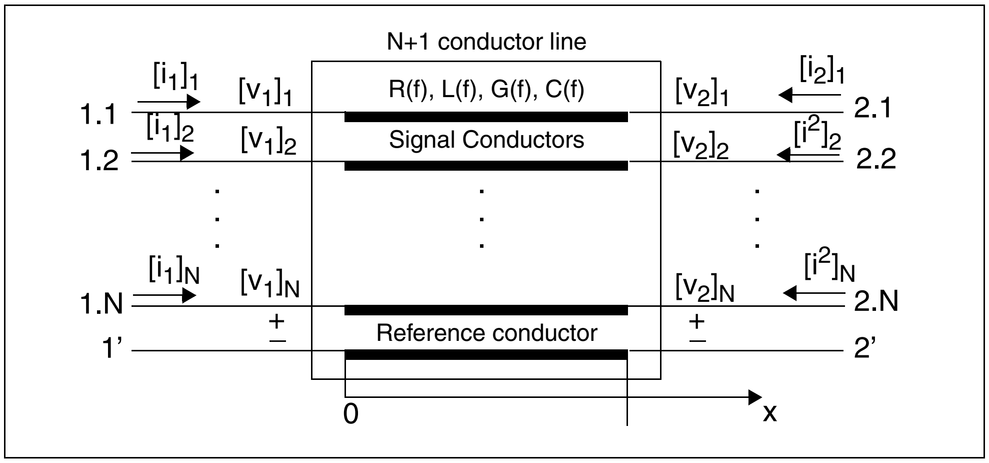
- `in1` and `in2` input nodes connect to the `out1` and `out2` output node.
- Both signal references are grounded.
- `smod_1` references the S Model.
- The transmission line is `10` meters long.

You can specify parameters in the W Element card in any order. You can specify the number of signal conductors, `N`, after the node list. You can also mix nodes and parameters in the W Element card.

You can specify only one of the `RLGCfile`, `FSmodel`, `Umodel`, or `Smodel` models, in a single W Element card.

Figure 11 shows node numbering for the element syntax.

Figure 11   Terminal Node Numbering for the W Element



For additional information about the W element, see the "Modeling Coupled Transmission Lines Using the W Element" chapter in the *HSPICE Signal Integrity User Guide*.

Lossless (T Element)

General form:

```
Txxx in refin out refout Z0=val TD=val <L=val>
+ <IC=v1,i1,v2,i2>

Txxx in refin out refout Z0=val F=val <NL=val>
+ <IC=v1,i1,v2,i2>
```

U Model form:

```
Txxx in refin out refout mname L=val
```

Parameter	Description
Txxx	Lossless transmission line element name. Must begin with T, followed by up to 1023 alphanumeric characters.
in	Signal input node.
refin	Ground reference for the input signal.
out	Signal output node.

refout	Ground reference for the output signal.
Z0	Characteristic impedance of the transmission line.
TD	Signal delay from a transmission line, in seconds per meter.
L	Physical length of the transmission line, in units of meters. Default=1.
IC=v1,i1,v2,i2	Initial conditions of the transmission line. Specify the voltage on the input port (v1), current into the input port (i1), voltage on the output port (v2), and the current into the output port (i2).
F	Frequency at which the transmission line has the electrical length specified in NL.
NL	Normalized electrical length of the transmission line (at the frequency specified in the F parameter), in units of wavelengths per line length. Default=0.25, which is a quarter-wavelength.
mname	U-model reference name. A lossy transmission line model, representing the characteristics of the lossless transmission line.

Only one input and output port is allowed.

Example 1

The T1 transmission line connects the in node to the out node:

```
T1 in gnd out gnd Z0=50 TD=5n L=5
```

- Both signal references are grounded.
- Impedance is 50 ohms.
- The transmission delay is 5 nanoseconds per meter.
- The transmission line is 5 meters long.

Example 2

The Tcable transmission line connects the in1 node to the out1 node:

```
Tcable in1 gnd out1 gnd Z0=100 F=100k NL=1
```

- Both signal references are grounded.
- Impedance is 100 ohms.
- The normalized electrical length is 1 wavelength at 100 kHz.

Example 3

The Tnet1 transmission line connects the driver node to the output node:

```
Tnet1 driver gnd output gnd Umodel1 L=1m
```

- Both signal references are grounded.
- Umodel1 references the U-model.
- The transmission line is 1 millimeter long.

Ideal Transmission Line

For the ideal transmission line, voltage and current will propagate without loss along the length of the line (±x direction) with spatial and time-dependence given according to the following equation:

$$v(x, t) = Re[Ae^{j(\omega t - \beta x)} + Be^{j(\varpi t + \beta x)}]$$

$$v(x, t) = Re\left[\frac{A}{Z_0}e^{j(\omega t - \beta x)} - \frac{B}{Z_0}e^{j(\omega t + \beta x)}\right]$$

The A represents the incident voltage, B represents the reflected voltage, Z_0 is the characteristic impedance, and β is the propagation constant. The latter are related to the transmission line inductance (L) and capacitance (C) by the following equation:

$$Z_0 = \sqrt{\frac{L}{C}}$$

$$\beta = \omega\sqrt{LC}$$

The L and C terms are in per-unit-length units (Henries/meter, Farads/meter). The following equation gives the phase velocity:

$$\upsilon_\rho = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

At the end of the transmission line ($x = l$), the propagation term βl becomes the following equation:

$$\beta l = \omega\sqrt{LC} \cdot l = \omega\frac{l}{v_p}$$

This is equivalent to an ideal delay with the following value:

$$T = \frac{l}{V_P} = \sqrt{LC} \cdot l$$

Where,

T : absolute time delay (sec)

l : physical length (L) (meters)

V_P : phase velocity (meters/sec)

Using standard distance=velocity*time relationships, the HSPICE T element parameter values are related to these terms according to:

$$V_P = f \cdot \lambda = \frac{1}{t_d}$$

Where,

f : frequency

λ : wavelength

t_d : relative time delay (TD) (sec/meter)

$$T = \frac{l}{V_p} = t_d \cdot l = \frac{l}{f \cdot \lambda} = \frac{l/\lambda}{f} = \sqrt{LC} \cdot l$$

Where,

l : physical length (L) (meters)

l/λ : normalized length (NL)

f : frequency at NL (F) (Hz)

$$T = TD \cdot L = \frac{NL}{L} = \sqrt{LC} \cdot L$$

HSPICE therefore allows you to specify a transmission line in three different ways:

- Z_0, TD, L
- Z_0, NL, F
- L, with $\sqrt{\frac{L}{C}}$ and $\sqrt{LC}$ values taken from a U model.

Lossy (U Element)

```
Uxxx in1 <in2 <...in5>> refin out1 <out2 <...out5>>
+ refout mname L=val <LUMPS=val>
```

Parameter	Description
Uxxx	Lossy (U Element) transmission line element name. Must begin with U, followed by up to 1023 alphanumeric characters.
inx	Signal input node for the xth transmission line (in1 is required).
refin	Ground reference for the input signal.
outx	Signal output node for the xth transmission line (each input port must have a corresponding output port).
refout	Ground reference for the output signal.
mname	Model reference name for the U-model lossy transmission-line.
L	Physical length of the transmission line, in units of meters.
LUMPS	Number of lumped-parameter sections used to simulate the element.

In this syntax, the number of ports on a single transmission line is limited to five in and five out. One input and output port, the ground references, a model reference, and a length are all required.

Example 1

The U1 transmission line connects the in node to the out node:

```
U1 in gnd out gnd umodel_RG58 L=5
```

- Both signal references are grounded.
- umodel_RG58 references the U-model.
- The transmission line is 5 meters long.

Example 2

The Ucable transmission line connects the in1 and in2 input nodes to the out1 and out2 output nodes:

```
Ucable in1 in2 gnd out1 out2 gnd twistpr L=10
```

- Both signal references are grounded.
- twistpr references the U-model.
- The transmission line is 10 meters long.

Example 3

The Unet1 element is a five-conductor lossy transmission line:

```
Unet1 i1 i2 i3 i4 i5 gnd o1 gnd o3 gnd o5 gnd Umodel1 L=1m
```

- The i1, i2, i3, i4, and i5 input nodes connect to the o1, o3, and o5 output nodes.
- The i5 input, and the three outputs (o1, o3, and o5) are all grounded.
- Umodel1 references the U-model.
- The transmission line is 1 millimeter long.

Frequency-Dependent Multi-Terminal S Element

The S element uses the following parameters to define a frequency-dependent, multi-terminal network:

- S (scattering)
- Y (admittance)
- Z (impedance)

You can use an S element in the following types of analyses:

- DC
- AC
- Transient
- Small Signal

For a description of the S parameter and SP model analysis, see the "S Parameter Modeling Using the S Element" chapter in the *HSPICE Signal Integrity Guide*.

S Element Syntax (HSPICE):

```
Sxxx nd1 nd2 ... ndN ndRef
+ <MNAME=Smodel_name> <FQMODEL=sp_model_name>
+ <TYPE=[s|y]> <Zo=[value|vector_value]>
+ <FBASE=base_frequency> <FMAX=maximum_frequency>
+ <PRECFAC=val> <DELAYHANDLE=[1|0|ON|OFF]>
+ <DELAYFREQ=val>
+ <INTERPOLATION=STEP|LINEAR|SPLINE>
+ <INTDATTYP =[RI|MA|DBA]> <HIGHPASS=value>
+ <LOWPASS=value> <MIXEDMODE=[0|1]>
+ <DATATYPE=data_string>
+ <DTEMP=val> <NOISE=[1|0]>
```

S Element Syntax (HSPICE RF):

```
Sxxx nd1 nd2 ... ndN [ndR] s_model_name
```

S model Syntax (HSPICE):

```
.MODEL S_model_name S
+ N=dimension
+ [FQMODEL=sp_model_name | TSTONEFILE=filename |
+ CITIFILE=filename] <TYPE=[s | y]>
+ <Zo=[value | vector_value]>
+ <FBASE=base_frequency> <FMAX=maximum_frequency>
+ <PRECFAC=val> <DELAYHANDLE=ON | OFF> <DELAYFREQ=val>
```

S Model Syntax (HSPICE RF):

```
.model S_model_name S
+ [FQMODEL=sp_model_name | TSTONEFILE=filename |
+ CITIFILE=filename] <TYPE=[S | Y | Z]>
+ <FBASE=base_frequency> <FMAX=max_frequency>
+ <Zo=[50 | vector_value ] | Zof=ref_model>
+ <HIGHPASS=[0 | 1 | 2]> <LOWPASS=[0 | 1 | 2]>
+ <DELAYHANDLE=[0 | 1]> <DELAYFREQ=val>
```

Parameter	Description
nd1 nd2 ... ndN	Nodes of an S element (see Figure 12 on page 129). Three kinds of definitions are present: ▪ With no reference node `ndRef`, the default reference node in this situation is GND. Each node `ndi` (i=1~N) and GND construct one of the N ports of the S element. ▪ With one reference node, `ndRef` is defined. Each node `ndi` (i=1~N) and the `ndRef` construct one of the N ports of the S element. With an N reference node, each port has its own reference node. You can write the node definition in a clearer way as: `nd1+ nd1- nd2+ nd2- ... ndN+ ndN-` Each pair of the nodes (`ndi+` and `ndi-`, i=1~N) constructs one of the N ports of the S element.

Parameter	Description
nd_ref or NdR	Reference node.
MNAME	Name of the S model.
FQMODEL	Frequency behavior of the S,Y, or Z parameters. .MODEL statement of sp type, which defines the frequency-dependent matrices array.
TSTONEFILE	Name of a Touchstone file. Data contains frequency-dependent array of matrixes. Touchstone files must follow the .s#p file extension rule, where # represents the dimension of the network. For details, see *Touchstone® File Format Specification* by the EIA/IBIS Open Forum (http://www.eda.org).
CITIFILE	Name of the CITIfile, which is a data file that contains frequency-dependent data. For details, see *Using Instruments with ADS* by Agilent Technologies (http://www.agilent.com).
TYPE	Parameter type: ■ S (scattering), the default ■ Y (admittance) ■ Z (impedance)
Zo	Characteristic impedance value of the reference line (frequency-independent). For multi-terminal lines (N>1), HSPICE assumes that the characteristic impedance matrix of the reference lines are diagonal, and their diagonal values are set to `Zo`. You can also set a vector value for non-uniform diagonal values. Use Zof to specify more general types of a reference-line system. The default is `50`.

Parameter	Description
FBASE	Base frequency used for transient analysis. HSPICE uses this value as the base frequency point for Inverse Fast Fourier Transformation (IFFT). ■ If FBASE is not set, HSPICE uses a reciprocal of the transient period as the base frequency. ■ If FBASE is set smaller than the reciprocal value of transient period, transient analysis performs circular convolution by using the reciprocal value of FBASE as a base period.
FMAX	Maximum frequency for transient analysis. Used as the maximum frequency point for Inverse Fast Fourier Transform (IFFT).
PRECFAC	Preconditioning factor to avoid a singularity (infinite admittance matrix). See Preconditioning S Parameters on page 131. Default=0.75.
DELAYHANDLE	Delay frequency for transmission line type parameters. Default=OFF. ■ 1 of ON activates the delay handler. See Group Delay Handler in Time Domain Analysis on page 130 ■ 0 of OFF (default) deactivates the delay handler. You must set the delay handler, if the delay of the model is longer than the base period specified in the FBASE parameter. If you set DELAYHANDLE=OFF but DELAYFQ is not zero, HSPICE simulates the S element in delay mode.
DELAYFREQ	Delay frequency for transmission-line type parameters. The default is FMAX. If the DELAYHANDLE is set to OFF, but DELAYFREQ is nonzero, HSPICE still simulates the S element in delay mode.
INTERPOLATION	The interpolation method: ■ `STEP`: piecewise step ■ `SPLINE`: b-spline curve fit ■ `LINEAR`: piecewise linear (default)

Parameter	**Description**
INTDATTYP	Data type for the linear interpolation of the complex data. ▪ `RI`: real-imaginary based interpolation ▪ `DBA`: dB-angle based interpolation ▪ `MA`: magnitude-angle based interpolation (default)
HIGHPASS	Specifies high-frequency extrapolation: 0: Use zero in Y dimension (open circuit). 1: Use highest frequency. 2: Use linear extrapolation, with the highest two points. 3: Apply window function (default). This option overrides EXTRAPOLATION in ,model SP.
LOWPASS	Specifies low-frequency extrapolation: 0: Use zero in Y dimension (open circuit). 1: Use lowest frequency (default). 2: Use linear extrapolation, with the lowest two points. This option overrides EXTRAPOLATION in .model SP.
MIXEDMODE	Set to 1 if the parameters are represented in the mixed mode.
DATATYPE	A string used to determine the order of the indices of the mixed-signal incident or reflected vector. The string must be an array of a letter and a number (Xn) where: ▪ X=D to indicate a differential term =C to indicate a common term =S to indicate a single (grounded) term ▪ n=the port number

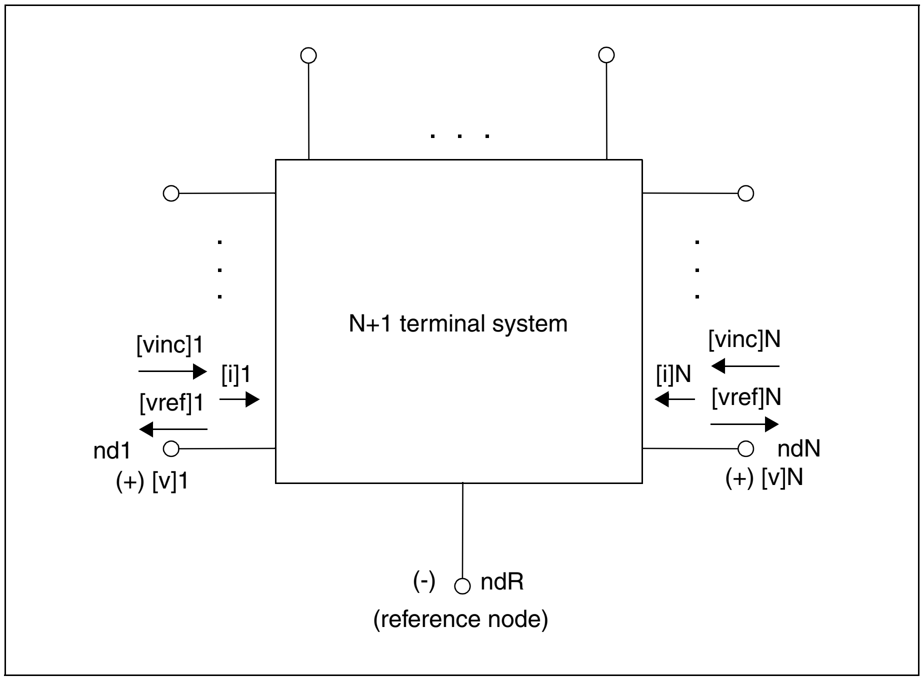
Parameter	Description
DTEMP	Temperature difference between the element and the circuit.[a] Expressed in °C. The default is 0.0.
NOISE	Activates thermal noise. ▪ 1 (default): element generates thermal noise ▪ 0: element is considered noiseless

a. Circuit temperature is specified by using the .TEMP statement or by sweeping the global TEMP variable in .DC, .AC, or .TRAN statements. When neither .TEMP or TEMP is used, circuit temperature is set by using .OPTION TNOM. The default for TNOM is 25 °C, unless you use .OPTION SPICE, which has a default of 27 °C. You can use the DTEMP parameter to specify the temperature of the element.

You can set all optional parameters, except `MNAME`, in both the S element and the S model statement. Parameters in element statements have higher priorities. You must specify either the `FQMODEL`, `TSTONEFILE`, or `CITIFILE` parameter in either the S model or the S element statement.

When used with the generic frequency-domain model (`.MODEL SP`), an S (scattering) element is a convenient way to describe a multi-terminal network.

Figure 12 Terminal Node Notation



Frequency Table Model

The frequency table model (SP model) is a generic model that you can use to describe frequency-varying behavior. Currently, the S element and `.LIN` command use this model. For a description of this model, see “Small-Signal Parameter Data Frequency Table Model” in the *HSPICE Signal Integrity User Guide*.

Group Delay Handler in Time Domain Analysis

The S element accepts a constant group delay matrix in time-domain analysis. You can also express a weak dependence of the delay matrix on the frequency, as a combination of the constant delay matrix and the phase shift value at each frequency point.

To activate or deactivate this delay handler, specify the `DELAYHANDLE` keyword in the S model statement.

The delay matrix is a constant matrix, which HSPICE RF extracts using finite difference calculation at selected target frequency points. HSPICE RF obtains the $\Upsilon_{\omega(i,\,j)}$ delay matrix component as:

$$\Upsilon_{\omega(i,\,j)} = \frac{d\theta_{Sij}}{d\omega} = \frac{1}{2\pi}\cdot\frac{d\theta_{Sij}}{df}$$

- *f* is the target frequency, which you can set using `DELAYFREQ=val`. The default target frequency is the maximum frequency point.
- θ_{Sij} is the phase of *S*ij.

After time domain analysis obtains the group delay matrix, the following equation eliminates the delay amount from the frequency domain system-transfer function:

$$y'_{mn(\omega)} = y_{mn(\omega)} \times e^{j\omega T_{mn}}$$

The convolution process then uses the following equation to calculate the delay:

$$i_{k(t)} = (y'_{k1(t)}, y'_{k2(t)}, \ldots, y'_{kN(t)}) \times \left(v_{1(t-T_{K1})}, v_{2(t-T_{K2})}, \ldots, v_{Nt-T_{KN}}\right)^T$$

Preconditioning S Parameters

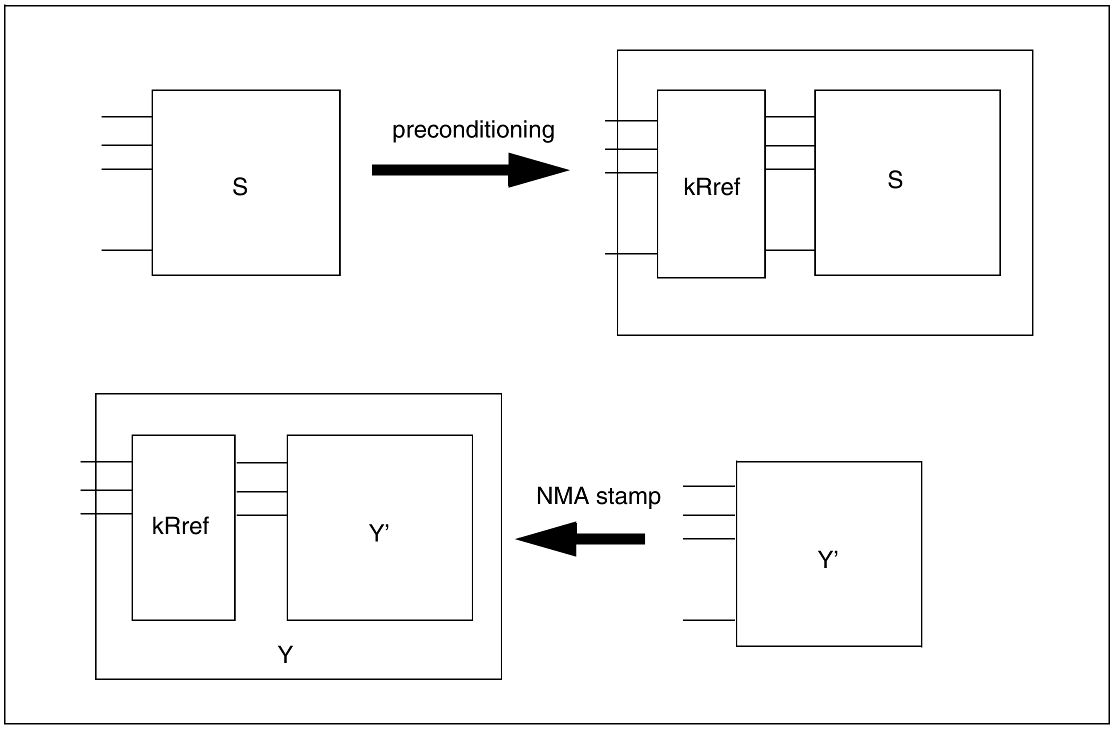
Certain S parameters, such as series inductor (2-port), show a singularity when converting S to Y parameters. To avoid this singularity, the S element preconditions S matrices by adding kR_{ref} series resistance:

$$S' = [kI + (2-k)S][(2+k)I - kS]^{-1}$$

- R_{ref} is the reference impedance vector.
- *k* is the preconditioning factor.

To compensate for this modification, the S element adds a negative resistor ($-kR_{ref}$) to the modified nodal analysis (NMA) matrix, in actual circuit compensation. To specify this preconditioning factor, use the `<PREFAC=`*val*`>` keyword in the S model statement. The default preconditioning factor is 0.75.

Figure 13   Preconditioning S Parameters



6

Parameters and Functions

Describes how to use parameters within HSPICE RF netlists.

Parameters are similar to the variables used in most programming languages. Parameters hold a value that you assign when you create your circuit design or that the simulation calculates based on circuit solution values. Parameters can store static values for a variety of quantities (resistance, source voltage, rise time, and so on). You can also use them in sweep or statistical analysis.

For descriptions of individual HSPICE and HSPICE RF commands referenced in this chapter, see Chapter 2, Netlist Commands, and Chapter 3, RF Netlist Commands in the *HSPICE and HSPICE RF Command Reference*.

Using Parameters in Simulation (.PARAM)

Defining Parameters

Parameters in HSPICE are names that you associate with numeric values. (See Assigning Parameters on page 135.) You can use any of the methods described in Table 9 to define parameters.

Table 9 .PARAM Statement Syntax

Parameter	**Description**
Simple assignment	.PARAM <SimpleParam>=1e-12
Algebraic definition	.PARAM <AlgebraicParam>=‘SimpleParam*8.2’ SimpleParam excludes the output variable. You can also use algebraic parameters in .PRINT and .PROBE statements. For example: .PRINT AlgebraicParam=par(’algebraic expression’) You can use the same syntax for .PROBE, statements. See Using Algebraic Expressions on page 138.
User-defined function	.PARAM <*MyFunc*(*x, y*)>=‘Sqrt((*x***x*)+(*y***y*))’
Character string definition	.PARAM <*paramname*>=str(‘*string*’)
Subcircuit default	.SUBCKT <SubName> <ParamDefName>=<Value> str(‘string’) .MACRO <SubName> <ParamDefName>=<Value> str(‘string’)
Predefined analysis function	.PARAM <mcVar>=Agauss(1.0,0.1)
.MEASURE statement	.MEASURE <DC | AC | TRAN> result TRIG ... + TARG ... <GOAL=val> <MINVAL=val> + <WEIGHT=val> <MeasType> <MeasParam> (See Specifying User-Defined Analysis (.MEASURE) on page 252.)
.PRINT | .PROBE |	.PRINT | .PROBE + outParam=Par_Expression

A parameter definition in HSPICE always uses the last value found in the input netlist (subject to local versus global parameter rules). The definitions below assign a value of 3 to the *DupParam* parameter.

```
.PARAM DupParam=1
...
.PARAM DupParam=3
```

HSPICE assigns `3` as the value for all instances of `DupParam`, including instances that are earlier in the input than the `.PARAM DupParam=3` statement.

All parameter values in HSPICE are IEEE double floating point numbers. The parameter resolution order is:

1. Resolve all literal assignments.
2. Resolve all expressions.
3. Resolve all function calls.

Table 10 shows the parameter passing order.

Table 10 Parameter Passing Order

.OPTION PARHIER=GLOBAL	.OPTION PARHIER=LOCAL
Analysis sweep parameters	Analysis sweep parameters
.PARAM statement (library)	.SUBCKT call (instance)
.SUBCKT call (instance)	.SUBCKT definition (symbol)
.SUBCKT definition (symbol)	.PARAM statement (library)

Assigning Parameters

You can assign the following types of values to parameters:

- Constant real number
- Algebraic expression of real values
- Predefined function
- Function that you define
- Circuit value
- Model value

To invoke the algebraic processor, enclose a complex expression in single quotes. A simple expression consists of one parameter name.

The parameter keeps the assigned value, unless:

- A later definition changes its value, or
- An algebraic expression assigns a new value during simulation.

HSPICE does not warn you, if it reassigns a parameter.

Inline Parameter Assignments

To define circuit values, using a direct algebraic evaluation:

```
r1 n1 0 R='1k/sqrt(HERTZ)' $ Resistance for frequency
```

Parameters in Output

To use an algebraic expression as an output variable in a `.PRINT`, `.PROBE` or `.MEASURE` statement, use the PAR keyword. (See Chapter 7, Simulation Output, for more information.)

Example

```
.PRINT DC v(3) gain=PAR('v(3)/v(2)') PAR('v(4)/v(2)')
```

User-Defined Function Parameters

You can define a function that is similar to the parameter assignment, but you cannot nest the functions more than two deep.

- An expression can contain parameters that you did not define.
- A function must have at least one argument, and can have up to 20 (and in many cases, more than 20) arguments.
- You can redefine functions.

The format of a function is:

```
funcname1(arg1[,arg2...])=expression1
+ [funcname2(arg1[,arg2...])=expression2] off
```

Parameter	Description
funcname	Specifies the function name. This parameter must be distinct from array names and built-in functions. In subsequently defined functions, all embedded functions must be previously defined.
arg1, arg2	Specifies variables used in the expression.

Parameter	Description
off	Voids all user-defined functions.

Example

```
.PARAM f(a,b)=POW(a,2)+a*b g(d)=SQRT(d)
+ h(e)=e*f(1,2)-g(3)
```

Predefined Analysis Function

HSPICE includes specialized analysis types, such as Optimization and Monte Carlo, that require a way to control the analysis.

Measurement Parameters

`.MEASURE` statements produce a *measurement* parameter. The rules for measurement parameters are the same as for standard parameters, except that measurement parameters are defined in a `.MEASURE` statement, not in a `.PARAM` statement. For a description of the `.MEASURE` statement, see Specifying User-Defined Analysis (.MEASURE) on page 252.

.PRINT and .PROBE Parameters

`.PRINT,and.PROBE` statements in HSPICE produce a *print* parameter. The rules for print parameters are the same as the rules for standard parameters, except that you define the parameter directly in a `.PRINT` or `.PROBE` statement, not in a `.PARAM` statement

For more information about the `.PRINT` or `.PROBE` statements, see Displaying Simulation Results on page 231.

Multiply Parameter

The most basic subcircuit parameter in HSPICE is the M (multiply) parameter. For a description of this parameter, see M (Multiply) Parameter on page 58.

Using Algebraic Expressions

Note:

> Synopsys HSPICE uses double-precision numbers (15 digits) for expressions, user-defined parameters, and sweep variables. For better precision, use parameters (instead of constants) in algebraic expressions, because constants are only single-precision numbers (7 digits).

In HSPICE, an algebraic expression, with quoted strings, can replace any parameter in the netlist.

In HSPICE, you can then use these expressions as output variables in `.PRINT`, statements. Algebraic expressions can expand your options in an input netlist file.

Some uses of algebraic expressions are:

- Parameters:

```
.PARAM x='y+3'
```

- Functions:

```
.PARAM rho(leff,weff)='2+*leff*weff-2u'
```

- Algebra in elements:

```
R1 1 0 r='ABS(v(1)/i(m1))+10'
```

- Algebra in `.MEASURE` statements:

```
    .MEAS vmax MAX V(1)
    .MEAS imax MAX I(q2)
    .MEAS ivmax PARAM='vmax*imax'
```

- Algebra in output statements:

```
.PRINT conductance=PAR('i(m1)/v(22)')
```

The basic syntax for using algebraic expressions for output is:

PAR('*algebraic expression*')

In addition to using quotations, you must define the expression inside the `PAR( )` statement for output.The continuation character for quoted parameter strings, in HSPICE, is a double backslash (\\). (Outside of quoted strings, the single backslash (\) is the continuation character.)

Built-In Functions and Variables

In addition to simple arithmetic operations (`+`, `-`, `*`, `/`), you can use the built-in functions listed in Table 11 and the variables listed in Table 10 on page 135 in HSPICE expressions.

Table 11 Synopsys HSPICE Built-in Functions

HSPICE Form	Function	Class	Description
sin(x)	sine	trig	Returns the sine of x (radians)
cos(x)	cosine	trig	Returns the cosine of x (radians)
tan(x)	tangent	trig	Returns the tangent of x (radians)
asin(x)	arc sine	trig	Returns the inverse sine of x (radians)
acos(x)	arc cosine	trig	Returns the inverse cosine of x (radians)
atan(x)	arc tangent	trig	Returns the inverse tangent of x (radians)
sinh(x)	hyperbolic sine	trig	Returns the hyperbolic sine of x (radians)
cosh(x)	hyperbolic cosine	trig	Returns the hyperbolic cosine of x (radians)
tanh(x)	hyperbolic tangent	trig	Returns the hyperbolic tangent of x (radians)
abs(x)	absolute value	math	Returns the absolute value of x: $\|x\|$
sqrt(x)	square root	math	Returns the square root of the absolute value of x: sqrt(-x)=-sqrt(|x|)
pow(x,y)	absolute power	math	Returns the value of x raised to the integer part of y: $x^{(\text{integer part of y})}$
pwr(x,y)	signed power	math	Returns the absolute value of x, raised to the y power, with the sign of x: (sign of x)$\|x\|^{y}$

Table 11 Synopsys HSPICE Built-in Functions (Continued)

HSPICE Form	Function	Class	Description
x**y	power		If x<0, returns the value of x raised to the integer part of y. If x=0, returns 0. If x>0, returns the value of x raised to the y power.
log(x)	natural logarithm	math	Returns the natural logarithm of the absolute value of x, with the sign of x: (sign of x)log(|x|)
log10(x)	base 10 logarithm	math	Returns the base 10 logarithm of the absolute value of x, with the sign of x: (sign of x)$\log_{10}$(|x|)
exp(x)	exponential	math	Returns e, raised to the power x: e^x
db(x)	decibels	math	Returns the base 10 logarithm of the absolute value of x, multiplied by 20, with the sign of x: (sign of x)20$\log_{10}$(|x|)
int(x)	integer	math	Returns the integer portion of x. The fractional portion of the number is lost.
nint(x)	integer	math	Rounds x up or down, to the nearest integer.
sgn(x)	return sign	math	Returns -1 if x is less than 0. Returns 0 if x is equal to 0. Returns 1 if x is greater than 0
sign(x,y)	transfer sign	math	Returns the absolute value of x, with the sign of y: (sign of y)|x|
min(x,y)	smaller of two args	control	Returns the numeric minimum of x and y
max(x,y)	larger of two args	control	Returns the numeric maximum of x and y
val(element)	get value	various	Returns a parameter value for a specified element. For example, val(r1) returns the resistance value of the *r1* resistor.

Table 11 Synopsys HSPICE Built-in Functions (Continued)

HSPICE Form	Function	Class	Description
val(element. parameter)	get value	various	Returns a value for a specified parameter of a specified element. For example, val(rload.temp) returns the value of the *temp* (temperature) parameter for the *rload* element.
val(model_type: model_name. model_param)	get value	various	Returns a value for a specified parameter of a specified model of a specific type. For example, val(nmos:mos1.rs) returns the value of the *rs* parameter for the *mos1* model, which is an nmos model type.
lv(<Element>) or lx(<Element>)	element templates	various	Returns various element values during simulation. See Element Template Output (HSPICE Only) on page 251 for more information.
v(<Node>), i(<Element>)...	circuit output variables	various	Returns various circuit values during simulation. See DC and Transient Output Variables on page 236 for more information.
[cond] ?x : y	ternary operator		Returns *x* if *cond* is not zero. Otherwise, returns *y*. .param z='condition ? x:y'
<	relational operator (less than)		Returns 1 if the left operand is less than the right operand. Otherwise, returns 0. .para x=y<z (y less than z)
<=	relational operator (less than or equal)		Returns 1 if the left operand is less than or equal to the right operand. Otherwise, returns 0. .para x=y<=z (y less than or equal to z)
>	relational operator (greater than)		Returns 1 if the left operand is greater than the right operand. Otherwise, returns 0. .para x=y>z (y greater than z)

Table 11 Synopsys HSPICE Built-in Functions (Continued)

HSPICE Form	Function	Class	Description
>=	relational operator (greater than or equal)		Returns 1 if the left operand is greater than or equal to the right operand. Otherwise, returns 0. .para x=y>=z (y greater than or equal to z)
==	equality		Returns 1 if the operands are equal. Otherwise, returns 0. .para x=y==z (y equal to z)
!=	inequality		Returns 1 if the operands are not equal. Otherwise, returns 0. .para x=y!=z (y not equal to z)
&&	Logical AND		Returns 1 if neither operand is zero. Otherwise, returns 0. .para x=y&&z (y AND z)
||	Logical OR		Returns 1 if either or both operands are not zero. Returns 0 only if both operands are zero. .para x=y||z (y OR z)

Example

```
.parameters p1=4 p2=5 p3=6
r1 1 0 value='p1 ? p2+1 : p3'
```

HSPICE reserves the variable names listed in Table 12 on page 142 for use in elements, such as E, G, R, C, and L. You can use them in expressions, but you cannot redefine them; for example, this statement would be illegal:

```
.param temper=100
```

Table 12 Synopsys HSPICE Special Variables

HSPICE Form	Function	Class	Description
time	current simulation time	control	Uses parameters to define the current simulation time, during transient analysis.

Table 12 Synopsys HSPICE Special Variables (Continued)

HSPICE Form	Function	Class	Description
temper	current circuit temperature	control	Uses parameters to define the current simulation temperature, during transient/temperature analysis.
hertz	current simulation frequency	control	Uses parameters to define the frequency, during AC analysis.

Parameter Scoping and Passing

If you use parameters to define values in sub-circuits, you need to create fewer similar cells, to provide enough functionality in your library. You can pass circuit parameters into hierarchical designs, and assign different values to the same parameter within individual cells, when you run simulation.

For example, if you use parameters to set the initial state of a latch in its subcircuit definition, then you can override this initial default in the instance call. You need to create only one cell, to handle both initial state versions of the latch.

You can also use parameters to define the cell layout. For example, you can use parameters in a MOS inverter, to simulate a range of inverter sizes, with only one cell definition. Local instances of the cell can assign different values to the size parameter for the inverter.

In HSPICE, you can also perform Monte Carlo analysis or optimization on a cell that uses parameters.

How you handle hierarchical parameters depends on how you construct and analyze your cells. You can construct a design in which information flows from the top of the design, down into the lowest hierarchical levels.

- To centralize the control at the top of the design hierarchy, set *global* parameters.
- To construct a library of small cells that are individually controlled from within, set *local* parameters and build up to the block level.

This section describes the scope of parameter names, and how HSPICE resolves naming conflicts between levels of hierarchy.

Library Integrity

Integrity is a fundamental requirement for any symbol library. Library integrity can be as simple as a consistent, intuitive name scheme, or as complex as libraries with built-in range checking.

Library integrity might be poor if you use libraries from different vendors in a circuit design. Because names of circuit parameters are not standardized between vendors, two components can include the same parameter name for different functions. For example, one vendor might build a library that uses the name `Tau` as a parameter to control one or more subcircuits in their library. Another vendor might use `Tau` to control a different aspect of their library. If you set a global parameter named `Tau` to control one library, you also modify the behavior of the second library, which might not be the intent.

If the scope of a higher-level parameter is global to all subcircuits at lower levels of the design hierarchy, higher-level definitions override lower-level parameter values with the same names. The scope of a lower-level parameter is local to the subcircuit where you define the parameter (but global to all subcircuits that are even lower in the design hierarchy). Local scoping rules in HSPICE prevent higher-level parameters from overriding lower-level parameters of the same name, when that is not desired.

Reusing Cells

Parameter name problems also occur if different groups collaborate on a design. Global parameters prevail over local parameters, so all circuit designers must know the names of all parameters, even those used in sections of the design for which they are not responsible. This can lead to a large investment in standard libraries. To avoid this situation, use local parameter scoping, to encapsulate all information about a section of a design, within that section.

Creating Parameters in a Library

To ensure that the input netlist includes critical, user-supplied parameters when you run simulation, you can use “illegal defaults”—that is, defaults that cause the simulator to abort if you do not supply overrides for the defaults.

If a library cell includes illegal defaults, you must provide a value for each instance of those cells. If you do not, the simulation aborts.

For example, you might define a default MOSFET width of 0.0. HSPICE aborts, because MOSFET models require this parameter.

Example 1

```
* Subcircuit default definition
.SUBCKT Inv A Y Wid=0 $ Inherit illegal values by default
mp1 <NodeList> <Model> L=1u W='Wid*2'
mn1 <NodeList> <Model> L=1u W=Wid
.ENDS

* Invoke symbols in a design
x1 A Y1 Inv        $ Bad! No widths specified
x2 A Y2 Inv Wid=1u $ Overrides illegal value for Width
```

This simulation aborts on the `x1` subcircuit instance, because you never set the required `Wid` parameter on the subcircuit instance line. The `x2` subcircuit simulates correctly. Additionally, the instances of the `Inv` cell are subject to accidental interference, because the `Wid` global parameter is exposed outside the domain of the library. Anyone can specify an alternative value for the parameter, in another section of the library or the circuit design. This might prevent the simulation from catching the condition on `x1`.

Example 2

In this example, the name of a global parameter conflicts with the internal library parameter named `Wid`. Another user might specify such a global parameter, in a different library. In this example, the user of the library has specified a different meaning for the `Wid` parameter, to define an independent source.

```
.Param Wid=5u         $ Default Pulse Width for source
v1 Pulsed 0 Pulse ( 0v 5v 0u 0.1u 0.1u Wid 10u )
...
* Subcircuit default definition
.SUBCKT Inv A Y Wid=0      $ Inherit illegals by default
mp1 <NodeList> <Model> L=1u W='Wid*2'
mn1 <NodeList> <Model> L=1u W=Wid
.Ends
* Invoke symbols in a design
x1 A Y1 Inv        $ Incorrect width!
x2 A Y2 Inv Wid=1u   $ Incorrect! Both x1 and x2
$ simulate with mp1=10u and
$ mn1=5u instead of 2u and 1u.
```

Under global parameter scoping rules, simulation succeeds, but incorrectly. HSPICE does not warn you that the x1 inverter has no assigned width, because the global parameter definition for `Wid` overrides the subcircuit default.

Note:

Similarly, sweeping with different values of *Wid* dynamically changes both the *Wid* library internal parameter value, and the pulse width value to the *Wid* value of the current sweep.

In global scoping, the highest-level name prevails, when resolving name conflicts. Local scoping uses the lowest-level name.

When you use the parameter inheritance method, you can specify to use local scoping rules.

When you use local scoping rules, the Example 2 netlist correctly aborts in x1 for W=0 (default Wid=0, in the `.SUBCKT` definition, has higher precedence, than the `.PARAM` statement). This results in the correct device sizes for x2. This change can affect your simulation results, if you intentionally or accidentally create a circuit such as the second one shown above.

As an alternative to width testing in the Example 2 netlist, you can use `.OPTION DEFW` to achieve a limited version of library integrity. This option sets the default width for all MOS devices during a simulation. Part of the definition is still in the top-level circuit, so this method can still make unwanted changes to library values, without notification from the HSPICE simulator.

Table 13 compares the three primary methods for configuring libraries, to achieve required parameter checking for default MOS transistor widths.

Table 13 Methods for Configuring Libraries

Method	Parameter Location	Pros	Cons
Local	On a .SUBCKT definition line	Protects library from global circuit parameter definitions, unless you override it. Single location for default values.	
Global	At the global level and on .SUBCKT definition lines	Works with all HSPICE versions.	An indiscreet user, another vendor assignment, or the intervening hierarchy can change the library. Cannot override a global value at a lower level.
Special	.OPTION DEFW statement	Simple to do.	Third-party libraries, or other sections of the design, might depend on .OPTION DEFW.

String Parameter (HSPICE Only)

HSPICE uses a special delimiter to identify string and double parameter types. The single quotes (‘), double quotes (“), or curly brackets ({}) do not work for these kinds of delimiters. Instead, use the sp1=str('string') keyword for an sp1 parameter definition and use the str(sp1) keyword for a string parameter instance.

Example

The following sample netlist shows an example of how you can use these definitions for various commands, keywords, parameters, and elements:

```
xibis1 vccq vss out in IBIS
+ IBIS_FILE=str('file1.ibs') IBIS_MODEL=str('model1')
xibis2 vccq vss out in IBIS
+ IBIS_FILE=str('file2.ibs') IBIS_MODEL=str('model2')

.subckt IBIS vccq vss out in
+ IBIS_FILE=str('file.ibs')
+ IBIS_MODEL=str('ibis_model')
ven en 0 vcc
BMCH vccq vss out in en v0dq0 vccq vss buffer=3
+ file= str(IBIS_FILE) model=str(IBIS_MODEL)
+ typ=typ ramp_rwf=2 ramp_fwf=2 power=on
.ends
```

HSPICE can now support these kinds of definitions and instances with the following netlist components:

- `.PARAM` statements
- `.SUBCKT` statements
- `FQMODEL` keywords
- S Parameters
- `FILE` and `MODEL` keywords
- B Elements
- `RLGCFILE`, `UMODEL`, `FSMODEL`, `RLGCMODEL`, `TABLEMODEL`, and `SMODEL` keywords in the W Element

Parameter Defaults and Inheritance

Use the `.OPTION PARHIER` parameter to specify scoping rules.

Syntax:

```
.OPTION PARHIER=< GLOBAL | LOCAL >
```

The default setting is `GLOBAL`.

Example

This example explicitly shows the difference between local and global scoping for using parameters in subcircuits.

The input netlist includes the following:

```
.OPTION parhier=<global | local>
.PARAM DefPwid=1u
.SUBCKT Inv a y DefPwid=2u DefNwid=1u
Mp1 <MosPinList> pMosMod L=1.2u W=DefPwid
Mn1 <MosPinList> nMosMod L=1.2u W=DefNwid
.ENDS
```

Set the `.OPTION PARHIER=parameter scoping` option to `GLOBAL`. The netlist also includes the following input statements:

```
xInv0 a y0 Inv           $ override DefPwid default,
$ xInv0.Mp1 width=1u
xInv1 a y1 Inv DefPwid=5u $ override DefPwid=5u,
$ xInv1.Mp1 width=1u

.measure tran Wid0 param='lv2(xInv0.Mp1)' $ lv2 is the
               $ template for
.measure tran Wid1 param='lv2(xInv1.Mp1)' $ the channel
               $ width
           $ `lv2(xInv1.Mp1)'
.ENDS
```

Simulating this netlist produces the following results in the listing file:

```
wid0=1.0000E-06
wid1=1.0000E-06
```

If you change the `.OPTION PARHIER=parameter scoping` option to `LOCAL`:

```
xInv0 a y0 Inv           $ not override .param
  $ DefPwid=2u,
  $ xInv0.Mp1 width=2u
xInv1 a y1 Inv DefPwid=5u      $ override .param
         $ DefPwid=2u,
         $ xInv1.Mp1 width=5u:
.measure tran Wid0 param='lv2(xInv0.Mp1)'$ override the
.measure tran Wid1 param='lv2(xInv1.Mp1)'$ global .PARAM
```

```
...
```

Simulation produces the following results in the listing file:

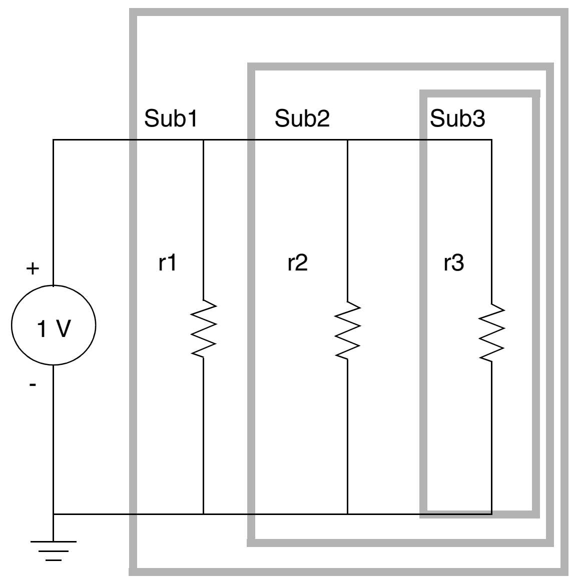
```
wid0=2.0000E-06
wid1=5.0000E-06
```

Parameter Passing

Figure 14 on page 149 shows a flat representation of a hierarchical circuit, which contains three resistors.

Each of the three resistors obtains its simulation time resistance from the *Val* parameter. The netlist defines the *Val* parameter in four places, with three different values.

Figure 14   Hierarchical Parameter Passing Problem



```
TEST OF PARHIER
.OPTION list node post=2
+ ingold=2
+ parhier=<Local|Global>
.PARAM Val=1
x1 n0 0 Sub1
.SubCkt Sub1 n1 n2 Val=1
   r1 n1 n2 Val
   x2 n1 n2 Sub2
.Ends Sub1
.SubCkt Sub2 n1 n2 Val=2
   r2 n1 n2 Val
   x3 n1 n2 Sub3
.Ends Sub2
.SubCkt Sub3 n1 n2 Val=3
   r3 n1 n2 Val
.Ends Sub3
.OP
.END
```

The total resistance of the chain has two possible solutions: 0.3333Ω and 0.5455Ω.

You can use `.OPTION PARHIER` to specify which parameter value prevails, when you define parameters with the same name at different levels of the design hierarchy.

Under global scoping rules, if names conflict, the top-level assignment `.PARAM Val=1` overrides the subcircuit defaults, and the total is 0.3333Ω. Under local scoping rules, the lower level assignments prevail, and the total is 0.5455Ω (one, two, and three ohms in parallel).

The example in Figure 14 produces the results in Table 14, based on how you set `.OPTION PARHIER` to local/global:

Table 14 PARHIER=LOCAL vs. PARHIER=GLOBAL Results

Element	PARHIER=Local	PARHIER=Global
r1	1.0	1.0
r2	2.0	1.0
r3	3.0	1.0

Parameter Passing Solutions

The checklist below determines whether you will see simulation differences when you use the default scoping rules. These checks are especially important if your netlists contain devices from multiple vendor libraries.

- Check your sub-circuits for parameter defaults, on the `.SUBCKT` or `.MACRO` line.
- Check your sub-circuits for a `.PARAM` statement, within a `.SUBCKT` definition.
- To check your circuits for global parameter definitions, use the `.PARAM` statement.
- If any of the names from the first three checks are identical, set up two HSPICE simulation jobs: one with `.OPTION PARHIER=GLOBAL`, and one with `.OPTION PARHIER=LOCAL`. Then look for differences in the output.

7 Testbench Elements

Describes the specialized elements supported by HSPICE RF for high-frequency analysis and characterization.

In addition to the elements described in the *HSPICE Elements and Device Models Manual*, HSPICE RF also supports several specialized elements for high-frequency analysis and characterization.

Behavioral Passive Elements

HSPICE RF accepts equation-based resistors and capacitors. You can specify the value of a resistor or capacitor as an arbitrary equation that involves node voltages or variable parameters. Unlike HSPICE, you cannot use parameters to indirectly reference node voltages in HSPICE RF.

Resistors

The following general input syntax is for a resistor.

```
Rxxx node1 node2 < modelname > < R = > resistance
+ < TC1 = val > < TC2 = val > < TC = val > < W = val >
+ < L = val > < M = val > < C = val > < DTEMP = val >
+ < SCALE = val >

Rxxx node1 node2 . . . <R=> 'equation' . . .
```

Parameter	Description
R*xxx*	Name of a resistor.
node1 and node2	Names of the connecting nodes.

Parameter	Description
modelname	Name of the resistor model.
value	Minimal resistance value in ohms.
R	Resistance in ohms, at room temperature.
TC1, TC2, TC	First- and second-order temperature coefficients. TC is alias for TC1. The current definition overrides the previous definition.
W	Resistor width.
L	Resistor length.
M	Parallel multiplier.
C	Parasitic capacitance between node2 and the substrate.
DTEMP	Temperature difference between element and circuit.
SCALE	Scaling factor.
equation	Resistance can be a function of any node voltage, and any branch current, but not a function of time, frequency, or temperature.

This support is similar to HSPICE. For additional information, see Resistor Elements in a HSPICE or HSPICE RF Netlist the *HSPICE Simulation and Analysis User Guide*.

The following are some basic examples for HSPICE RF.

Example 1

`R1` is a resistor whose resistance follows the voltage at node `c`.

```
R1 1 0 ‘v(c)’
```

Example 2

`R2` is a resistor whose resistance is the sum of the absolute values of nodes `c` and `d`.

```
R2 1 0 ‘abs(v(c)) + abs(v(d))’
```

Example 3

`R3` is a resistor whose resistance is the sum of the `rconst` parameter, and `100` times `tx1` for a total of 1100 ohms.

```
.PARAM rconst=100 tx1=10
R3 4 5 ‘rconst + tx1 * 100’
```

`R3` takes its value from the RX parameter, and uses the TC1 and TC2 temperature coefficients, which become 0.001 and 0, respectively.

Example 4

You can use the HERTZ keyword to form frequency-dependent resistors. HSPICE RF accurately analyzes these in all time-domain and frequency-domain simulations. In this example, `R4` has resistance with both DC and skin-effect contributions:

```
R4 in out R='100.0 + sqrt(HERTZ)/1000.0'
```

Frequency-Dependent Resistors

You can specify frequency-dependent resistors using the R=expression with the HERTZ keyword. The HERTZ keyword represents the operating frequency. In time domain analyses, an expression with the HERTZ keyword behaves differently according to the value assigned to the CONVOLUTION keyword.

Syntax

```
Rxxx n+ n- R=expression(with HERTZ) <CONVOLUTION=0|1|2>
+ <FBASE=value> <FMAX=value>>
```

Parameter	Description
CONVOLUTION	Indicates which method is used. ▪ 0 : Acts the same as the conventional method. This is the default. ▪ 1 : Applies recursive convolution, and if the rational function is not accurate enough, it switches to linear convolution. ▪ 2 : Applies linear convolution.

Parameter	Description
FBASE	Specifies the lower bound of the transient analysis frequency. For CONVOLUTION=1 mode, HSPICE starts sampling at this frequency. For CONVOLUTION=2 mode, HSPICE uses this value as the base frequency point for Inverse Fourier Transformation. For recursive convolution, the default value is 0Hz, and for linear convolution, HSPICE uses the reciprocal of the transient period.
FMAX	Specifies the possible maximum frequency of interest. The default value is the frequency point where the function reaches close enough to infinity value, assuming that the monotonous function is approaching the infinity value and that it is taken at 10THz. The equation should be a function of HERTZ. If CONVOLUTION is turned on when a HERTZ keyword is not used in the equation, it is automatically be turned off to let the resistor behave as conventional.The equation can be a function of temperature, but it cannot be node voltage or branch current and time.

The equation can only be a function of time-independent variables such as hertz, and temperature.

Example:

```
R1 1 2 r='1.0 + 1e-5*sqrt(HERTZ)' CONVOLUTION=1
```

Capacitors

The following general input syntax is for a capacitor.

```
Cxxx node1 node2 < modelname > < C = > capacitance
+ < TC1 = val > < TC2 = val > <W = val > < L = val >
+ < DTEMP = val > < M = val > < SCALE = val > < IC = val >

Cxxx n1 n2 . . . C='equation' CTYPE=[0|1|2]
```

Parameter	Description
C*xxx*	Capacitor element name. Must begin with C, followed by up to 1023 alphanumeric characters.

Parameter	**Description**
node1 and node2	Names or numbers of connecting nodes.
capacitance	Nominal capacitance value in Farads.
modelname	Capacitance model name.
C	Capacitance at room temperature in Farads.
TC1, TC2	First-order and second-order temperature coefficient.
W	Capacitor width in meters.
L	Capacitor length in meters.
M	Multiplier to simulate multiple parallel capacitors.
DTEMP	Temperature difference between element and circuit.
SCALE	Scaling factor.
IC	Initial capacitor voltage.
equation	Capacitance can be a function of any node voltage, and any branch current, but not a function of time, frequency, or temperature.
CTYPE	Determines the calculation mode for elements that use capacitance equations. Set this parameter carefully to ensure correct simulation results. HSPICE RF extends the definition and values of CTYPE relative to HSPICE: ■ 0, if C depends only on its own terminal voltages—that is, a function of V(n1<, n2>). This is consistent with HSPICE. ■ 1, if C depends only on outside voltages or currents. This is consistent with HSPICE. ■ 2, if C depends on both its own terminal and outside voltages (default for HSPICE RF). HSPICE does not use CTYPE=2.

This support is similar to HSPICE. For additional information, see Capacitors the *HSPICE Simulation and Analysis User Guide*.

Example 1

```
Cbypass 1 0 10PF
C1 2 3 CBX
.MODEL CBX C
CB B 0 10P IC = 4V
CP X1.XA.1 0 0.1P
```

In this example:

- `Cbypass` is a straightforward, 10 pF capacitor.
- `C1` calls the `CBX` model, and its capacitance is not constant.
- `CB` is a 10 pF capacitor with an initial voltage of `4V` across it.
- `CP` is a 0.1 pF capacitor.

Example 2

```
V1 1 0 pwl(0n 0v 100n 10v)
V2 2 0 pwl(0n 0v 100n 10v)
C1 1 0 C='(V(1) + V(2))*1e-12' CTYPE=2
```

Example 3 (HSPICE RF Only)

```
C2 1 0 C='1 + TIME' $ Time-varying capacitor
```

Charge-Based Capacitors

You can also specify capacitors using behavioral equations for charge.

Syntax

Cxxx *n1 n2* Q='*equation*'

$C = \frac{dQ}{dV}, \ V = V(n1,n2)$ is equivalent to:

```
Cxxx a b Q='f(V(a,b))'
```

In the preceding equations, $d(x) = \frac{df(x)}{dx}$.

Example 1

```
C1 a b Q = 'sin(V(a,b)) + V(c,d)*V(a,b)'
```

This example is equivalent to:

```
C1 a b C = 'cos (V(a,b)) + V(c,d)'
```

Example 2

```
C3 3 0 Q = 'TIME+TIME'    $ supported in HPICE RF only
```

Frequency-Dependent Capacitors

You can specify frequency-dependent capacitors using the `C='equation'` with the `HERTZ` keyword. The `HERTZ` keyword represents the operating frequency. In time domain analyses, an expression with the `HERTZ` keyword behaves differently according to the value assigned to the `CONVOLUTION` keyword.

Syntax

```
Cxxx n1 n2 C='equation' <CONVOLUTION=[0|1|2]
+ <FBASE=val> <FMAX=val>>
```

Parameter	Description
n1 n2	Names or numbers of connecting nodes.
equation	Expressed as a function of HERTZ. If CONVOLUTION=1 or 2 and HERTZ is not used in the equation, CONVOLUTION is turned off and the capacitor behaves conventionally. The equation can be a function of temperature, but it does not support variables of node voltage, branch current, or time. If these variables exist in the expression and CONVOLUTION=1 or 2, then only their values at the operating point are considered in calculation.
CONVOLUTION	Specifies the method used. ▪ 0 (default): HERTZ=0 in time domain analysis. ▪ 1 or 2: performs Inverse Fast Fourier Transformation (IFFT) linear convolution.
FBASE	Base frequency to use for transient analysis. This value becomes the base frequency point for Inverse Fast Fourier Transformation (IFFT) when CONVOLUTION=1 or 2. If you do not set this value, the base frequency is a reciprocal value of the transient period.
FMAX	Maximum frequency to use for transient analysis. Used as the maximum frequency point for Inverse Fourier Transformation. If you do not set this value, the reciprocal value of RISETIME is taken.

Example

```
C1 1 2 C='1e-6 - HERTZ/1e16' CONVOLUTION=1 fbase=10 fmax=30meg
```

Frequency-Dependent Inductors

You can specify frequency-dependent inductors using the `L='equation'` with the `HERTZ` keyword. The `HERTZ` keyword represents the operating frequency. In time domain analyses, an expression with the `HERTZ` keyword behaves differently according to the value assigned to the `CONVOLUTION` keyword.

Syntax

```
Lxxx n1 n2 L=equation <CONVOLUTION=[0|1|2] <FBASE=valule>
+ <FMAX=value>>
```

Parameter	Description
Lxxx	Inductor element name. Must begin with L, followed by up to 1023 alphanumeric characters
n1 n2	Positive and negative terminal node names.
equation	The equation should be a function of HERTZ. If CONVOLUTION is turned on when a HERTZ keyword is not used in the equation, CONVOLUTION is automatically be turned off and the inductor behaves conventionally.The equation can be a function of temperature, but it does not support variables of node voltage, branch current, or time. If these variables exist in the equation with CONVOLUTION turned on, only their values at the operating point are considered in the calculation.
CONVOLUTION	Indicates which method is used. ▪ 0 (default): Acts the same as the conventional method. ▪ 1 : Applies recursive convolution, and if the rational function is not accurate enough, it switches to linear convolution. ▪ 2 : Applies linear convolution.
FBASE	Specifies the lower bound of the transient analysis frequency. ▪ For CONVOLUTION=1 mode, HSPICE starts sampling at this frequency. ▪ For CONVOLUTION=2 mode, HSPICE uses this value as the base frequency point for Inverse Fourier Transformation. ▪ For recursive convolution, the default value is 0Hz. ▪ For linear convolution, HSPICE uses the reciprocal of the transient period.

Parameter	Description
FMAX	Specifies the possible maximum frequency of interest. The default value is the frequency point where the function reaches close enough to infinity value, assuming that the monotonous function is approaching the infinity value and that it is taken at 10THz.

Example

```
L1 1 2 L='0.5n + 0.5n/(1 + HERTZ/1e8)' CONVOLUTION=1 fbase=10
+ fmax=30meg
```

DC Block and Choke Elements

In HSPICE RF, you can specify an INFINITY value for capacitors and inductors to model ideal DC block and choke elements. The following input syntax is for the DC block (ideal infinite capacitor):

Syntax

```
Cxxx node1 node2 <C=> INFINITY <IC=val>
```

HSPICE RF does not support any other capacitor parameters for DC block elements, because HSPICE RF assumes that the infinite capacitor value is independent of temperature and scaling factors. The DC block acts as an open circuit for all DC analyses. HSPICE RF calculates the DC voltage across the circuit's nodes. In all other (non-DC) analyses, a DC voltage source of this value represents the DC block (that is, HSPICE RF does not then allow dv/dt variations).

The following input syntax is for the Choke (ideal infinite inductor):

Syntax

```
Lxxx node1 node2 <L=> INFINITY <IC=val>
```

HSPICE RF does not support any other inductor parameters, because HSPICE RF assumes that the infinite inductance value is independent of temperature and scaling factors. The choke acts as a short circuit for all DC analyses. HSPICE RF calculates the DC current through the inductor. In all other (non-DC) analyses, a DC current source of this value represents the choke (that is, HSPICE RF does not then allow di/dt variations).

Ideal Transformers

You can use the `IDEAL` keyword with the K element to designate ideal transformer coupling.

Syntax

```
Kxxx Ij Lj <k=IDEAL | IDEAL>
```

The `IDEAL` keyword replaces the coupling factor value. This keyword activates the following equation set for non-DC values, which is presented here with multiple coupled inductors. I*j* is the current into the first terminal of L*j*.

$$\frac{v1}{\sqrt{L1}} = \frac{v2}{\sqrt{L2}} = \frac{v3}{\sqrt{L3}} = \frac{v4}{\sqrt{L4}} = \ldots$$

$$0 = (il \cdot \sqrt{L1}) + (i2 \cdot \sqrt{L2}) + (i3 \cdot \sqrt{L3}) + (i4 \cdot \sqrt{L4}) + \ldots$$

HSPICE RF can solve any i or v in terms of L ratios.

For two inductors (non-DC values):

$$\frac{v1}{\sqrt{L1}} = \frac{v2}{\sqrt{L2}}$$

$$0 = (il \cdot \sqrt{L1}) + (i2 \cdot \sqrt{L2})$$

$$v2 = v1 \cdot \sqrt{\frac{L2}{L1}}$$

$$i2 = i1 \cdot \sqrt{\frac{L1}{L2}}$$

DC is treated as usual—inductors are treated as short circuits. DC ignores mutual coupling.

You can couple inductors that use the `INFINITY` keyword to `IDEAL` K elements. All inductors involved must have the `INFINITY` value, and for `K=IDEAL`, the ratios of all L values is unity. Then, for two L values:

```
v2 = v1
i2 = -i1
```

Example 1

This example is a standard 5-pin ideal balun transformer subcircuit. Two pins are grounded for standard operation. With all K values being `IDEAL`, the absolute L values are not crucial—only their ratios are important.

```
**
**   all K's ideal  -----o out1
**                  Lo1=.25
**   o----in-       -----o 0
**         Lin=1    Lo2=.25
** 0 o-------       -----o out2
**
.subckt BALUN1  in  out1  out2
Lin    in    gnd   L=1
Lo1    out1  gnd   L=0.25
Lo2    gnd   out2  L=0.25
K12    Lin  Lo1    IDEAL
K13    Lin  Lo2    IDEAL
K23    Lo1  Lo2    IDEAL
.ends
```

Example 2

This example is a 2-pin ideal 4:1 step-up balun transformer subcircuit with shared DC path (no DC isolation). Input and output have a common pin, and both inductors have the same value. Note that Rload = 4*Rin.

```
**
**   all K's ideal
**in o-------------------o out=in
**                  L1=1
**                  -----o 0
**                  L2=1
**                  -----o out2
**
** With all K's ideal, the actual L's values are
** not important -- only their ratio to each other.
.subckt BALUN2 in  out2
L1     in   gnd   L=1
L2     gnd  out2  L=1
K12    L1   L2   IDEAL
.ends
```

Example 3

This example is a 3-pin ideal balun transformer with shared DC path (no DC isolation). All inductors have the same value (here set to unity).

```
**
**   all K's ideal  -----o out1
**                  Lo2=1
**                  -----o 0
**                  Lo1=1
**                  -----o out2
**    in            Lin=1
**   o------------------o in
**
.subckt BALUN3 in  out1  out2
Lo2    gnd  out1  L=1
Lo1    out2 gnd   L=1
Lin    in   out2  L=1
K12    Lin  Lo1  IDEAL
K13    Lin  Lo2  IDEAL
K23    Lo1  Lo2  IDEAL
.ends
```

Coupled Inductor Element

This section describes the multiport syntax for coupled inductor elements. This syntax extends the existing linear (L*xxx*) and mutual (K*xxx*) inductor elements. Two syntax configurations are available:

- a reluctance format that is used by Star-RCXT for inductance extraction
- an ideal transformer format that can be used to create balanced converter (that is, balun) models in HSPICE RF.

Reluctance Format

The element topology is specified on the L record. Two forms are available: an inline form and an external file reference form.

Syntax

```
Lxxx n1p n1n ... nNp nNn RELUCTANCE=(r1, c1, val1, r2, c2,
+ val2, ... , rm, cm, valm) <SHORTALL=yes|no>
+ <IGNORE_COUPLING=yes|no>

Lxxx n1p n1n ... nNp nNn RELUCTANCE FILE=<filename1>”
+ [FILE=”<filename2>” [...]] <SHORTALL=yes|no>
+ <IGNORE_COUPLING=yes|no>
```

+ <M = *val*> <DTEMP = *val*> <R = *val*>

Parameter	Description
Lxxx	Inductor element name. Must begin with L, followed by up to 1023 alphanumeric characters.

Parameter	Description
n1p n1n ... nNp nNn	Positive and negative terminal node names. The number of terminals must be even. Each pair of reports represents the location of an inductor.
RELUCTANCE	Reluctance provided in units of inverse Henry (H^{-1}). When present, this keyword indicates that tokens between L*xxx* and it are node names. ▪ Only terms along and above the diagonal are specified for the reluctance matrix. The simulator fills in the lower triangle to ensure symmetry. If you specify a lower diagonal term, the simulator converts that entry to the appropriate upper diagonal term. ▪ In general, the reluctance matrix is sparse and only non-zero values in the matrix need be given. Each matrix entry is represented by a triplet (*r*,*c*,*val*). Here, *r* and *c* are integers referring to a pair of inductors from the list of terminal nodes. If there are 2*N terminal nodes, there will be N inductors, and the *r* and *c* values must be in the range [1,N]. The *val* value is a reluctance value for the (*r*,*c*) matrix location. ▪ If you supply multiple entries for the same (*r*,*c*) location, then only the first one will be used, and a warning issued to indicate that some entries were ignored. ▪ All diagonal entries of the reluctance matrix must be assigned a positive value.
RELUCTANCE FILE	The data files should contain three columns of data. Each row should contain an (*r*,*c*,*val*) triplet separated by white space. The *r*, *c*, and *val* values may be expressions surrounded by single quotes. Multiple files may be specified to allow the reluctance data to be spread over several files if necessary. The files should not contain a header row.
SHORTALL	Causes all inductors to be converted to short circuits, and all reluctance matrix values to be ignored.
IGNORE_COUPLING	Causes all off-diagonal terms to be ignored (that is, set to 0).

Ideal Transformer Format in HSPICE RF

The ideal transformer format simplifies modeling of baluns. Previously, baluns were modeled using mutual inductors (K elements) with the `IDEAL` keyword.

Multiple L and K elements were needed for a given balun model. The ideal transformer model allows modeling of a balun using a single L element.

In the ideal transformer format, no absolute inductance or reluctance values are specified. Instead, the transformer's coupling characteristics are specified using inductor number-of-turns values. The behavior of the ideal transformer depends on ratios of the inductors' number of turns.

Syntax

```
Lxxx n1p n1n ... nNp nNn TRANSFORMER_NT=(nt1, ... , ntN)
```

Parameter	Description
Lxxx	Inductor element name. Must begin with L, followed by up to 1023 alphanumeric characters.
n1p n1n ... nNp nNn	Positive and negative terminal node names. The number of terminals must be even. Each pair of reports represents the location of an inductor.
TRANSFORMER_NT	Number of turns values. These parameters must match the number of inductors.

The ideal transformer element obeys the standard ideal transformer equations:

$$\frac{v_1}{nt_1} = \frac{v_2}{nt_2} = \ldots = \frac{v_N}{nt_N}$$

$$i_1 nt_1 + i_2 nt_2 + \ldots + i_N nt_N = 0$$

Example

```
L1 1 0 0 2 3 0 transformer_nt=(1,2,2)
```

Scattering Parameter Data Element

A transmission line is a passive element that connects any two conductors at any distance apart. For more information about transmission lines, see S Parameter Modeling Using the S Element in the *HSPICE Signal Integrity Guide*.

Frequency-Dependent Multi-Terminal (S) Element

When used with the generic frequency-domain model (`.MODEL SP`), a S element is a convenient way to describe the behavior of a multi-terminal network.

The S element describes a linear time-invariant system, and provides a series of data that describe the frequency response of the system. The S element is particularly useful for high-frequency characterization of distributed passive structures. A common use of the S element is in microwave circuits, because electronic devices in this frequency domain no longer act as they do in low frequencies. In this case, distributed system parameters must be considered.

The S element uses the following parameters to define a frequency-dependent, multi-terminal network:

- S (scattering) parameter
- Y (admittance) parameter

  Note:

  All HSPICE and HSPICE RF analyses can use the S element.

The S parameter is the reflection coefficient of the system, which is measured through ratios of incident and reflected sinusoidal waves. For passive systems, the magnitude of an S parameter varies between zero and one. Because the reflection coefficient is easy to measure in real microwave circuits, the S parameter can be a very useful tool for microwave engineers.

You can use the S element with a `.MODEL SP`, or with data files that describe the frequency response of a network and provide discrete frequency dependent data (Touchstone and CITIfile). You can measure this data directly using network analyzers such as Hewlett-Packard's MDS (Microwave Design System) or HFSS (High Frequency Structure Simulator). HSPICE can also extract the S element from a real circuit system.

For a description of the S parameter and SP analyses, see S Parameter Model in the *HSPICE Signal Integrity Guide*.

S Element Syntax

```
Sxxx nd1 nd2 ... ndN ndRef
+ <MNAME=Smodel_name> <FQMODEL=sp_model_name>
+ <TYPE=[s|y]> <Zo=[value|vector_value]>
+ <FBASE = base_frequency> <FMAX=maximum_frequency>
+ <PRECFAC=val> <DELAYHANDLE=[1|0|ON|OFF]>
+ <DELAYFREQ=val>
+ <INTERPOLATION=STEP|LINEAR|SPLINE>
+ <INTDATTYP =[RI|MA|DBA]> <HIGHPASS=value>
+ <LOWPASS=value> <MIXEDMODE=[0|1]>
+ <DATATYPE=data_string> <DTEMP=val>
+ <NOISE=[1|0]>
```

Parameter	Specifies
nd1 nd2 ... ndN	*N* signal (terminal) nodes (see Figure 15 on page 170). Three kinds of definitions are present: ■ With no reference node ndRef, the default reference node in this situation is GND. Each node ndi (i=1~N) and GND construct one of the N ports of the S element. ■ With one reference node, ndRef is defined. Each node ndi (i=1~N) and the ndRef construct one of the N ports of the S element. ■ With an N reference node, each port has its own reference node. You can write the node definition in a clearer way as: nd1+ nd1- nd2+ nd2- ... ndN+ ndN- Each pair of the nodes (ndi+ and ndi-, i=1~N) constructs one of the N ports of the S element.
ndR (nd_ref)	Reference node.
MNAME	Name of the S model.
FQMODEL	Frequency behavior of the S,Y, or Z parameters. .MODEL statement of sp type, which defines the frequency-dependent matrices array.
TYPE	Parameter type: ■ S (scattering) (default) ■ Y (admittance) ■ Z (impedance)
Zo	Characteristic impedance value for reference line (frequency-independent). For multiple terminals (*N*>1), HSPICE or HSPICE RF assumes that the characteristic impedance matrix of the reference lines is diagonal, and that you set diagonal values to Zo. To specify general types of reference lines, use Zof. Default value is 50.

Parameter	Specifies
FBASE	Base frequency to use for transient analysis. This value becomes the base frequency point for Inverse Fast Fourier Transformation (IFFT). ■ If you do not set this value, the base frequency is a reciprocal value of the transient period. ■ If you do not set this value, the reciprocal value of RISETIME is taken. (See .OPTION RISETIME in the *HSPICE and HSPICE RF Command Reference* for more information.) ■ If you set a frequency that is smaller than the reciprocal value of the transient, then transient analysis performs circular convolution, and uses the reciprocal value of `FBASE` as its base period.
FMAX	Maximum frequency to use for transient analysis. Used as the maximum frequency point for Inverse Fourier Transformation.
PRECFAC	In almost all cases, you do not need to specify a value for this parameter. This parameter specifies the precondition factor keyword used for the precondition process of the S parameter. A precondition is used to avoid an infinite admittance matrix. The default is `0.75`, which is good for most cases.
DELAYHANDLE	Delay handler for transmission-line type parameters. Set DELAYHANDLE to ON (or 1) to turn on the delay handle; set DELAYHANDLE to OFF (or 0) to turn off the delay handle (default). If you set DELAYHANDLE=OFF but DELAYFQ is not zero, HSPICE simulates the S element in delay mode.
DELAYFREQ	Delay frequency for transmission-line type parameters. The default is FMAX. If the DELAYHANDLE is set to OFF, but DELAYFREQ is nonzero, HSPICE still simulates the S element in delay mode.
INTERPOLATION	The interpolation method: ■ STEP: piecewise step ■ SPLINE: b-spline curve fit ■ LINEAR: piecewise linear (default)

Parameter	Specifies
INTDATTYP	Data type for the linear interpolation of the complex data. ■ RI: real-imaginary based interpolation ■ DBA: dB-angle based interpolation ■ MA: magnitude-angle based interpolation (default)
HIGHPASS	Method to extrapolate higher frequency points. ■ 0: cut off ■ 1: use highest frequency point ■ 2: perform linear extrapolation using the highest 2 points ■ 3: apply the window function to gradually approach the cut-off level (default) This option overrides EXTRAPOLATION in ,MODEL SP.
LOWPASS	Method to extrapolate lower frequency points. ■ 0: cut off ■ 1: use the magnitude of the lowest point ■ 2: perform linear extrapolation using the magnitude of the lowest two points This option overrides EXTRAPOLATION in ,MODEL SP.
MIXEDMODE	Set to 1 if the parameters are represented in the mixed mode.
DATATYPE	A string used to determine the order of the indices of the mixed-signal incident or reflected vector. The string must be an array of a letter and a number (Xn) where: ■ X = D to indicate a differential term = C to indicate a common term = S to indicate a single (grounded) term ■ n = the port number

Parameter	**Specifies**
DTEMP	Temperature difference between the element and the circuit.[a] Expressed in °C. The default is 0.0.
NOISE	Activates thermal noise. ■ 1 (default): element generates thermal noise ■ 0: element is considered noiseless

a. Circuit temperature is specified by using the .TEMP statement or by sweeping the global TEMP variable in .DC, .AC, or .TRAN statements. When neither .TEMP or TEMP is used, circuit temperature is set by using .OPTION TNOM. The default for TNOM is 25⁄*C, unless you use .OPTION SPICE, which has a default of 27 °C. You can use the DTEMP parameter to specify the temperature of the element.*

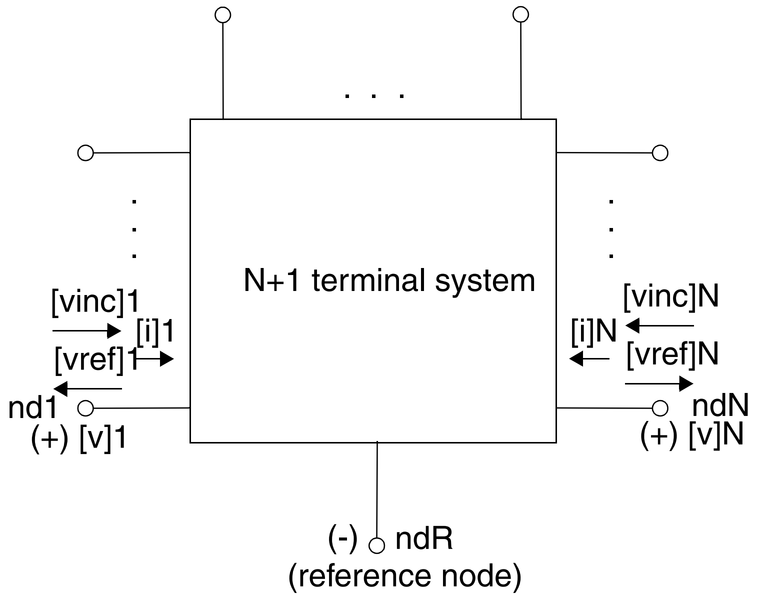
The preceding table lists descriptions of the S element parameters. For other parameters, refer to the S model parameter descriptions.

The nodes of the S element must come first. If `MNAME` is not declared, you must specify the `FQMODEL`. You can specify all the optional parameters in both the S element and S model statements, except for `MNAME` argument.

You can enter the optional arguments in any order, and the parameters specified in the element statement have a higher priority.

If the number of nodes in the element card is smaller than the number specified in the model card (or external file) by 1, then the reference node is the default. The default reference node is 0 (gnd).

Figure 15 Terminal Node Notation



S Model Syntax

```
.MODEL Smodel_name S
+ <N=dimension>
+ [FQMODEL=sp_model_name | TSTONEFILE=filename |
+ CITIFILE=filename]
+ <TYPE=[s | y]> <Zo=[value | vector_value]>
+ <FBASE=base_frequency> <FMAX=maximum_frequency>
+ <HIGHPASS=[0|1|2]> <LOWPASS=[0|1|2]>
+ <PRECFAC=val> <DELAYHANDLE=[1|0|ON|OFF]>
+ <DELAYFREQ=val> <MIXEDMODE=[0|1]>
+ <DATATYPE=data_string> <XLINELENGTH=val>
```

Parameter	Specifies
Smodel_name	Name of the S model.
S	Specifies that the model type is an S model.
N	S model dimension, which is the terminal number of the S element, excluding the reference node.
FQMODEL	Frequency behavior of the S,Y, or Z parameters. `.MODEL` statement of `SP` type, which defines the frequency-dependent matrices array.

Parameter	**Specifies**
TSTONEFILE	Name of a Touchstone file. Data contains frequency-dependent array of matrixes. Touchstone files must follow the .sp# file extension rule, where # represents the dimension of the network. For details, see *Touchstone® File Format Specification* by the EIA/IBIS Open Forum (http://www.eda.org).
CITIFILE	Name of the CITIfile, which is a data file that contains frequency-dependent data. For details, see *Using Instruments with ADS* by Agilent Technologies (http://www.agilent.com).
TYPE	One of the following parameter types: ■ S (scattering) (default) ■ Y (admittance) ■ Z (impedance)
Zo	Characteristic impedance value of the reference line (frequency-independent). For multi-terminal lines (N>1), HSPICE assumes that the characteristic impedance matrix of the reference lines are diagonal, and their diagonal values are set to `Zo`. You can also set a vector value for non-uniform diagonal values. Use Zof to specify more general types of a reference-line system. The default is 50.
FBASE	Base frequency to use for transient analysis. This value becomes the base frequency point for Inverse Fast Fourier Transformation (IFFT). ■ If you do not set this value, the base frequency is a reciprocal value of the transient period. ■ If you set a frequency that is smaller than the reciprocal value of the transient, then the transient analysis performs circular convolution, and uses the reciprocal value of FBASE as its base period.
FMAX	Maximum frequency for transient analysis. Used as the maximum frequency point for Inverse Fast Fourier Transform (IFFT).
LOWPASS	Specifies low-frequency extrapolation: ■ 0: Use zero in Y dimension (open circuit). ■ 1: Use lowest frequency (default). ■ 2: Use linear extrapolation with the lowest two points. This option overrides EXTRAPOLATION in .MODEL SP.

Parameter	Specifies
HIGHPASS	Specifies high-frequency extrapolation: ■ 0: Use zero in Y dimension (open circuit). ■ 1: Use highest frequency. ■ 2: Use linear extrapolation with the highest two points. ■ 3: Apply window function (default). This option overrides EXTRAPOLATION in .MODEL SP.
PRECFAC	Preconditioning factor to avoid a singularity in the form of an infinite admittance matrix. See Pre-Conditioning S Parameters on page 175 for more information. The default=0.75.
DELAYHANDLE	Delay handler for transmission line type parameters. ■ 1 or ON activates the delay handler. See Group Delay Handler in Time Domain Analysis on page 175. ■ 0 or OFF (default) deactivates the delay handler. You must set the delay handler, if the delay of the model is longer than the base period specified in the FBASE parameter. If you set DELAYHANDLE=OFF but DELAYFQ is not zero, HSPICE simulates the S element in delay mode.
DELAYFREQ	Delay frequency for transmission line type parameters, which is the frequency point when HSPICE RF extracts the matrix delay. The default is the FMAX value, which is the maximum frequency used in the transient analysis. If you set DELAYHANDLE to OFF, but DELAYFREQ is not zero, HSPICE still simulates the S element in delay mode.
MIXEDMODE	Set to 1 if the parameters are represented in the mixed mode.
DATATYPE	A string used to determine the order of the indices of the mixed-signal incident or reflected vector. The string must be an array of a letter and a number (*Xn*) where: ■ X = D to indicate a differential term = C to indicate a common term = S to indicate a single (grounded) term ■ n = the port number
XLINELENGTH	The line length of the transmission line system where the S parameters are extracted. This keyword is required only when the S Model is used in a W element.

The `FQMODEL`, `TSTONEFILE`, and `CITIFILE` parameters describe the frequency-varying behavior of a network. Only specify one of the parameters in an S model card. If more than one method is declared, only the first one is used and HSPICE issues a warning message.

`FQMODEL` can be set in S element and S model statements, but both statements must refer to the same model name.

The S element is capable of reading in two-port noise parameter data from Touchstone data files and then transform the raw data into a form used for noise (and `.LIN 2PNOISE`) analysis.

For example, you can represent a two-port system with an S element and then perform a noise analysis (or any other analysis). The S element noise model supports both normal and two-port noise analysis (`.NOISE` and `.LIN NOISECALC=1`).

Example 1

```
s1 n1 n2 n3 n_ref mname=smodel
.model smodel s n=3 fqmodel=sfqmodel zo=50 fbase=25e6
+ fmax=1e9
```

Example 2

```
s1 n1 n2 n3 n_ref fqmodel=sfqmodel zo=50 fbase=25e6 fmax=1e9
```

Examples 1 and 2 return the same result.

Example 3

```
s1 n1 n2 n3 n_ref mname=smodel zo=100
.model smodel s n=3 fqmodel=sfqmodel zo=50 fbase=25e6
+ fmax=1e9
```

In this example, the characteristic impedance of each port is 100 ohms, instead of 50 ohms as defined in `smodel`, because parameters defined in the S element statement have higher priority than those defined in the S model statement.

Example 4

```
s1 n1 n2 n3 n_ref mname=smodel
.model smodel s n=3 fqmodel=sfqmodel zo=50 50 100
```

In this example, the characteristic impedance of port1 and port2 are 50 ohms, and the characteristic impedance of port3 is 100 ohms.

Example 5

```
s1 n1 n2 n3 n_ref mname=smodel
.model smodel s tstonefile=expl.s3p
```

In this example, the name of the tstone file, expl.s3p, reveals that the network has three ports.

Example 6

```
s1 n1 n2 n3 n_ref mname=smodel
.model smodel s fqmodel=sfqmodel tstonefile=expl.s3p
+ citifile=expl.citi0
```

In this example, `fqmodel`, `tstonefile`, and `citifile` are all declared. HSPICE uses only the `fqmodel`, ignores `tstonefile` and `citifile`, and reports warning messages.

Example 7

```
s1 n1 n2 n3 n_ref mname=smodel fqmodel=sfqmodel_1
.model smodel s n=3 fqmodel=sfqmodel_2
```

In this example, `fqmodel` is declared in both the S element statement and the S model statement, and they have different `fqmodel` names. This is not allowed in HSPICE.

Example 8

```
s1 n1 n2 n3 n_ref mname=smodel fqmodel=sfqmodel
.model smodel s tstonefile=expl.s3p
```

In this example, `fqmodel` is already declared in the `s1` statement, and `tstonefile` is declared in the related `smodel` card. This is a conflict when describing the frequency-varying behavior of the network, which is not allowed in HSPICE.

Frequency Table Model

The frequency table model (SP model) is a generic model that you can use to describe frequency-varying behavior. Currently, the S element and the `.LIN` command use this model. For a description of this model, see section Small-Signal Parameter Data Frequency Table Model in the *HSPICE Signal Integrity Guide*.

Group Delay Handler in Time Domain Analysis

The S element accepts a constant group delay matrix in time-domain analysis. You can also express a weak dependence of the delay matrix on the frequency as a combination of the constant delay matrix and the phase shift value at each frequency point.

To activate or deactivate this delay handler, specify the `DELAYHANDLE` keyword in the S model statement.

The delay matrix is a constant matrix, which HSPICE RF extracts using finite difference calculation at selected target frequency points. HSPICE RF obtains the $T_{\omega(i,j)}$ delay matrix component as:

$$T_{\omega(i,j)} = \frac{d\theta_{Sij}}{d\omega} = \frac{1}{2\pi} \cdot \frac{d\theta_{Sij}}{df} \qquad (1)$$

- f is the target frequency, which you can set using `DELAYFREQ`. The default target frequency is the maximum frequency point.
- θ_{Sij} is the phase of Sij.

After time domain analysis obtains the group delay matrix, the following equation eliminates the delay amount from the frequency domain system-transfer function:

$$y'_{mn(\omega)} = y_{mn(\omega)} \times e^{j\omega T_{mn}} \qquad (2)$$

The convolution process then uses the following equation to calculate the delay:

$$i_{k(t)} = (y'_{k1(t)}, y'_{k2(t)}, \ldots, y'_{kN(t)}) \times (v_{1(t-T_{K1})}, v_{2(t-T_{K2})}, \ldots, v_{Nt-T_{KN}})^T \qquad (3)$$

Pre-Conditioning S Parameters

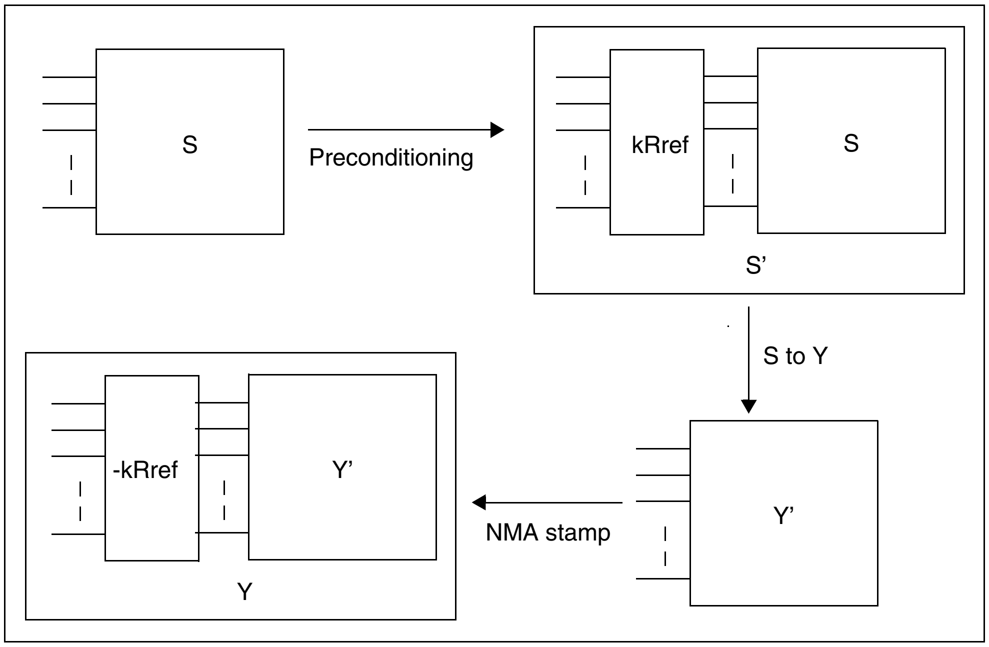
Certain S parameters, such as series inductor (2-port), show a singularity when converting S to Y parameters. To avoid this singularity, the S element adds kR$_{ref}$ series resistance to pre-condition S matrices:

$$S' = [kI + (2-k)S][(2+k)I - kS]^{-1}$$

- R$_{ref}$ is the reference impedance vector.
- k is the pre-conditioning factor.

To compensate for this modification, the S element adds a negative resistor (-kR_{ref}) to the modified nodal analysis (NMA) matrix in actual circuit compensation. To specify this pre-conditioning factor, use the `PREFAC` keyword in the S model statement. The default pre-conditioning factor is 0.75.

Figure 16 Pre-Conditioning S Parameters



Port Element

The port element identifies the ports used in LIN analysis. Each port element requires a unique port number. If your design uses *N* port elements, your netlist must contain the sequential set of port numbers, 1 through *N*. For example, in a design containing 512 ports, you must number each port sequentially, 1 to 512.

Each port has an associated system impedance, `zo`. If you do not explicitly specify the system impedance, the default is 50 ohms.

The port element behaves as either a noiseless impedance or a voltage source in series with the port impedance for all other analyses (DC, AC, or TRAN).

- You can use this element as a pure terminating resistance or as a voltage or power source.
- You can use the `RDC`, `RAC`, `RHB`, `RHBAC`, and `RTRAN` values to override the port impedance value for a particular analysis.

Port Element Syntax

```
Pxxx p n port=portnumber
+ $ **** Voltage or Power Information ********
+ <DC mag> <AC <mag <phase>>> <HBAC <mag <phase>>>
+ <HB <mag <phase <harm <tone <modharm <modtone>>>>>>>
+ <transient_waveform> <TRANFORHB=[0|1]>
+ <DCOPEN=[0|1]>
+ $ **** Source Impedance Information ********
+ <Z0=val> <RDC=val> <RAC=val>
+ <RHBAC=val> <RHB=val> <RTRAN=val>
+ $ **** Power Switch ********
+ <power=[0|1|2|W|dbm]>
```

Parameter	Description
port=portnumber	The port number. Numbered sequentially beginning with 1 with no shared port numbers.
<DC mag>	DC voltage or power source value.
<AC <mag <phase>>>	AC voltage or power source value.
<HBAC <mag <phase>>>	(HSPICE RF) HBAC voltage or power source value.
<HB <mag <phase <harm <tone <modharm <modtone>>>>>>>	(HSPICE RF) HB voltage, current, or power source value. Multiple HB specifications with different *harm*, *tone*, *modharm*, and *modtone* values are allowed. ■ *phase* is in degrees ■ *harm* and *tone* are indices corresponding to the tones specified in the `.HB` statement. Indexing starts at 1 (corresponding to the first harmonic of a tone). ■ *modtone* and *modharm* specify sources for multi-tone simulation. A source specifies a tone and a harmonic, and up to 1 offset tone and harmonic (*modtone* for tones and *modharm* for harmonics). The signal is then described as: V(or I) = mag*cos(2*pi*(harm*tone+modharm*modtone)*t + phase)
<transient_waveform>	(Transient analysis) Voltage or power source waveform. Any one of waveforms: AM, EXP, PULSE, PWL, SFFM, or SIN. Multiple transient descriptions are not allowed.

Parameter	Description
<TRANFORHB=[0|1]>	■ 0 (default): The transient description is ignored if an HB value is given or a DC value is given. If no DC or HB value is given and TRANFORHB=0, then HB analysis treats the source as a DC source, and the DC source value is the time=0 value. ■ 1: HB analysis uses the transient description if its value is VMRF, SIN, PULSE, PWL, or LFSR. If the type is a non-repeating PWL source, then the time=infinity value is used as a DC analysis source value. For example, the following statement is treated as a DC source with value=1 for HB analysis: v1 1 0 PWL (0 0 1n 1 1u 1) + TRANFORHB=1 In contrast, the following statement is a 0V DC source: v1 1 0 PWL (0 0 1n 1 1u 1) + TRANFORHB=0 The following statement is treated as a periodic source with a 1us period that uses PWL values: v1 1 0 PWL (0 0 1n 1 0.999u 1 1u 0) R + TRANFORHB=1 To override the global TRANFORHB option, explicitly set TRANFORHB for a voltage or current source.
DCOPEN	Switch for open DC connection when DC *mag* is not set. ■ 0 (default): P element behaves as an impedance termination. ■ 1 : P element is considered an open circuit in DC operating point analysis. `DCOPEN=1` is mainly used in `.LIN` analysis so the P element will not affect the self-biasing device under test by opening the termination at the operating point.
<z0=val>	(LIN analysis) System impedance used when converting to a power source, inserted in series with the voltage source. Currently, this only supports real impedance. ■ When power=0, z0 defaults to 0. ■ When power=1, z0 defaults to 50 ohms. You can also enter zo=val.

Parameter	Description
<RDC=val>	(DC analysis) Series resistance (overrides `z0`).
<RAC=val>	(AC analysis) Series resistance (overrides `z0`).
<RHBAC=val>	(HSPICE RF HBAC analysis) Series resistance (overrides `z0`).
<RHB=val>	(HSPICE RF HB analysis) Series resistance (overrides `z0`).
<RTRAN=val>	(Transient analysis) Series resistance (overrides `z0`).
<power=[0 | 1 | 2 | W | dbm]>	(HSPICE RF) power switch ■ When 0 (default), element treated as a voltage or current source. ■ When 1 or W, element treated as a power source, realized as a voltage source with a series impedance. In this case, the source value is interpreted as RMS available power in units of Watts. ■ When 2 or dbm, element treated as a power source in series with the port impedance. Values are in dbms. You can use this parameter for Transient analysis if the power source is either DC or SIN.

Example

For example, the following port element specifications identify a 2-port network with 50-ohm reference impedances between the “in” and “out” nodes.

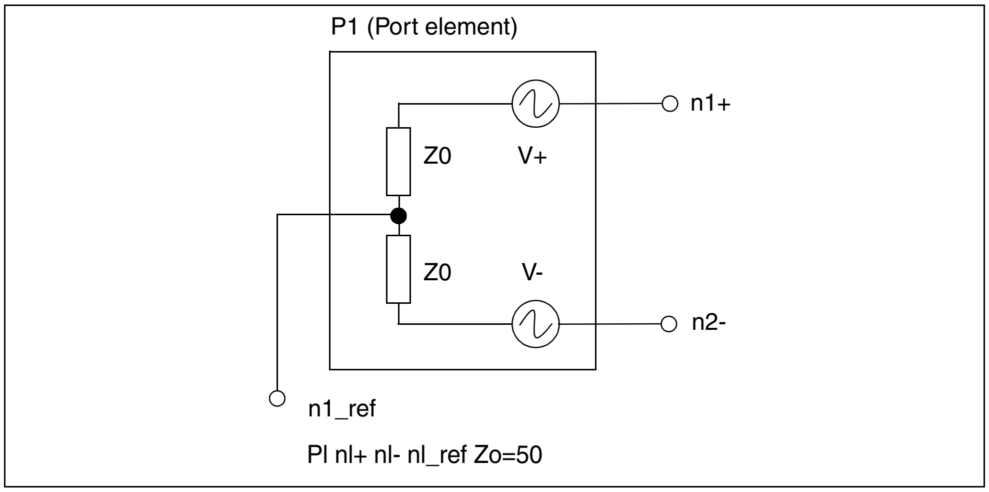
```
P1 in gnd port=1 z0=50
P2 out gnd port=2 z0=50
```

Computing scattering parameters requires `z0` reference impedance values. The order of the `port` parameters (in the P element) determines the order of the S, Y, and Z parameters. Unlike the `.NET` command, the `.LIN` command does not require you to insert additional sources into the circuit. To calculate the requested transfer parameters, HSPICE automatically inserts these sources as needed at the port terminals. You can define an unlimited number of ports.

Using the Port Element for Mixed-Mode Measurement

You can use a port element with three terminals as the port element for measuring the mixed mode S parameters. Except for the number of external terminals, the syntax of the port element remains the same. The LIN analysis function internally sets the necessary drive mode (common/differential) of these mixed mode port elements. For analyses other than the LIN analysis (such as DC, AC, TRAN, and so on), the mixed-mode P element acts as a differential driver that drives positive nodes with half of their specified voltage and the negative nodes with a negated half of the specified voltage. Figure 17 on page 180 shows the block diagram of the mixed mode port element.

Figure 17 Mixed Mode Port Element



Steady-State Voltage and Current Sources

The I (current source) and V (voltage source) elements include extensions that allow you to use them as sources of steady-state sinusoidal signals for HB and HBAC analyses. When you use a power parameter to specify the available power, you can also use these elements as power sources.

For a general description of the I and V elements, see Power Sources in the *HSPICE Simulation and Analysis User Guide*.

I and V Element Syntax

```
Vxxx p n
+ $ **** Voltage or Power Information ********
+ <<dc> mag> <ac <mag <phase>>> <HBAC <mag <phase>>>
+ <hb <mag <phase <harm <tone <modharm <modtone>>>>>>>
+ <transient waveform> <TRANFORHB=[1|0]>
+ $ **** Power Switch ********
+ <power=[0 | 1 | W | dbm]> <z0=val> <rdc=val> <rac=val>
+ <RHBAC=val> <rhb=val> <rtran=val>
```

```
Ixxx p n
+ $ **** Current or Power Information ********
+ <<dc> mag> <ac <mag <phase>>> <HBAC <mag <phase>>>
+ <hb <mag <phase <harm <tone <modharm <modtone>>>>>>>
+ <transient waveform> <TRANFORHB=[1|0]>
+ $ **** Power Switch ********
+ <power=[0 | 1 | W | dbm]> <z0=val> <rdc=val> <rac=val>
+ <RHBAC=val> <rhb=val> <rtran=val>
```

Parameter	Description
<<dc> mag>	DC voltage or power source value. You don't need to specify DC explicitly (default=0).
<ac <mag <phase>>>	AC voltage or power source value.
<HBAC <mag <phase>>>	(HSPICE RF) HBAC voltage or power source value.
<hb <mag <phase <harm <tone <modharm <modtone>>>>>>>	(HSPICE RF) HB voltage, current, or power source value. Multiple HB specifications with different harm, tone, modharm, and modtone values are allowed. ▪ *phase* is in degrees ▪ *harm* and *tone* are indices corresponding to the tones specified in the `.HB` statement. Indexing starts at 1 (corresponding to the first harmonic of a tone). ▪ *modtone* and *modharm* specify sources for multi-tone simulation. A source specifies a tone and a harmonic, and up to 1 offset tone and harmonic (modtone for tones and modharm for harmonics). The signal is then described as: V(or I) = mag*cos(2*pi*(harm*tone+modharm*modtone)*t + phase)

Parameter	Description
<transient waveform>	(Transient analysis) Any one of waveforms: AM, EXP, PULSE, PWL, SFFM, or SIN. Multiple transient descriptions are not allowed.
<power=[0 I 1 I W I dbm]>	(HSPICE RF) Power Switch ■ When 0 (default), element treated as a voltage or current source. ■ When 1 or W, element treated as a power source, realized as a voltage source with a series impedance. In this case, the source value is interpreted as RMS available power in units of Watts. ■ When dbm, element treated as a power source in series with the port impedance. Values are in dbms. You can use this parameter for Transient analysis if the power source is either DC or SIN.
<z0=val>	(LIN analysis) System impedance used when converting to a power source, inserted in series with the voltage source. Currently, this only supports real impedance. ■ When power=0, z0 defaults to 0. ■ When power=1, z0 defaults to 50 ohms. You can also enter zo=val.
<rdc=val>	(DC analysis) Series resistance (overrides `z0`).
<rac=val>	(AC analysis) Series resistance (overrides `z0`).
<RHBAC=val>	(HSPICE RF HBAC analysis) Series resistance (overrides z0).
<rhb=val>	(HSPICE RF HB analysis) Series resistance (overrides z0).
<rtran=val>	(Transient analysis) Series resistance (overrides z0).

Parameter	Description
<TRANFORHB=[0|1]>	▪ 0 (default): The transient description is ignored if an HB value is given or a DC value is given. If no DC or HB value is given and TRANFORHB=0, then HB treats the source as a DC source, and the DC source value is the time=0 value. ▪ 1: HB analysis uses the transient description if its value is VMRF, SIN, PULSE, PWL, or LFSR. If the type is a non-repeating PWL source, then the time=infinity value is used as a DC source value. For example, the following statement is treated as a DC source with value=1 for HB: v1 1 0 PWL (0 0 1n 1 1u 1) TRANFORHB=1 In contrast, the following statement is a 0V DC source: v1 1 0 PWL (0 0 1n 1 1u 1) TRANFORHB=0 The following statement is treated as a periodic source with a 1us period that uses PWL values: v1 1 0 PWL (0 0 1n 1 0.999u 1 1u 0) R TRANFORHB=1 To override the global TRANFORHB option, explicitly set TRANFORHB for a V/I source.

Example 1

This example shows an HB source for a single tone analysis:

```
.hb tones=100MHz harms=7
```

I1 1 2 dc=1mA hb 3mA 0. 1 1

`I1` is a current source with a the following time-domain description:

```
I1=1mA + 3mA*cos(2*pi*1.e8*t)
```

Example 2

This example shows HB sources used for a two-tone analysis:

```
.hb tones=1.e9 1.1e9 intmodmax=5
Vin lo 0 dc=0. hb 1.5 90 1 1
```

Vrf rf 0 dc=0. hb 0.2 0 1 2

These sources have the following time-domain descriptions:

```
Vin=1.5*cos(2*pi*1.e9*t - 90*pi/180) V
```

Vrf = 0.2*cos(2*pi*1.1e9*t) V

Example 3

The following HB source uses a `modtone` and `modharms`:

```
.hb tones=2.e9 1.9e9 harms=5 5
```

Vm input gnd dc=0.5 hb 0.2 0. 1 1 -1 2

`Vm` has the following time-domain description:

Vm = 0.5 + cos(2*pi*1.e8*t)

Example 4

This example uses an HB source specified with a `SIN` source and `HBTRANINIT`.

```
.hb tone=1.e8 harms=7
```

Vt 1 2 SIN(0.1 1.0 2.e8 0. 0. 90) tranforhb=1

`Vt` is converted to the following HB source:

```
Vt 1 2 dc=0.1 hb 1.0 0.0 2 1
```

Example 5

This example shows a power source (the units are Watts).

```
.hb tones=1.1e9 harms=9
```

Pt Input Gnd power=1 Z0=50. 1m 0. 1 1

`Pt` delivers 1 mW of power through a 50 ohm impedance.

Steady-State HB Sources

The fundamental frequencies used with harmonic balance analysis are specified with the `.HB TONES` command. These frequencies can then be referenced by their integer indices when specifying steady-state signal sources. For example, the .HB specification given by the following line:

.HB TONES=1900MEG,1910MEG INTMODMAX=5

This specifies two fundamental frequencies: $f[tone = 1] = 1.9GHz$ and $f[tone = 2] = 1.91GHz$. Their mixing product at 10 MHz can then be referenced using indices as $|f[2] - f[1]|$, while their 3rd order intermodulation product at 1.89 GHz can be referenced as $|2f[1] - f[2]|$.

Steady-state voltage and current sources are identified with the HB keyword according to

<HB <mag <phase <harm <tone <modharm <modtone>>>>>>

The source is mathematically equivalent to a cosine signal source that follows the equation

$$A\cos(\omega t + \phi)$$

where

$$A = mag$$

$$\omega = 2\pi|harm \cdot f[tone] + modharm \cdot f[modtone]|$$

$$\phi = \frac{\pi}{180} \cdot phase$$

Values for tone and modtone (an optional modulating tone) must be non-negative integers that specify index values for the frequencies specified with the `.HB TONES` command. Values for `harm` (harmonic) and `modharm` (modulating tone harmonic) must be integers (negative values are OK) that specify harmonic indices.

Example 1

The following example is a 1.0 Volt (peak) steady-state cosine voltage source, which is at the fundamental HB frequency with zero phase and with a zero volt DC value:

```
Vsrc  in   gnd   DC  0  HB  1.0  0  1  1
```

Example 2

The following example is a steady-state cosine power source with 1.0mW available power, which is implemented with a Norton equivalent circuit and a 50 ohm input impedance:

```
Isrc  in   gnd   HB  1.0e-3  0  1  1  power=1 z0=50
```

Example 3

Five series voltage sources sum to produce a stimulus of five equally spaced frequencies at and above 2.44 GHz using modharm and modtone parameters. These are commensurate tones (an integer relation exists); therefore, you only need to specify two tones when invoking the HB analysis.

```
.param Vin=1.0
.param f0=2440MEG
.param deltaf=312.5K
```

```
.param fcenter='f0 + 2.0*deltaf'
Vrfa    in    ina    HB   'Vin'   0   1   1          $ 2.440625
   GHz
Vrfb    ina   inb    HB   'Vin'   0   1   1   -1   2   $
2.4403125   GHz
Vrfc    inb   inc    HB   'Vin'   0   1   1   -2   2   $
2.440   GHz
Vrfd    inc   ind    HB   'Vin'   0   1   1   +1   2   $
2.4409375   GHz
Vrfe    ind   gnd    HB   'Vin'   0   1   1   +2   2   $ 2.44125
   GHz
.HB tones=fcenter,deltaf intmodmax=5
```

Phase Differences Between HB and SIN Sources

The HB steady-state cosine source has a phase variation compared to the `TRAN` time-domain `SIN` source. The `SIN` source (with no offset, delay or damping) follows the equation:

$$A\sin(\omega t+\phi)$$

while the HB sources follow

$$A\cos(\omega t+\phi)$$

In order for the two sources to yield identical results it is necessary to align them by setting their phase values accordingly using:

$$A\cos(\omega t+\phi) = A\sin(\omega t+\phi+90°)$$

$$A\sin(\omega t+\phi) = A\cos(\omega t+\phi-90°)$$

To specify sources with matching phase for HB and TRAN analysis, use a convention similar to:

```
** Example #1 with equivalent HB and SIN sources
** SIN source is given +90 phase shift
.param freq1=2400MEG Vin=1.0
Vsrc in gnd DC 0 HB 'Vin' 0 1 1 SIN(0 'Vin' 'freq1' 0 0 90)
.HB tones=freq1 intmodmax=7
** Example #2 with equivalent HB and SIN sources
** HB source is given -90 phase shift to align with SIN
.param freq1=2400MEG Vin=1.0
Vsrc in gnd DC 0 HB 'Vin' -90 1 1 SIN(0 'Vin' 'freq1' 0)
.HB tones=freq1 intmodmax=7
** Example #3 with equivalent .HB and .TRAN sources
** SIN source is activated for HB using "TRANFORHB"
.param freq1=2400MEG Vin=1.0
```

```
Vsrc in gnd DC 0 SIN(0 'Vin' 'freq1' 0) TRANFORHB=1
.HB tones=freq1 intmodmax=7
```

Behavioral Noise Sources

In HSPICE RF, you can use the G element to specify noise sources. Frequency domain noise analyses (`.NOISE`, `.HBNOISE`, and `.PHASENOISE`) take these noise sources into account.

You can attach noise sources to behavioral models. For example, you can use a G element with the `VCCAP` parameter to model a varactor, which includes a noise model. You can also simulate effects such as substrate noise, including its effect on oscillator phase noise. You can also use this G element syntax to simulate behavioral descriptions of substrate noise during any frequency domain noise analysis, which includes phase noise analysis. For example,

```
gname node1 node2 noise='noise_equation'
gname node1 node2 node3 node4 noise='noise_equation'
```

The first line creates a simple two-terminal current noise source, whose value is described in A^2/(Hz). The output noise generated from this noise source is:

noise_equation*H

Where `H` is the transfer function from the terminal pair (node1,node2) to the circuit output, where HSPICE RF measures the output noise.

The second line produces a noise source correlation between the (node1,node2) and (node3,node4) terminal pairs. The resulting output noise is calculated as noise_equation*sqrt(H1*H2*); where,

- `H1` is the transfer function from (node1,node2) to the output
- `H2` is the transfer function from (node3,node4) to the output.

The noise_equation expression can involve node voltages and currents through voltage sources.

For the PAC phasenoise simulation to evaluate the frequency-dependent noise, the frequency-dependent noise factor in the phasenoise must be expressed in between the parentheses. For example:

```
gname node1 node2 noise = '(frequency_dependent_noise)*
 bias_dependent_noise'
```

This is only true when the total noise can be expressed in this form and when the frequency-dependent noise can be evaluated in the PAC phasenoise simulation. You can also input the behavioral noise source as a noise table with the help of predefined Table() function. The Table() function takes two formats:

- Noise table can be input directly through the Table() function. For example:

```
gname node1 node2 noise = 'Table(arg1,f1,v1,f2,v2,......)'
```

- The *f1,v1,f2,v2,.....* parameters describe the noise table. When arg1 == f1, the function returns v1. The *arg1* can be an expression of either `HERTZ`, bias, or both. For example, `arg1 = 'HERTZ * 1.0E+3'`.
- The noise table can be input through a `.DATA` structure:

```
.DATA d1
+ x y
+ f1 v1
+ f2 v2
.ENDDATA

gname node1 node2 noise = 'TABLE(arg1,d1)'
```

The `x`, `y` parameters in the `DATA` structure are two placeholder strings that can be set to whatever you prefer even if they are in conflict with other parameters in the netlist. The `arg1` parameter can be an expression of `HERTZ` and bias. When `arg1 == f2`, the function will return `v2`.

Power Supply Current and Voltage Noise Sources

You can implement the power supply noise source with G and E elements. The G element for the current noise source and the E element for the voltage noise source. As noise elements, they are two-terminal elements that represent a noise source connected between two specified nodes.

Syntax

Expression form

```
Gxxx node1 node2 noise='expression'
Exxx node1 node2 noise='expression'
```

The G noise element represents a noise current source and the E noise element represents a noise voltage source. The `xxx` parameter can be set with a value up to 1024 characters. The *node1* and *node2* are the positive and negative nodes that connect to the noise source. The noise expression can contain the bias, frequency, or other parameters.

Data form

```
Gxxx node1 node2 noise data=dataname
Exxx node1 node2 noise data=dataname
.data dataname
+ pname1 pname2
+ freq1 noise1
+ freq2 noise2
+ ...
.enddata
```

The data form defines a basic frequency-noise table. The `.DATA` statement contains two parameters: frequency and noise to specify the noise value at each frequency point. The unit for frequency is hertz, and the unit for noise is A^2/Hz (for G current noise source) or V^2/Hz (for E voltage noise source).

Example

The following netlist shows a 1000 ohm resistor (`g1`) using a G element. The `g1noise` element, placed in parallel with the `g1` resistor, delivers the thermal noise expected from a resistor. The `r1` resistor is included for comparison: The noise due to `r1` should be the same as the noise due to `g1noise`.

```
* Resistor implemented using g-element
v1 1 0 1
r1 1 2 1k
g1 1 2 cur='v(1,2)*0.001'
g1noise 1 2
+ noise='4*1.3806266e-23*(TEMPER+273.15)*0.001'
rout 2 0 1meg
.ac lin 1 100 100
.noise v(2) v1 1
.end
```

Function Approximations for Distributed Devices

High-order rational function approximations constructed for distributed devices used at RF frequencies are obtained in the pole-residue form (also known as Foster canonical form). The popular method of recursive convolution also uses this form.

HSPICE supports the pole-residue form for its frequency-dependent controlled sources (G and E elements). You can enter the pole-residue form directly without first converting to another form.

Foster Pole-Residue Form for Transconductance or Gain

The Foster pole-residue form for transconductance G(s) or gain E(s) has the form:

$$G(s) = k_0 + k_1 s + \sum_{i=1}^{N} \left(\frac{A_i}{s - p_i} + \frac{A_i^*}{s - p_i^*} \right)$$

Where,

- k_0, k_1 are real constants
- residues A_i and poles p_i are complex numbers (or real as a special case of complex
- asterisk (*) denotes the expression's complex conjugate

Advantages of Foster Form Modeling

The advantages of Foster canonical form modeling are:

- models high-order systems. It can theoretically model systems having infinite poles without numerical problems.
- equivalent to Laplace and Pole-zero models
- popular method of recursive convolution uses this form.

G and E Element Syntax

Transconductance G(s) form

```
Gxxx n+ n- FOSTER in+ in- k0 k1
+ (Re{A1}, Im{A1})/ (Re{p1}, Im{p1})
+ (Re{A2}, Im{A2})/ (Re{p2}, Im{p2})
+ (Re{A3}, Im{A3})/ (Re{p3}, Im{p3})
+ ...
```

Gain E(s) form

```
Exxx n+ n- FOSTER in+ in- k0 k1
+ (Re{A1}, Im{A1})/ (Re{p1}, Im{p1})
+ (Re{A2}, Im{A2})/ (Re{p2}, Im{p2})
+ (Re{A3}, Im{A3})/ (Re{p3}, Im{p3})
+ ...
```

In the above syntax, parenthesis , commas, and slashes are separators—they have the same meaning as a space. A pole-residue pair is represented by four numbers (real and imaginary part of the residue, then real and imaginary part of the pole).

You must make sure that Re[pi]<0; otherwise, the simulations will certainly diverge. Also, it is a good idea to assure passivity of the model (for an N-port admittance matrix Y, Re{Y} should be positive-definite), or the simulation is likely to diverge).

Example

To represent a G(s) in the form,

$$G(s) = 0.001 + 1 \times 10^{-12}s + \frac{0.0008}{s + 1 \times 10^{10}} + \frac{(0.001 - j0.006)}{s - (-1 \times 10^{8} + j1.8 \times 10^{10})} + \frac{(0.001 + j0.006)}{s - (-1 \times 10^{8} - j1.8 \times 10^{10})}$$

You would input:

```
G1 1 0 FOSTER 2 0 0.001 1e-12
+(0.0004, 0)/(-1e10, 0) (0.001, -0.006)/(-1e8, 1.8e10)
```

Note:

In the case of a real poles, half the residue value is entered, because it's essentially applied twice. In the above example, the first pole-residue pair is real, but we still write it as “A1/(s-p1)+A1/(s-p1)”; therefore, 0.0004 is entered rather than 0.0008.

Complex Signal Sources and Stimuli

To predict radio-frequency integrated circuit (RFIC) performance, some analyses require simulations that use representative RF signal sources. Among the representative sources available in HSPICE RF is the complex modulated RF source. Also known as the *Vector Modulated* source, it allows digital modulation of an RF carrier using in-phase and quadrature components created from a binary data stream.

Vector-Modulated RF Source

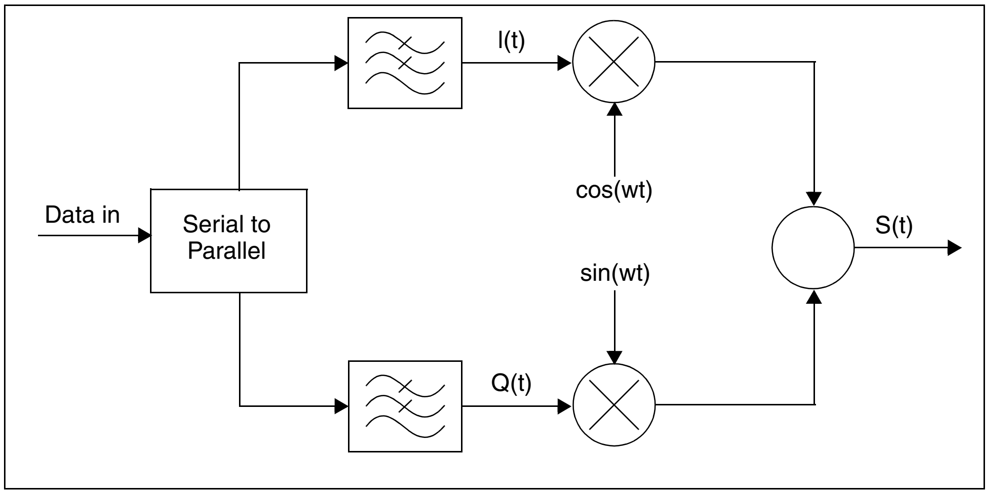
Digital RF waveforms are typically constructed by modulating an RF carrier with in-phase (I) and quadrature (Q) components. In HSPICE RF, this is accomplished using the Vector Modulated RF (VMRF) signal source.

The VMRF signal source function is supported both for independent voltage and current sources (V and I elements), and with controlled sources (E, F, G, and H elements).

- When used with independent sources, a baseband data stream can be input in binary or hexadecimal format, and the scheme used to divide the data into I and Q signals can be specified.
- With controlled VMRF sources, the modulating I and Q signals can be separately specified with other signal sources (such as a PWL source) and then used as control inputs into the VMRF source.

Implementation

The VMRF source is a mathematical implementation of the following block diagram:



The following equation calculates the time and frequency domain stimuli from the quadrature modulated signal sources:

$$s(t) = I(t)\cos(2\pi f_c t + \phi_0) - Q(t)\sin(2\pi fct + \phi_0)$$

The discrete ideal I (in-phase) and Q (quadrature) signal components are digital. Discrete values allow uniform scaling of the overall signal. HSPICE RF generates data streams for the I and Q signals based on interpreting the data string, breaking the data string into a binary representation, and then using the bit pairs to assign values for the I and Q data streams.

For BPSK (binary phase shift keying) modulation, the discrete signals are scaled so that $\sqrt{I^2 + Q^2} = 1$:

Data In	I Data	Q Data
0	$\frac{-1}{\sqrt{2}}$	$\frac{-1}{\sqrt{2}}$
1	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$

For QPSK (quadrature phase shift keying) modulation, the data stream is broken into bit pairs to form the correct I and Q values. This function is represented as the serial to parallel converter:

Data In	I Data	Q Data
00	$\frac{-1}{\sqrt{2}}$	$\frac{-1}{\sqrt{2}}$
01	$\frac{-1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$
10	$\frac{1}{\sqrt{2}}$	$\frac{-1}{\sqrt{2}}$
11	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$

To generate a continuous-time waveform, the VMRF source takes the resulting digital I and Q data streams and passes them through ideal filters. Rectangular and Nyquist (raised-cosine) filter options are available. The output waveforms are therefore band-limited according to the specified data rate.

Voltage and Current Source Elements

The V and I elements can include VMRF signal sources that you can use to generate BPSK and QPSK waveforms.

V and I Element Syntax

```
Vxxx n+ n- VMRF <(> AMP=sa FREQ=fc PHASE=ph MOD=MOD
+ FILTER=FIL FILCOEF=filpar RATE=Rb BITSTREAM=data
+ <TRANFORHB=0/1> <)>
```

```
Ixxx n+ n- VMRF <(> AMP=sa FREQ=fc PHASE=ph MOD=MOD
+ FILTER=FIL FILCOEF=filpar RATE=Rb BITSTREAM=data
+ <TRANFORHB=0/1> <)>
```

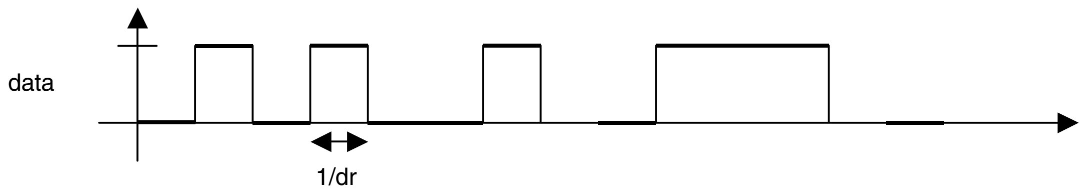
Parameter	Description
Vxxx	Independent voltage source.
Ixxx	Independent current source.
n+ n-	Positive and negative controlled source connecting nodes.
VMRF	Keyword that identifies and activates the Vector Modulated RF signal source.
AMP	Signal amplitude (in volts or amps).
FREQ	Carrier frequency in hertz. Set fc=0.0 to generate baseband I/Q signals. For harmonic balance analysis, the frequency spacing must coincide with the .HB TONES settings.
PHASE	Carrier phase (in degrees). If fc=0.0, ▪ ph=0 and baseband I(t) is generated ▪ ph=-90 and baseband q(t) is generated ▪ Otherwise, $s(t) = I(t)\cos(\phi_0) - Q(t)\sin(\phi_0)$
MOD	One of the following keywords identifies the modulation method used to convert a digital stream of information to I(t) and Q(t) variations: ▪ BPSK (binary phase shift keying) ▪ QPSK (quadrature phase shift keying)

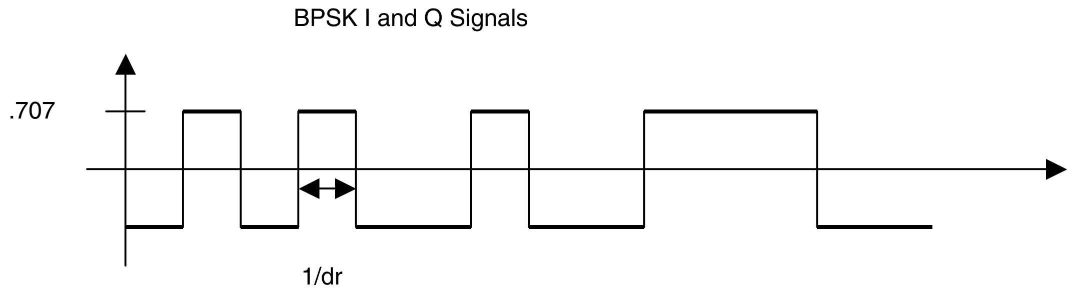
Parameter	Description
FILTER	One of the following keywords identifies the method used to filter the I and Q signals before modulating the RF carrier signal: ▪ COS (raised cosine Nyquist filter) ▪ RECT (rectangular filtering)
FILCOEF	Filter parameter for the COS filter: 0 ≤ filpar ≤ 1
RATE	Bit rate for modulation (bits per second). ▪ For BPSK modulation, the data rate and the symbol rate are the same. ▪ For QPSK modulation, the symbol rate is half the data rate. The Rb value must be greater than zero.
BITSTREAM	A binary (b) or hexadecimal (h) string that represents an input data stream. Valid data string characters are: ▪ 0 or 1 for binary (b) mode. ▪ 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, a, b, c, d, e, or f for hexadecimal (h) mode. For example: ▪ 01010011b (binary) ▪ 0F647A30E9h (hexadecimal)

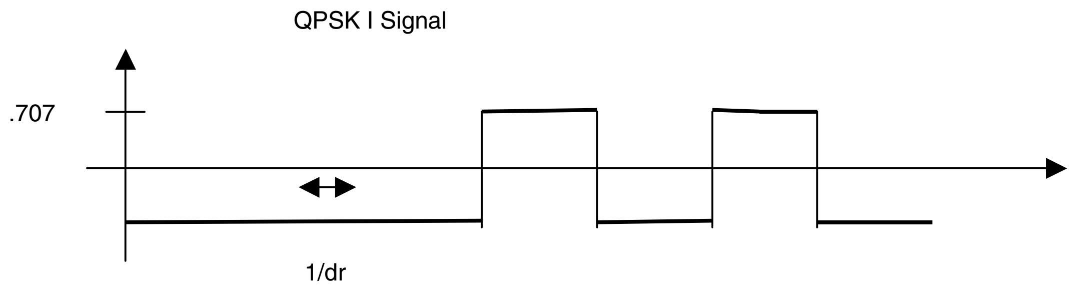
You can also use the standard V source and I source options for non-transient simulations (such as `DC=`*`val`* and `AC=`*`mag,ph`*) a with the VMRF source.

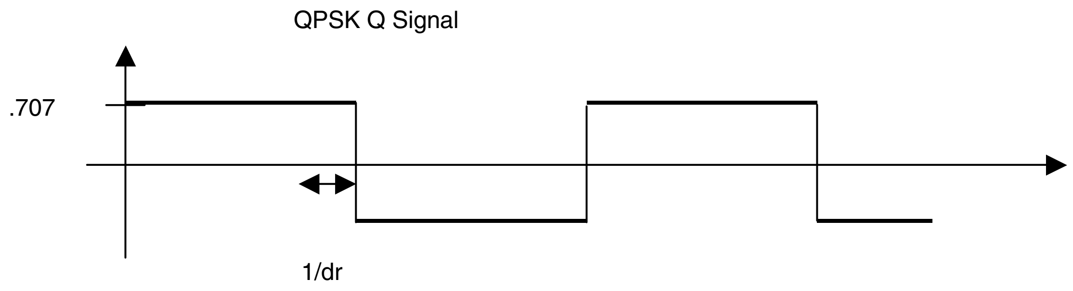
Example

```
BITSTREAM=01010010011100b
```









The `Rb` parameter represents the data rate. The associated symbol rate represents how fast the I and Q data streams change. The period for each bit of data is:

$$T_b = \frac{1}{R_b}$$

The symbol rate depends on whether you select `BPSK` or `QPSK` modulation:

- For `BPSK`, the symbol rate is the same as the data rate:

$$_S R^{BPSK} = R_b$$

- For `QPSK` modulation, two bits are used to create each symbol so the symbol rate is half the data rate.

$$_S R^{QPSK} = \frac{R_b}{2}$$

The period for each symbol is computed as:

$$T_s = \frac{1}{R_s}$$

This value is necessary for establishing the characteristics of Nyquist filters.

The following equation calculates the raised cosine (COS) filter response:

$$H_{rc}(f) = \int_0^{T_s} T_s cos^2\left[\frac{\pi T_s}{2\alpha}\left(|f| - \frac{1-\alpha}{2T_s}\right)\right] \qquad \begin{array}{c} |f| \le \frac{1-\alpha}{2T_s} \\ \frac{1-\alpha}{2T_s} \le |f| \le \frac{1+\alpha}{2T_s} \\ |f| > \frac{1+a}{2T_s} \end{array}$$

The VMRF signal source is designed primarily for TRAN and HB analyses, and can generate baseband signals. You can also specify DC and AC values as with any other HSPICE signal source:

- In DC analysis, the VMRF source is a constant DC source.
- In AC analysis, the source is a short or an open, unless you specify an AC value.
- In HB analysis, you must specify `.OPTION TRANFORHB` on the source statement line. The `TRANFORHB` option supports the VMRF signal source as well as the SIN, PULSE, and PWL sources.

The VMRF quadrature signal source typically involves an HF carrier signal that is modulated with a baseband signal on a much different time scale. You must set source and simulation control parameters appropriately to avoid time-consuming simulations in both the time and frequency domains.

E, F, G, and H Element Statements

For E, F, G, and H elements, you can use the VMRF function to modulate I(t) and Q(t) signals with a RF carrier signal. The I and Q signal are driven by PWL sources that might be generated by an external tool, such as MATLAB. The PWL source accepts a text file containing time and voltage (or current) pairs.

When the VMRF function is used with controlled sources, it is anticipated that the in-phase (I) and quadrature (Q) signals are not digital, but continuous-time analog signals. The VMRF function therefore includes no filtering, and merely serves to create the complex modulation on the RF carrier.

```
Exxx n+ n- <VCVS> VMRF <(> Iin+ Iin- Qin+ Qin- FREQ=fc
+ PHASE=ph <SCALE=A> <)>

Fxxx n+ n- <CCCS> VMRF <(> VI VQ FREQ=fc PHASE=ph
+ <SCALE=A> <)>

Gxxx n+ n- <VCCS> VMRF <(> Iin+ Iin- Qin+ Qin- FREQ=fc
+ PHASE=ph <SCALE=A> <)>

Hxxx n+ n- <CCVS> VMRF <(> VI VQ FREQ=fc PHASE=ph
+ <SCALE=A> <)>
```

Parameter	Description
Exxx	Voltage-controlled voltage source.
Fxxx	Current-controlled current source.
G*xxx*	Voltage-controlled current source.
H*xxx*	Current-controlled current source.
VCVS	Keyword for voltage-controlled voltage source.
CCCS	Keyword for current-controlled current source.
VCCS	Keyword for voltage-controlled current source.
CCVS	Keyword for current-controlled current source.
n+ n-	Positive and negative controlled source connecting nodes.

Parameter	Description
VMRF	Keyword that identifies and activates the vector-modulated RF signal source.
Iin+ Iin-	Node names for input I(t) signal.
Qin+ Qin-	Node names for input Q(t) signal.
VI VQ	
FREQ	Carrier frequency in Hertz. Set fc=0.0 to generate baseband I/Q signals.
PHASE	Carrier phase (in degrees). If fc=0.0, ▪ ph=0 and baseband I(t) is generated ▪ ph=-90 and baseband Q(t) is generated
SCALE	Unit-less amplitude scaling parameter.

Example

```
Emod1 inp1 inn1 VMRF It_plus It_neg Qt_plus Qt_neg
+ freq=1g phase=0 scale=1.5
```

File-Driven PWL Source

```
Vxxx n1 n2 PWL PWLFILE='filename' <col1, <col2>> <R=repeat>
+ <TD=delay> <options>

Ixxx n1 n2 PWL PWLFILE='filename' <col1, <col2>> <R=repeat>
+ <TD=delay> <options>
```

Parameter	Description
Vxxx	Independent voltage source.
Ixxx	Independent current source.
n1 n2	Positive and negative terminal node names.
PWL	Keyword for piecewise linear.

Parameter	Description
PWLFILE	Text file containing the PWL data consisting of time and voltage (or current) pairs. This file should not contain a header row, unless it is a comment. The PWL source data is obtained by extracting col1 and col2 from the file.
col1, <*col2*>	Time values are in col1 and voltage (or current) values are in col2. By default, col1=1 and col2=2.
R	Repeat function. When an argument is not specified, the source repeats from the beginning of the function. The argument repeated is the time, in seconds, which specifies the start point of the waveform being repeat. The repeat time must be less than the greatest time point in the file.
TD	Time delay, in seconds, of the PWL function.
options	Any standard V or I source options.

Example

```
Vit It_plus It_neg PWL PWLFILE='Imod.dat'
```

SWEEPBLOCK in Sweep Analyses

You can use the `.SWEEPBLOCK` statement to specify complicated sweeps. Sweeps affect:

- DC sweep analysis
- Parameter sweeps around TRAN, AC, or HB analyses
- Frequency values used in AC or HBAC analyses

Currently, HSPICE supports the following types of sweeps:

- Linear sweeps: sweeps a variable over an interval with a constant increment. The syntax is one of the following:
  - variable *start stop increment*
  - variable *lin npoints start stop*
- Logarithmic sweeps: sweeps a variable over an interval. To obtain each point, this sweep multiplies the previous point by a constant factor. You can specify the factor as a number of points per decade or octave as in:

- variable *dec npoints start stop*
- variable *oct npoints start stop*

- Point sweeps: a variable takes on specific values that you specify as a list. The syntax is:

```
variable poi npoints p1 p2 …
```

- Data sweeps: a `.DATA` statement identifies the swept variables and their values. The syntax is:

```
data=dataname
```

You can use the `SWEEPBLOCK` feature to combine linear, logarithmic, and point sweeps, which creates more complicated sets of values over which a variable is swept.

The `.TRAN`, `.AC`, `.DC`, and `.HB` commands can specify `SWEEPBLOCK=`*blockname* as a sweep instead of `LIN`, `DEC`, `OCT`, and so forth. Also, you can use `SWEEPBLOCK` for frequency sweeps with the `.AC`, `.HBAC`, `.PHASENOISE`, and `.HBNOISE` commands.

All commands that can use `SWEEPBLOCK` must refer to the `SWEEPBLOCK` sweep type. In addition, you must specify `SWEEPBLOCK` as one of the syntax types allowed for frequency sweeps with the `.HBAC`, `.PHASENOISE`, and `.HBNOISE` commands.

Input Syntax

The `SWEEPBLOCK` feature creates a sweep whose set of values is the union of a set of linear, logarithmic, and point sweeps. To specify the set of values in the `SWEEPBLOCK`, use the `.SWEEPBLOCK` command. This command also assigns a name to the `SWEEPBLOCK`. For example,

```
.SWEEPBLOCK swblockname sweepspec [sweepspec
+ [sweepspec […]]]]
```

You can use `SWEEPBLOCK` to specify DC sweeps, parameter sweeps, AC and HBAC frequency sweeps, or wherever HSPICE accepts sweeps.

You can specify an unlimited number of *sweepspec* parameters. Each `sweepspec` can specify a linear, logarithmic, or point sweep by using one of the following forms:

```
start stop increment
lin npoints start stop
dec npoints start stop
```

```
oct npoints start stop
poi npoints p1 p2 …
```

Example

The following example specifies a logarithmic sweep from 1 to 1e9 with more resolution from 1e6 to 1e7:

```
.sweepblock freqsweep dec 10 1 1g dec 1000 1meg 10meg
```

Using SWEEPBLOCK in a DC Parameter Sweep

To use the sweepblock in a DC parameter sweep, use the following syntax:

```
.DC sweepspec [sweepspec [sweepspec]]
```

Each *sweepspec* can be a linear, logarithmic, point, or data sweep, or it can be in the form:

```
variable SWEEPBLOCK=swblockname
```

The `SWEEPBLOCK` syntax sweeps the specified variable over the values contained in the `SWEEPBLOCK`.

Example

```
.dc vin1 0 5 0.1 vin2 sweepblock=vin2vals
```

Using in Parameter Sweeps in TRAN, AC, and HB Analyses

To use the sweepblock in parameter sweeps on `.TRAN`, `.AC`, and `.HB` commands, and any other commands that allow parameter sweeps, use the following syntax:

```
variable sweepblock=swblockname
```

Example 1

.tran 1n 100n sweep rout sweepblock=rvals

AC and HBAC analysis frequency sweeps can use `sweepblock=`*swblockname* to specify the frequency values.

Example 2

.ac sweepblock=freqsweep

Limitations

- You cannot use recursive `SWEEPBLOCK` specifications. That is, a `.SWEEPBLOCK` command cannot refer to another `SWEEPBLOCK` to build its list of values.
- You cannot include data sweeps in a `.SWEEPBLOCK` statement.

References

[1] L.J. Greenstein and M.Shafi, *Microwave Digital Radio*, IEEE Press, 1988.

[2] N. Sheikholeslami and P. Kabal, “A Family of Nyquist Filters Based on Generalized Raised-Cosine Spectra,” *Proceedings of the 19th Biennial Symposium on Communications* (Kingston, Ontario), pages 131-135, June 1998.

8

Steady-State Harmonic Balance Analysis

Describes how to use harmonic balance analysis for frequency-driven, steady-state analysis.

HSPICE RF provides several new analyses that support the simulation and analysis of radio-frequency integrated circuits (RFICs). These analyses provide simulation capabilities that are either much more difficult to perform, or are not practically possible by using standard HSPICE analyses. The RF analyses include:

- Harmonic Balance (HB) for frequency-domain, steady-state analysis.
- Harmonic Balance OSC (HBOSC) for oscillator analysis (see Chapter 9, Oscillator and Phase Noise Analysis).
- Harmonic Balance AC (HBAC) for periodic AC analysis (see Chapter 11, Harmonic Balance-Based AC and Noise Analyses).
- Harmonic Balance Noise (HBNOISE) for periodic, time-varying AC noise analysis (see Chapter 11, Harmonic Balance-Based AC and Noise Analyses).
- Frequency translation S-parameter extraction for describing N-port circuits that exhibit frequency translation effects (see Chapter 11, Harmonic Balance-Based AC and Noise Analyses).
- Envelope Analysis (ENV) (see Chapter 12, Envelope Analysis).

You can use steady-state analysis on a circuit if it contains only DC and periodic sources. These analyses assume that all “start-up” transients have completely died out with only the steady-state response remaining. Sources that are not periodic or DC are treated as zero-valued in these analyses.

Harmonic Balance Analysis

Harmonic balance analysis (HB) is a frequency-domain, steady-state analysis technique. In HSPICE RF, you can use this analysis technique on a circuit that is excited by DC and periodic sources of one or more fundamental tones. The solution that HB finds is a set of phasors for each signal in the circuit. You can think of this set as a set of truncated Fourier series. You must specify the solution spectrum to use in an analysis. HB then finds a set of phasors at these frequencies that describes the circuit response.

Linear circuit elements are evaluated in the frequency domain, while nonlinear elements are evaluated in the time domain. The nonlinear response is then transformed to the frequency domain where it is added to (or “balanced” with) the linear response. The resulting composite response satisfies KCL and KVL (Kirchoff's current and voltage laws) when the circuit solution is found.

Typical applications include performing intermodulation analysis and gain compression analysis, on amplifiers and mixers. HB analysis also serves as a starting point for periodic AC and noise analyses.

Harmonic Balance Equations

The condition in this equation must be satisfied in the time domain.

$$f(v,t) = i(v(t)) + \frac{d}{dt}q(v(t)) + \int_{-\infty}^{t} y(t-\tau)v(\tau)d\tau + i_s(t) = 0$$

- *i(v(t))* represents the resistive currents from nonlinear devices
- *q* represents the charges from nonlinear devices
- *y* represents the admittance of the linear devices in the circuit
- i_s represents the vector of independent current sources
- *v* is a variable that represents the circuit unknowns, both node voltages and branch currents.

Transforming this equation to the frequency domain results in equation:

$$F(V) = I(V) + \Omega Q(V) + YV + I_s = 0$$

Note:

> Time-differentiation is transformed to multiplication by $j\omega$ terms (which make up the Ω matrix) in the frequency domain. The convolution integral is transformed to a simple multiplication. The Y matrix is the circuit's modified nodal admittance matrix.

All terms above are vectors, representing the circuit response at each analysis frequency.

The following equation shows the vector of (complex-valued) unknowns in the frequency domain for a circuit with *K* analysis frequencies and *N* unknowns.

$$V = \left[V\_(1,0)\ V\_(1,1)\ \ldots\ V\_(1,K-1)\ V\_(2,0)\ \ldots\ V\_(N,K-1)\right]$$

HSPICE RF finds the unknown vector (*V*), which satisfies the system of nonlinear equations shown in the equation above. This is done via the Newton-Raphson technique by using either a direct solver to factor the Jacobian matrix, or an indirect solver. The indirect solver available in HSPICE RF is the Generalized Minimum Residual (GMRES) Solver, a Krylov technique, and uses a matrix-implicit algorithm.

Features Supported

HB supports the following features:

- All existing HSPICE RF models.
- Unlimited number of independent input tones.
- Sources with multiple HB specifications.
- SIN, PULSE, VMRF, and PWL sources with `TRANFORHB=1`.

Prerequisites and Limitations

The following prerequisites and limitations apply to HB:

- Requires one `.HB` statement.
- Treats sources without a DC, HB, or TRANFORHB description as a zero-value for HB unless the sources have a transient description, in which case, the `time=0`. The value is used as a DC value.

Input Syntax

Without `SS_TONE`

```
.HB TONES=<F1> [<F2> <...> <FN>]
+ <NHARMS=<H1>, <H2> <...> <HN>> <INTMODMAX=n>
+ [SWEEP parameter_sweep]
```

With `SS_TONE`

```
.HB TONES=<F1> [<F2> <...> <FN>]
+ <NHARMS=<H1>, <H2> <...> <HN>> <INTMODMAX=n>
+ <SS_TONE=n> [SWEEP parameter_sweep]
```

Parameter	Description
TONES	Fundamental frequencies.
NHARMS	Number of harmonics to use for each tone. Must have the same number of entries as TONES. You must specify NHARMS, INTMODMAX, or both.
INTMODMAX	INTMODMAX is the maximum intermodulation product order that you can specify in the analysis spectrum. You must specify NHARMS, INTMODMAX, or both.
SS_TONE	Small-signal tone number for HBLIN analysis. The value must be an integer number. The default value is 0, indicating that no small signal tone is specified. For additional information, see Frequency Translation S-Parameter (HBLIN) Extraction on page 265.

Parameter	Description
SWEEP	Type of sweep. You can sweep up to three variables. You can specify either LIN, DEC, OCT, POI, SWEEPBLOCK, DATA, OPTIMIZE, or MONTE. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ■ LIN *nsteps start stop* ■ DEC *nsteps start stop* ■ OCT *nsteps start stop* ■ POI *nsteps freq_values* ■ SWEEPBLOCK *nsteps freq1 freq2* ... *freqn* ■ DATA=*dataname* ■ OPTIMIZE=OPT*xxx* ■ MONTE=*val*

HB Analysis Spectrum

The `NHARMS` and `INTMODMAX` input parameters define the spectrum.

- If `INTMODMAX=N`, the spectrum consists of all f=a*f_1 + b*f_2 + ... + n*fn frequencies so that f>=0 and |a|+|b|+...+|n|<=N. The a,b,...,n coefficients are integers with absolute value <=N.
- If you do not specify `INTMODMAX`, it defaults to the largest value in the `NHARMS` list.
- If entries in the `NHARMS` list are > `INTMODMAX`, HSPICE RF adds the m*f_k frequencies to the spectrum, where f_k is the corresponding tone, and m is a value <= the `NHARMS` entry.

Example 1

```
.hb tones=f1, f2 intmodmax=1
```

The resulting HB analysis spectrum={dc, f_1, f_2}

Example 2

```
.hb tones=f1, f2 intmodmax=2
```

The resulting HB analysis spectrum={dc, f_1, f_2, f_1+f_2, f_1-f_2, 2*f_1, 2*f_2}

Example 3

```
.hb tones=f1, f2 intmodmax=3
```

The resulting HB analysis spectrum={dc, f_1, f_2, f_1+f_2, f_1-f_2, 2*f_1, 2*f_2, 2*f_1+f_2, 2*f_1-f_2, 2*f_2+f_1, 2*f_2-f_1, 3*f_1, 3*f_2}

Example 4

```
.hb tones=f1, f2 nharms=2,2
```

The resulting HB analysis spectrum={dc, f_1, f_2, f_1+f_2, f_1-f_2, 2*f_1, 2*f_2}

Example 5

```
hb tones=f1, f2 nharms=2,2 intmodmax=3
```

The resulting HB analysis spectrum={dc, f_1, f_2, f_1+f_2, f_1-f_2, 2*f_1, 2*f_2, 2*f_1-f_2, 2*f_1+f_2, 2*f_2-f_1, 2*f_2+f_1}

Example 6

```
.hb tones=f1, f2 nharms=5,5 intmodmax=3
```

The resulting HB analysis spectrum={dc, f_1, f_2, f_1+f_2, f_1-f_2, 2*f_1, 2*f_2, 2*f_1-f_2, 2*f_1+f_2, 2*f_2-f_1, 2*f_2+f_1, 3*f_1, 3*f_2, 4*f_1, 4*f_2, 5*f_1, 5*f_2}

HB Analysis Options

The following table lists the `.OPTION` command options specific to HB analysis.

Table 15 HB Analysis Options

Option	Description
HBCONTINUE	Specifies whether to use the sweep solution from the previous simulation as the initial guess for the present simulation. ▪ HBCONTINUE=1 (default): Use solution from previous simulation as the initial guess. ▪ HBCONTINUE=0: Start each simulation in a sweep from the DC solution.

Table 15 HB Analysis Options (Continued)

Option	Description
HBJREUSE	Controls when to recalculate the Jacobian matrix: ▪ HBJREUSE=0 recalculates the Jacobian matrix at each iteration. ▪ HBJREUSE=1 reuses the Jacobian matrix for several iterations, if the error is sufficiently reduced. The default is 0 if HBSOLVER=1 or 2, or 1 if HBSOLVER=0.
HBJREUSETOL	Determines when to recalculate Jacobian matrix (if HBJREUSE=1). The percentage by which HSPICE RF must reduce the error from the last iteration so you can use the Jacobian matrix for the next iteration. Must be a real number, between 0 and 1. The default is 0.05.
HBKRYLOVDIM	Dimension of the Krylov subspace that the Krylov solver uses. Must be an integer, greater than zero. Default is 40.
HBKRYLOVTOL	The error tolerance for the Krylov solver. Must be a real number, greater than zero. The default is 0.01.
HBLINESEARCHFAC	The line search factor. If Newton iteration produces a new vector of HB unknowns with a higher error than the last iteration, then scale the update step by HBLINESEARCHFAC, and try again. Must be a real number, between 0 and 1. The default is 0.35.
HBMAXITER	Specifies the maximum number of Newton-Raphson iterations that the HB engine performs. Analysis stops when the number of iterations reaches this value. The default is 10000.
HBSOLVER	Specifies a preconditioner to solve nonlinear circuits. ▪ HBSOLVER=0: invokes the direct solver. ▪ HBSOLVER=1 (default): invokes the matrix-free Krylov solver. ▪ HBSOLVER=2: invokes the two-level hybrid time-frequency domain solver.
HBTOL	The absolute error tolerance for determining convergence. Must be a real number that is greater than zero. The default is 1.e-9.

Table 15 HB Analysis Options (Continued)

Option	Description
LOADHB	LOADHB='filename' loads the state variable information contained in the specified file. These values are used to initialize the HB simulation.
SAVEHB	SAVEHD='filename' saves the final state (that is, the no sweep point or the steady state of the first sweep point) variable values from a HB simulation in the specified file. This file can be loaded as the starting point for another simulation by using a LOADHB option.
TRANFORHB	■ TRANFORHB=1: forces HB to recognize V/I sources that include SIN, PULSE, VMRF, and PWL transient descriptions, and to use them in analysis. However, if the source also has an HB description, analysis uses the HB description instead. ■ TRANFORHB=0: forces HB to ignore transient descriptions of V/I sources, and to use only HB descriptions. To override this option, specify TRANFORHB in the source description.

Harmonic Balance Output Measurements

This section explains the harmonic balance output measurements you receive after HSPICE runs an HB simulation.

Harmonic Balance Signal Representation

The HB cosine sources can be interpreted in real/imaginary and polar formats according to:

$$
\begin{aligned}
t) &= A\cos(\alpha t + \phi) = Re\{Ae^{j(\alpha t + \phi)}\} = Re\{Ae^{j\phi}e^{j\omega}\\
&= Re\{Ae^{j\phi}[\cos(\alpha t) + j\sin(\alpha t)]\}\\
&= Re\{[V_R + jV_I][\cos(\alpha t) + j\sin(\alpha t)]\}\\
&= V_R\cos(\alpha t) - V_I\sin(at)\\
&= A\cos(\phi)\cos(\alpha t) - A\sin(\phi)\sin(\alpha t)
\end{aligned}
$$

Note that real/imaginary and polar formats are related with the standard convention:

$$V_R + jV_I = Ae^{j\phi}$$

$$V_R = A\cos(\phi)$$

$$V_I = A\sin(\phi)$$

$$A = \sqrt{V_R^2 + V_I^2}$$

$$\tan\phi = \frac{V_I}{V_R}$$

The result of HB analysis is a complex voltage (current) spectrum at each circuit node (or specified branch). Let a[i] be the real part and b[i] be the imaginary part of the complex voltage at the ith frequency index. Conversion to a steady-state time-domain waveform is given by the Fourier series expansion:

$$\begin{aligned} v(t) = a[0] &+ a[1]*\cos(2\pi f[1]*t) - b[1]*\sin(2\pi f[1]*t) \\ &+ a[2]*\cos(2\pi f[2]*t) - b[2]*\sin(2\pi f[2]*t) \\ &+ a[3]*\cos(2\pi f[3]*t) - b[3]*\sin(2\pi f[3]*t) \\ &+ \ldots \\ &+ a[N]*\cos(2\pi f[N]*t) - b[N]*\sin(2\pi f[N]*t) \end{aligned}$$

Where:

- v[t] is the resulting time domain waveform.
- *N*+1 is the total number of harmonics (including DC) in the frequency domain spectrum in the *.hb0 file (the zero-th data point represents DC).
- a[i] is the real value of the ith data point (i.e. the real component at the ith frequency).
- b[i] is the imag value of the i'th data point (i.e., the imaginary component at the ith frequency).
- f[i] is the ith frequency value, which is the DC term. These frequencies need not be harmonically related.

The time-domain representation can be accessed and analyzed by using the `.PRINT` or `.PROBE HBTRAN` output option or by invoking the To Time Domain function on complex spectra within CosmosScope.

Output Syntax

This section describes the syntax for the HB `.PRINT` and `.PROBE` statements.

.PRINT and .PROBE Statements

```
.PRINT HB TYPE(NODES or ELEM)[INDICES]
.PROBE HB TYPE(NODES or ELEM)[INDICES]
```

Parameter	Description
TYPE(NODES or ELEM)	Specifies a harmonic type node or element. TYPE can be one of the following: ■ Voltage type – V = voltage magnitude and phase in degrees VR = real component VI = imaginary component VM = magnitude VP - Phase in degrees VPD - Phase in degrees VPR - Phase in radians VDB - dB units VDBM - dB relative to 1 mV ■ Current type – I = current magnitude and phase in degrees IR = real component II = imaginary component IM = magnitude IP - Phase in degrees IPD - Phase in degrees IPR - Phase in radians IDB - dB units IDBM - dB relative to 1 mV ■ Power type – P ■ Frequency type – ‘HERTZ[i]’, ‘HERTZ[i][j]’, ‘HERTZ[i][j][k]’ You must specify the harmonic index for the HERTZ keyword. The frequency of the specified harmonics is dumped.

Parameter	Description
	NODES or ELEM can be one of the following: ■ Voltage type – a single node name (n1), or a pair of node names, (n1,n2) ■ Current type – an element name (elemname) ■ Power type – a resistor (resistorname) or port (portname) element name.
INDICES	Index to tones in the form [n1, n2, ..., nN], where nj is the index of the HB tone and the HB statement contains N tones. If INDICES is used, then wildcards are not supported.

HB data can be transformed into the time domain and output using the following syntax:

```
.PRINT hbtran ov1 <ov2 ... >
.PROBE hbtran ov1 <ov2 ... >
```

Where `ov1 ...` are the output variables to print or probe.

Calculating Power Measurements After HB Analyses

Two types of power measurements are available: dissipated power in resistors and delivered power to port elements. The following subtle differences between these two measurements are described in this section.

Power Dissipated in a Resistor

All power calculations make use of the fundamental phasor power relationship given as the following equation, where voltage V and current I are complex phasors given in peak values (not rms, nor peak-to-peak):

$$P_{rms} = \frac{1}{2}Re\{VI*\}$$

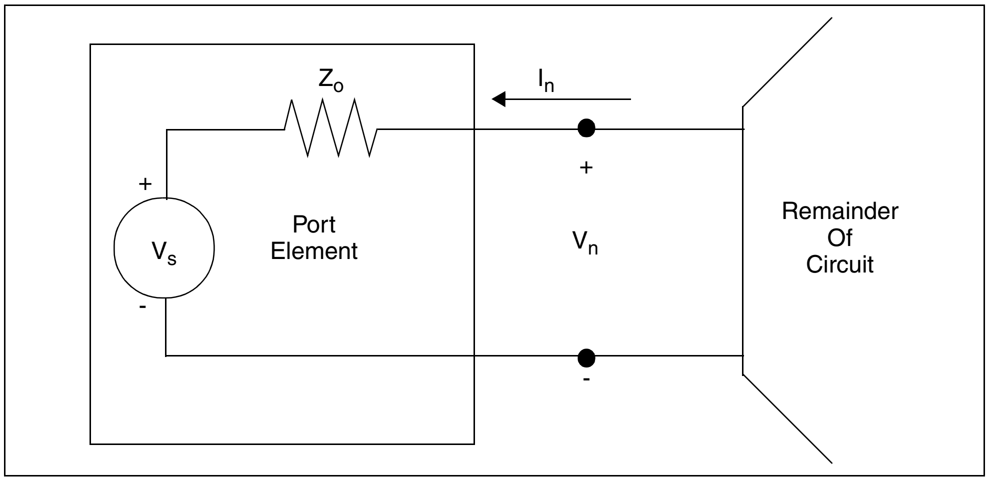
In the case of a simple resistor, its current and voltage are related according to V_n=I_nR. The power dissipated in a resistor of (real) value R at frequency index n is then given by:

$$P_{rms}(resistor)[n] = \frac{|V_n|^2}{2R}$$

Power Delivered to a Port Element

The port element can be either a source or sink for power. You can use a special calculation that computes the power flowing into a port element even if the port element itself is the source of that power. In the following figure is a port element connected to a circuit (the port element may or may not include a voltage source).

Figure 18 Port Element



Let V_n be the (peak) voltage across the terminals of the port element (at frequency index n). Let I_n be the (peak) current into the (1st) terminal of the port element (at frequency index n). Let Z_o be the impedance value of the z0 port element. Then, the power wave flowing into the terminals of the port element (at frequency index *n*) can be computed according to:

$$P_{in}[n] = \frac{1}{2}\left|\frac{V_n + Z_o I_n}{2\sqrt{Z_o}}\right|^2$$

This power expression remains valid whether or not the port element includes an internal voltage source at the same frequency. If the port element includes a voltage source at the same frequency, you can use this power calculation to compute the magnitude of the related large-signal scattering parameters.

If you expand the preceding formula, the power delivered to a port element with (real) impedance Z_o is given by

$$P_{rms}(port)[n] = \frac{1}{2}\left\{\frac{|V_n|^2 + Z_o^2\,|I_n|^2}{4Z_o} + \frac{1}{2}Re\{V_n I_n^*\}\right\}$$

This power value represents the power incident upon and delivered to the port element's load impedance (Zo) due to other power sources in the circuit, and due to reflections of its own generated power.

If the port element is used as a load resistor (no internal source), the preceding equation reduces to that for the simple resistor.

If you used the port element as a power source (with non-zero available power, i.e. a non-zero V_S) and it is terminated in a matched load (Zo), the port power measurement returns 0 W, because no power is reflected.

You can request power measurements in the form of complete spectra or in the form of scalar quantities that represent power at a particular element. To request a complete power spectrum, use the following syntax.

```
.PRINT HB P(Elem)
.PROBE HB P(Elem)
```

To request a power value at a particular frequency tone, use the following syntax:

```
.PRINT HB P(Elem)[n1<,n2<,n3<,...>>>]
.PROBE HB P(Elem)[n1<,n2<,n3<,...>>>]
```

The `Elem` is the name of either a Resistor (R) or Port (P) element, and *n1*,*n2*, and *n3* are integer indices used for selecting a particular frequency in the Harmonic Balance output spectrum.

Example 1

This example prints a table of the RMS power (spectrum) dissipated by resistor R1.

```
.PRINT HB P(R1)
```

Example 2

This example outputs the RMS power dissipated by resistor `R1` at the fundamental HB analysis frequency following a one-tone analysis.

```
.PROBE HB P(R1)[1] x
```

Example 3

This example prints the power dissipated by resistor `R1` at DC following a one-tone analysis.

```
.PRINT HB P(R1)[0]
```

Example 4

This example outputs the RMS power dissipated by resistor `R1` at the (low-side) 3rd order intermodulation product following an HB two-tone analysis.

```
.PROBE HB P(R1)[2,-1]
```

Example 5

This example prints the RMS power dissipated by resistor `R1` at the (high-side) 3rd order intermodulation product following an HB two-tone analysis.

```
.PRINT HB P(R1)[-1,2]
```

Example 6

This example outputs the RMS power (spectrum) delivered to port element Pload.

```
.PROBE HB P(Pload)
```

Example 7

The following example prints the RMS power delivered to port element `Pload` at the fundamental HB analysis frequency following a one-tone analysis.

```
.PRINT HB P(Pload)[1] $
```

Example 8

The following example outputs the RMS power delivered to port element Pload at the (low-side) 3rd order intermodulation product following an HB two-tone analysis.

```
.PROBE HB P(Pload)[2,-1]
```

Calculating for a Time-Domain Output

In addition to a frequency-domain output, HB analysis also supports a time-domain output. A frequency-domain signal is Inverse Fast Fourier Transformed into a time-domain by this formula

```
V(n1)@time t = SUM_OVER_m (REAL(V(n1)[m]) * COS(OMEGA[m] * t)
   - IMAG(V(n1)[m]) * SIN(OMEGA[m] * t)
```

Where *m* starts from 0 to the number of frequency points in the HB simulation.

The output syntax is

```
.PRINT [HBTRAN | HBTR] V(n1)
.PROBE [HBTRAN | HBTR] V(n1)
```

The output time ranges from 0 to twice the period of the smallest frequency in the HB spectra.

Output Examples

```
.PRINT HB P(rload)       $ RMS power (spectrum)
                         $ dissipated at the rload resistor
.PROBE HB V(n1,v2)       $ Differential voltage (spectrum)
                         $ between the n1,n2 nodes
.PRINT HB VP(out)[1]     $ Phase of voltage at the out
                         $ node, at the fundamental
                         $ frequency
.PROBE HB P(Pout)[2,-1]  $ RMS power delivered to the Pout
                         $ port, at third-order intermod
.PRINT HBTRAN V(n1)      $ Voltage at n1 in time domain
.PROBE HBTRAN V(n1<,n2>)  $ Differential voltages between n1
                         $ and n2 node in time domain.
```

Using .MEASURE with .HB Analyses

- For transient analysis (TRAN), the independent variable for calculating `.MEASURE` is time.
- For AC analysis, the independent variable for calculating `.MEASURE` is frequency.
- However, as with DC analysis, the use of a `.MEASURE` command is peculiar for HB analysis, because it has no obvious independent variable.

In HSPICE RF, the independent variable for HB `.MEASURE` analysis is the first swept variable specified in the `.HB` simulation control statement. This variable can be anything: frequency, power, voltage, current, a component value, and so on.

Example 1

For the following `.HB` simulation control statement, the independent variable is the swept tone frequency, and the `.MEASURE` command values return results based on this frequency sweep:

```
* HARMONIC BALANCE tone-frequency sweep for amplifier
.param freq1=1.91e9 power=1e-3
.HB tones=freq1 nharms=10 sweep freq1 LIN 10 1.91e9 2.0e9
.MEASURE HB Patf0 FIND P(Rload)[1] AT=1.95e9 $ Power at
+ f0=1.95Ghz
.MEASURE HB Frq1W WHEN P(Rload)[1]=1. $ freq1 @ 1 Watt
```

```
.MEASURE HB BW1W TRIG AT=1.92e9 TARG P(Rload)[1] VAL=1.
+ CROSS=2 $ 1 Watt bandwidth
.MEASURE HB MaxPwr MAX P(Rload)[1] FROM=1.91e9 TO=2.0e9
+ $ Finds max output power
.MEASURE HB MinPwr MIN P(Rload)[1] FROM=1.91e9 TO=2.0e9
+ $ Finds min output power
```

Example 2

In the following example, the independent variable is the *power* variable, and the `.MEASURE` values return results based on the power sweep. Units are in Watts.

```
* HARMONIC BALANCE power sweep for amplifier
.param freq1=1.91e9 power=1e-3
.HB tones=freq1 nharms=10 sweep power DEC 10 1e-6 1e-3
.MEASURE HB Pat1uW FIND P(Rload)[1] AT=1e-6 $ Pout at 1uW
.MEASURE HB Pin1W WHEN P(Rload)[1]=1. $ Pin @ 1 Watt Pout
.MEASURE HB Prange1W TRIG AT=1.92e9 TARG P(Rload)[1] VAL=1.
+ CROSS=2    $ 1W oper. range

.MEASURE HB ssGain DERIV P(Rload)[1] AT=1e-5
+ $ relative power gain at 10uW input
.MEASURE HB Gain3rd DERIV P(Rload)[3] AT=1e-5
+ $ 3rd harmonic gain at 10uW input
.MEASURE HB PAE1W FIND '(P(Rload)[1]-power)/P(Vdc)[0]'
+ WHEN P(Rload)[1]=1 $ PAE at 1 Watt output
```

Example 3

In this example, the independent variable is again the *power* variable, and the `.MEASURE` values return results based on the power sweep. This is a two-tone sweep, where both input frequency sources are at the same power level in Watts.

```
* HARMONIC BALANCE two-tone sweep for amplifier
* An IP3 calculation is made at 10uW in the sweep
.param freq1=1.91e9 freq2=1.91e9 power=1e-3
.HB tones=freq1,freq2 nharms=6,6 sweep power DEC 10 1e-6 1e-3
.MEASURE HB Pf1dBm FIND '10.*LOG(P(Rload)[1,0]/1.e-3)'
+ AT=1e-5 $ P(f1) at 10uW input
.MEASURE HB P2f1_f2dBm FIND '10.*LOG(P(Rload)[2,-1]/1.e-3)'
+ AT=1e-5 $ P(2f1-f2) at 10uW input
.MEASURE HB OIP3dBm PARAM = '0.5*(3.*Pf1dBm-P2f1_f2dBm)'
.MEASURE HB IIP3dBm PARAM = 'OIP3dBm-Pf1dBm+20.0'
.MEASURE HB AM2PM DERIV VP(outp,outn)[1] AT=1e-5
+ $ AM to PM Conversion in Deg/Watt
```

If you do not specify an HB sweep, then `.MEASURE` assumes a single-valued independent variable sweep.

You can apply the measurements to current, voltage, and power waveforms. The independent variable for measurements is the swept variable (such as power), not the frequency axis corresponding to a single HB steady state point.

HSPICE RF also supports the `.MEASURE [HBTRAN | HBTR] ...` syntax. Similar to the `.PROBE` and `.PRINT HBTR` statements in the section Calculating for a Time-Domain Output on page 218, a `.MEASURE HBTR` statement is applied on the signals obtained in the same way. Moreover, like a `.MEASURE` statement in transient analysis, the independent variable in a `.MEASURE HBTR` statement is time.

HSPICE RF optimization can read the data from `.MEASURE HB` and `.MEASURE HBTR` statements. The optimization syntax in HSPICE RF is identical to that in the HSPICE (for details, see Statistical Analysis and Optimization in the *HSPICE Simulation and Analysis User Guide*). Due to the difference in the independent variable between the `.MEASURE HB` and `.MEASURE HBTR` statements, these two types of measurements cannot be mixed in a HSPICE RF optimization. But a `.MEASURE HBTR` statement can be combined with a `.MEASURE PHASENOISE` statement (see Measuring PHASENOISE Analyses with .MEASURE on page 239) and a `.MEASURE HBNOISE` statement (see Measuring HBNOISE Analyses with .MEASURE on page 263) in a HSPICE RF optimization flow.

HB Output Data Files

The results of an HB analysis are complex spectral components at each frequency point. The a[i] is the real part, and b[i] is the imaginary part of the complex voltage at frequency index i. The conversion to a steady state time-domain is then given by the Fourier series expansion.

An HB analysis produces these output data files:

- Output from the `.PRINT HB` statement is written to a .printhb# file.
  - The header contains the large signal fundamental frequencies.
  - The columns of data are labeled as `HERTZ`, followed by frequency indices, and then the output variable names.
  - The sum of the frequency indices, multiplied by the corresponding fundamental frequencies, add up to the frequency in the first column.

- Output from the `.PROBE HB` statement is written to a .hb# file. It is in the same format as the HSPICE transient analysis .tr# file. Besides the output waveform, it contains the information of harmonic indices and basic tone frequencies.
- Output from the `.PRINT HBTRAN` statement is written to a .printhr# file. The format is identical to a .print# file.
- Output from the `.PROBE HBTRAN` statement is written to a .hr# file. The format is identical to a *.tr#* file.
- Reported performance log statistics are written to a .lis file:
  - Name of HB data file.
  - Simulation time:

    DC operating point (op) time

    HB time

    Total simulation time
  - Memory used
  - Size of matrix (nodes * harmonics)
  - Final HB residual error

Errors and Warnings

Table 16 lists the errors messages and Table 17 on page 223 lists the warning messages.

Table 16 HB Analysis Error Messages

File	Description
HB_ERR.1	Harmonic numbers must be positive non-zero.
HB_ERR.2	No .hb frequencies given.
HB_ERR.3	Negative frequency given.
HB_ERR.4	Number of harmonics should be greater than zero.
HB_ERR.5	Different number of tones, nharms.
HB_ERR.6	Bad probe node format for oscillator analysis.

Table 16 HB Analysis Error Messages (Continued)

File	Description
HB_ERR.7	Bad format for FSPTS.
HB_ERR.8	Bad .hb keyword.
HB_ERR.9	Tones must be specified for .hb analysis.
HB_ERR.10	Nharms or intmodmax must be specified for .hb analysis.
HB_ERR.11	Source harmonic out of range.
HB_ERR.12	Source named in the tones list is not defined.
HB_ERR.13	Source named in the tones list does not have TRANFORHB specified.
HB_ERR.14	Source named in the tones list has no transient description.
HB_ERR.15	Source named in the tones list must be HB, SIN, PULSE, PWL, or VMRF.
HB_ERR.16	Tone specification for the source is inconsistent with its frequency.
HB_ERR.17	HB oscillator analysis has reached the NULL solution.
HB_ERR.18	Bad subharms format.
HB_ERR.19	Modtone may not be set to the same value as tone.

Table 17 HB Analysis Warning Messages

File	Description
HB_WARN.1	.hb multiply defined. Last one will be used.
HB_WARN.2	Tone specified for V/I source not specified in .HB command.
HB_WARN.3	HB convergence not achieved.

Table 17 HB Analysis Warning Messages

File	Description
HB_WARN.4	Source specifies both HB and transient description. HB description will be used.
HB_WARN.5	Source specifies exponential decay. HB will ignore it.
HB_WARN.6	Source specifies a non-positive frequency.
HB_WARN.7	Source does not fit the HB spectrum.
HB_WARN.8	Source cannot be used with the TRANFORHB option.
HB_WARN.9	Frequency not found from transient analysis

References

[1] S. Maas, *Nonlinear Microwave Circuits*, Chapter 3, IEEE Press, 1997.

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9

Oscillator and Phase Noise Analysis

Describes how to use HSPICE RF to perform oscillator and phase noise analysis on autonomous (oscillator) circuits.

Harmonic Balance for Oscillator Analysis

HSPICE RF can analyze oscillator circuits. Because the frequency of oscillation is not determined by the frequencies of driving sources, these circuits are called *autonomous*. Autonomous simulation solves a slightly different set of nonlinear equations as shown in the following equation:

$$F(V, \omega_0) = I(V, \omega_0) + \Omega Q(V, \omega_0) + Y(\omega_0)V + I_s$$

HSPICE RF adds the fundamental frequency of oscillation to the list of unknown circuit quantities. To accommodate the extra unknown, the phase (or equivalently, the imaginary part) of one unknown variable (generally a node voltage) is set to zero. The phases of all circuit quantities are relative to the phase, at this reference node.

Additionally, HSPICE RF tries to avoid the “degenerate solution,” where all non-DC quantities are zero. Although this is a valid solution of the above equation (it is the correct solution, if the circuit does not oscillate), HB analysis might find this solution incorrectly, if the algorithm starts from a bad initial solution.

HSPICE RF follows the technique described by Ngoya, et al, which uses an internally-applied voltage probe to find the oscillation voltage and frequency. The source resistance of this probe is a short circuit at the oscillation frequency, and an open circuit otherwise. HSPICE RF uses a two-tier Newton approach to find a non-zero probe voltage, which results in zero probe current.

HSPICE RF uses the DC solution as a starting point for non-autonomous HB analysis. In addition to the DC solution, autonomous circuits need an accurate initial value for both the oscillation frequency and the probe voltage. HSPICE RF calculates the small-signal admittance that the voltage probe sees over a range of frequencies in an attempt to find potential oscillation frequencies. Oscillation is likely to occur where the real part of the probe current is negative, and the imaginary part is zero. You can use the `FSPTS` parameter to specify the frequency search. You must also supply an initial guess for the large signal probe voltage. A value of one-half the supply voltage is often a good starting point.

Input Syntax

```
.HBOSC TONE=F1,<F2>,...,<Fn>
+ NHARMS=H1,<H2>,...,<Hn> PROBENODE=N1,N2,VP
+ <OSCTONE=N> <FSPTS=NUM, MIN, MAX>
+ <SWEEP PARAMETER_SWEEP> <SUBHARMS=I>

ISRC N1,N2,VP HBOSCVPROBE=VP
.HBOSC TONE=F1 NHARMS=H1
+ PROBENODE=N1,N2,VP <FSPTS=NUM, MIN, MAX>
```

Parameter	Description
TONE	Approximate value for oscillation frequency (Hz). The search for an exact oscillation frequency begins from this value, unless you specify an FSPTS range or transient initialization (see HB Simulation of Ring Oscillators on page 230 for more information).
NHARMS	Number of harmonics to use for oscillator HB analysis.
PROBENODE	Nodes used to probe for oscillation conditions. ▪ N1 and N2 are the positive and negative nodes for a voltage probe inserted in the circuit for oscillator analysis. ▪ VP is the initial probe voltage value (one-half the supply voltage is a suggested value). The phase of the probe voltage is forced to zero; all other phases are relative to the probe phase. HSPICE RF uses this probe to calculate small-signal admittance for the initial frequency estimates. It should be connected to a non-linear device.
OSCTONE	Specifies what tone to use as the autonomous tone (counted from 1 up). The default is 1.

Parameter	Description
FSPTS	Specifies the frequency search points that HSPICE RF uses in its initial small-signal frequency search. Optional, but recommended unless the circuit is a ring oscillator (see HB Simulation of Ring Oscillators on page 230 for more information). ▪ NUM is an integer. ▪ MIN and MAX are in units of Hz. When present, this parameter causes the TONE parameter to be ignored.
SWEEP	Specifies the type of sweep. You can sweep up to three variables. You can specify either LIN, DEC, OCT, POI, SWEEPBLOCK, DATA, OPTIMIZE, or MONTE. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ▪ LIN *nsteps start stop* ▪ DEC *nsteps start stop* ▪ OCT *nsteps start stop* ▪ POI *nsteps freq_values* ▪ SWEEPBLOCK *nsteps freq1 freq2 ... freqn* ▪ DATA=*dataname* ▪ OPTIMIZE=OPT*xxx* ▪ MONTE=*val*
SUBHARMS	Allows subharmonics in the analysis spectrum. The minimum non-DC frequency in the analysis spectrum is f/subharms, where f is the frequency of oscillation.

Example 1

```
.HBOSC tone=900MEG nharms=9 probenode=gate,gnd,0.65
```

Performs an oscillator analysis, searching for frequencies in the vicinity of 900 MHz. This example uses nine harmonics with the probe inserted between the `gate` and `gnd` nodes. The probe voltage estimate is `0.65` V.

Example 2

```
.HBOSC tone=2400MEG nharms=11
+ probenode=drainP,drainN,1.0 fspts=20,2100MEG,2700MEG
```

Performs an oscillator analysis, searching for frequencies in the vicinity of 2.4 GHz. This example uses `11` harmonics with the probe inserted between the `drainP` and `drainN` nodes. The probe voltage estimate is `1.0` V.

Example 3

Another method to define the probenode information is through a zero-current source. The following two methods define an equivalent `.HBOSC` command:

- Method 1:

```
.HBOSC tone = 2.4G nharms = 10
+ probenode = drainP, drainN, 1.0
+ fspts = 20, 2.1G, 2.7G
```

- Method 2:

```
ISRC drainP drainN 0 HBOSCVPROBE = 1.0
.HBOSC tone = 2.4G nharms = 10
+ fspts = 20, 2.1G, 2.7G
```

In method 2, the `PROBENODE` information is defined by a current source in the circuit. Only one such current source is needed, and its current must be 0.0 with the HBOSC `PROBENODE` voltage defined through its `HBOSCVPROBE` property.

HB Simulation of Ring Oscillators

Ring oscillators require a slightly different simulation approach in HB. Since their oscillation is due to the inherent delay in the inverters of the ring, they are best modeled in the time domain and not in the frequency domain.

Also, ring oscillator waveforms frequently approach square waves, which require a large number of harmonics to be described in the frequency domain. An accurate initial guess is important if they are going to be simulated accurately with HB.

HSPICE RF HB oscillator analysis typically starts from the DC solution and looks for potential resonances in the linear portion of the circuit to determine the initial guess for the oscillation frequency. However, these resonances generally do not exist in ring oscillators, which do not contain many linear elements.

HB analysis provides a second method of obtaining a good initial guess for the oscillation frequency, which is specifically intended for ring oscillators. Instead of starting from the results of a DC analysis, this method starts from the result of a transient analysis. This method also provides a good initial guess for all the voltages and currents in the circuit.

HBOSC Analysis Options

To perform an HB analysis of a ring oscillator, set the following options in your HSPICE RF netlist.

Table 18 HBOSC Analysis Options

Option	Description
HBTRANINIT = <time>	Tells HB to use transient analysis to initialize all state variables. *<time>* is when the circuit has reached (or is near) steady-state. Default = 0.
HBTRANPTS = <npts>	*<npts>* specifies the number of points per period for converting the time-domain data results from transient analysis, into the frequency domain. *<npts>* must be an integer greater than 0. The units are in nharms (nh). Default=4*nh. This option is relevant only if you set .OPTION HBTRANINIT.
HBTRANSTEP = <stepsize>	*<stepsize>* specifies the step size for the transient analysis. The default is 1/(4*nh*f0), where nh is the nharms value and f0 is the oscillation frequency. This option is relevant only if you set .OPTION HBTRANINIT.
HBTRANFREQSEARCH = <1|0>	If HBTRANFREQSEARCH=1 (default), then HB analysis calculates the oscillation frequency from the transient analysis. Otherwise, HB analysis assumes that the period is 1/*f*, where *f* is the frequency specified in the tones description.

Note:

You can specify either `.OPTION HBTRANPTS` or `.OPTION HBTRANSTEP`, but not both.

You must also either specify the initial conditions or add a PWL or PULSE source to start the oscillator for transient analysis. This source should provide a brief stimulus, and then return to zero. HB analysis effectively ignores this type of source, treating it as zero-valued.

This method does the following:

1. If `HBTRANFREQSEARCH=1`, transient analysis runs for several periods, attempting to determine the oscillation frequency from the probe voltage signal.
2. Transient analysis continues until the time specified in `HBTRANINIT`.
3. Stores the values of all state variables over the last period of the transient analysis.
4. Transforms the state variables to the frequency domain by using a Fast Fourier Transform (FFT) to establish an initial guess for HB oscillator analysis.
5. Starts the standard HB oscillator analysis.

Additional .HBOSC Analysis Options

Oscillator analysis will make use of all standard HB analysis options as listed in the following table. In addition, the following options are specifically for oscillator applications.

Table 19 HBOSC Analysis Options for Oscillator Applications

Parameter	Description
HBFREQABSTOL	An additional convergence criterion for oscillator analysis. HBFREQABSTOL is the maximum absolute change in frequency between solver iterations for convergence. Default is 1 Hz.
HBFREQRELTOL	An additional convergence criterion for oscillator analysis. HBFREQRELTOL is the maximum relative change in frequency between solver iterations for convergence. Default is 1.e-9.
HBPROBETOL	HBOSC analysis tries to find a probe voltage at which the probe current is less than HBPROBETOL. This option defaults to the value of HBTOL, which defaults to 1.e-9.
HBMAXOSCITER	Maximum number of outer-loop iterations for HBOSC analysis. It defaults to 10000.

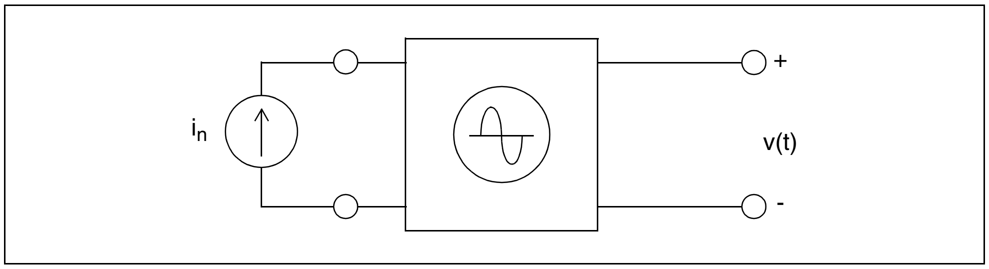
.HBOSC Output Syntax

The output syntax for .HBOSC analysis is identical to that for HB analysis (see Chapter 8, Steady-State Harmonic Balance Analysis). To output the final frequency of oscillation, use the `HERTZ` keyword. For example, *hertz[1]* identifies the fundamental frequency of oscillation.

Phase Noise Analysis

Figure 19 shows a simple free-running oscillator, which includes a port with injected current.

Figure 19 Oscillator with Injected Current



An ideal oscillator would be insensitive to perturbations with a fixed amplitude, frequency, and phase represented by:

$$v(t) = A\cos[\omega_0 t + \phi_0]$$

A noisy oscillator has amplitude and phase fluctuations:

$$v(t) = A(t)\cos[\omega_0 t + \phi(t)]$$

In the preceding equation:

- *A(t)* is the time varying amplitude for the noisy oscillator.
- $\phi(t)$ is the time varying phase for the noisy oscillator.
- ω_0 is the frequency of oscillation.

In most applications, the phase noise is of particular interest, because it represents frequency fluctuations about the fundamental, which you cannot remove. These fluctuations are random processes, and are typically expressed in terms of their power spectral density. For most oscillators, the phase noise is a low-frequency modulation that creates sidebands in the oscillator's spectrum, about ω_0 .

For example, the following equation represents a simple sinusoidal variation in the phase:

$$v(t) = A\cos\lfloor \omega_0 t + \theta_P \sin\omega_m t \rfloor$$

- θ_P is the peak phase deviation, specified as $\theta_P = \Delta\omega / \omega_m$
- $\Delta\omega$ is the peak angular frequency deviation.

For $\theta_P \ll 1$, the following equation approximates the output:

$$(t) = A\left\{ \cos(\omega_0 t) - \frac{\theta_P}{2}[\cos(\omega_0 + \omega_P)t - \cos(\omega_0 - \omega_m)t] \right.$$

That is, when the peak phase deviation is small, the result is frequency components on each side of the fundamental with amplitude $\theta_P/2$. Therefore, an effective treatment of the noisy oscillator is to consider it a frequency-modulated source, operating with a small modulation index $\beta = \theta_P$, under the conditions of the narrowband FM assumption (modulation results in only two sidebands about the carrier).

The Single-Sideband Phase Noise *L(fm)* is then the ratio of noise power to carrier power in a 1Hz bandwidth, at offset $\omega_m = 2\pi f_m$:

$$L(f_m) = \left(\frac{V_{sb}}{A}\right)^2 = \frac{\theta_P^2}{4} = \frac{\theta_{rms}^2}{2}$$

This model for oscillator noise shows that sidebands about the fundamental, due to noise, are directly related to the spectrum of the phase fluctuations $\theta(t)$. The power spectral density of phase fluctuations is related to phase noise:

$$S_\phi(\omega_m) = \frac{\theta_P^2}{2} = 2L(f_m)$$

Characterizing and measuring low-frequency phase variations of the oscillator, leads directly to its spectrum about the fundamental.

Input Syntax

```
.PHASENOISE <output> <frequency_sweep> <method=int>
+ <carrierindex=int> <listfreq=(frequencies|none|all)>
+ <listcount=val> <listfloor=val> <listsources=on|off>
```

Parameter	Description
output	An output node, pair of nodes, or 2-terminal element. HSPICE RF references phase noise calculations to this node (or pair of nodes). Specify a pair of nodes as V(n+,n-). If you specify only one node, V(n+), then HSPICE RF assumes that the second node is ground. You can also specify a 2-terminal element.
frequency_sweep	A sweep of type LIN, OCT, DEC, POI, or SWEEPBLOCK. Specify the type, nsteps, and start and stop time for each sweep type, where: ■ type = Frequency sweep type, such as OCT, DEC, or LIN. ■ nsteps = Number of steps per decade or total number of steps. ■ start = Starting frequency. ■ stop = Ending frequency. The four parameters determine the offset frequency sweep about the carrier used for the phase noise analysis. LIN *type nsteps start stop*OCT *type nsteps start stop*DEC *type nsteps start stop*POI *type nsteps start stop*SWEEPBLOCK *freq1 freq2 ... freqn*
method	■ METHOD=0 (default) selects the Nonlinear Perturbation (NLP) algorithm, which is used for low-offset frequencies. ■ METHOD=1 selects the Periodic AC (PAC) algorithm, which is used for high-offset frequencies. ■ METHOD=2 selects the Broadband Phase Noise (BPN) algorithm, which you can use to span low and high offset frequencies. You can use METHOD to specify any single method. See the section on Phasenoise Algorithms below for a more detailed discussion on using the METHOD parameter.

Parameter	Description
carrierindex	Optional. Specifies the harmonic index of the carrier at which HSPICE RF computes the phase noise. The phase noise output is normalized to this carrier harmonic. Default=1.

listfreq	Dumps the element phase noise value to the .lis file. You can specify which frequencies the element phase noise value dumps. The frequencies must match the sweep_frequency values defined in the parameter_sweep, otherwise they are ignored.
	In the element phase noise output, the elements that contribute the largest phase noise are dumped first. The frequency values can be specified with the NONE or ALL keyword, which either dumps no frequencies or every frequency defined in the parameter_sweep. Frequency values must be enclosed in parentheses. For example:
	listfreq=(none)
	listfreq=(all)
	listfreq=(1.0G)
	listfreq=(1.0G, 2.0G)
	The default value is the first frequency value.

listcount	Dumps the element phase noise value to the .lis file, which is sorted from the largest to smallest value. You do not need to dump every noise element; instead, you can define listcount to dump the number of element phase-noise frequencies. For example, listcount=5 means that only the top 5 noise contributors are dumped. The default value is 20.
listfloor	Dumps the element phase noise value to the .lis file and defines a minimum meaningful noise value (in dBc/Hz units). Only those elements with phase-noise values larger than the listfloor value are dumped. For example, listfloor=-200 means that all noise values below -200 (dBc/Hz) are not dumped. The default value is -300 dBc/Hz.

Parameter	Description
listsources	Dumps the element phase-noise value to the .lis file. When the element has multiple noise sources, such as a level 54 MOSFET, which contains the thermal, shot, and 1/f noise sources. When dumping the element phase-noise value, you can decide if you need to dump the contribution from each noise source. You can specify either ON or OFF: ON dumps the contribution from each noise source and OFF does not. The default value is OFF.

Phase Noise Algorithms

HSPICE RF provides three algorithms for oscillator phasenoise: nonlinear perturbation, periodic AC, and broadband calculations. These algorithms are selected by setting the METHOD parameter to 1, 2, or 3 respectively.

Each algorithm has their regions of validity and computational efficiency, so some thought is necessary to obtain meaningful results from a PHASENOISE simulation. For each algorithm, the region of validity depends on the particular circuit being simulated. However, there are some general rules that can be applied to oscillator types (that is, ring or harmonic) so that a valid region can be identified. And there are techniques that can be used to check validity of your simulation results.

Nonlinear Perturbation Algorithm

The nonlinear perturbation (NLP) algorithm, which is the default selection, is typically the fastest computation, but is valid only in a region close to the carrier. Generally, you will want to use this algorithm if you interested in phasenoise close to the carrier and do not need to determine a noise floor. NLP computation time is almost independent of the number of frequency points in the phasenoise frequency sweep.

Periodic AC Algorithm

The periodic AC (PAC) algorithm is valid in a region away from the carrier and is slower than the NLP algorithm. The PAC algorithm is used for getting phasenoise in the far carrier region and when you need to determine a noise floor.

The computation time for the PAC algorithm is approximately linearly dependent on the number of frequency points in the phasenoise frequency sweep. If you are using the PAC algorithm, you should try to minimize the number of points in the sweep.

Another issue is that the PAC algorithm becomes more ill-conditioned as you approach the carrier. This means that you may have to generate a steady-state solution with more harmonics to get an accurate simulation as you get closer to the carrier. So, if you find that the PAC is rolling off at close-in frequencies, you should rerun HB analysis with a larger number of harmonics. Although, typically, you will not see improvements in PAC accuracy beyond more than about 100-200 harmonics.

Early in your testing, the best way to verify that NLP and PAC are giving accurate results is to run both algorithms over a broad frequency range and check that the curves have some range in frequency where they overlap. Typically, you will see the NLP curve rolling off at 20 to 30 dB/decade as frequency increases, characteristic of white noise or 1/f noise behavior. Also, the PAC curve will at first be flat or even noisy close to the carrier. At some point though, you will see this curve match the NLP roll-off.

The lowest frequency at which the curves overlap defines the point, f_{PAC} above which the PAC algorithm is valid. Sometimes, by increasing the number of HB harmonics, it is possible to move f_{PAC} to lower frequencies. The highest frequency at which the curves overlap defines the point, f_{NLP} below which the NLP algorithm is valid. A rough rule of thumb is that $f_{PAC} = f_o/Q$, where f_o is the carrier frequency and Q is the oscillator Q-value. This implies that for high-Q oscillators, such as crystal and some harmonic oscillators, that PAC will be accurate to values quite close to the carrier.

Broadband Phasenoise Algorithm

The broadband phasenoise (BPN) algorithm has been added to HSPICE RF to allow phasenoise simulation over a broad frequency range. The BPN algorithm actually runs both the NLP and PAC algorithms and then connects them in the overlap region to generate a single phasenoise curve. This algorithm is ideal for verifying the NLP and PAC accuracy regions and when you require a phasenoise curve over a broad frequency range.

Measuring PHASENOISE Analyses with .MEASURE

The `.MEASURE PHASENOISE` syntax supports five types of measurements:

- trigger-target

  ```
  .MEASURE PHASENOISE result TRIG trig_var VAL = trig_val
  + < TD =time_delay > < CROSS = c > < RISE = r >
  + < FALL = f > TARG ...
  ```

  This measurement yields the result of the frequency difference between the trigger event and the target event.

- find-when

  ```
  .MEASURE PHASENOISE result FIND out_var1
  + WHEN out_var2 = out_val2 <TD = time_delay >
  + < RISE = r > < FALL = f > < CROSS = c>
  .MEASURE PHASENOISE result FIND out_var1
  + At = Input_Frequency_Band value
  ```

  The previous measurement yields the result of a variable value at a specific input frequency band (IFB) point.

  ```
  .MEASURE PHASENOISE result FIND out_var1
  + WHEN out_var2 = out_var3
  ```

  The previous measurement yields the result at the input frequency point when *out_var2* == *out_var3*.

  ```
  .MEASURE PHASENOISE result WHEN out_var2 = out_var3
  ```

  The previous measurement yields the input frequency point when *out_var2* == *out_var3*.

- average, RMS, min, max, and peak-to-peak

  ```
  .MEASURE PHASENOISE result <RMS> out_var
  + < FROM = IFB1 > < TO = IFB2 >
  ```

  This measurement yields the `RMS` of *out_var* from frequency `IFB1` to frequency `IFB2`. You can replace the `<RMS>` with `<AVG>` to find the average value of *out_var*. Similarly, you can replace `<RMS>` with `<MIN>`, `<MAX>`, or `<PP>` to find the result of min, max, or pp.

- integral evaluation

  ```
  .MEASURE PHASENOISE result INTEGRAL out_var
  + < FROM = IFB1 > < TO = IFB2 >
  ```

This measurement integrates the *out_var* value from the `IFB1` frequency to the `IFB2` frequency.

- derivative evaluation

  ```
  .MEASURE PHASENOISE result DERIVATIVE out_var AT = IFB1
  ```

  This measurement finds the derivative of *out_var* at the IFB1 frequency point.

  Note:

  > `.MEASURE PHASENOISE` cannot contain an expression that uses an phasenoise variable as an argument. You also cannot use `.MEASURE PHASENOISE` for error measurement and expression evaluation of `PHASENOISE`.

The HSPICE RF optimization flow can read the measured data from a `.MEASURE PHASENOISE` analysis. This flow can be combined in the HSPICE RF optimization routine with a `.MEASURE HBTR` analysis (see Using .MEASURE with .HB Analyses on page 219) and a `.MEASURE HBNOISE` analysis (see Measuring HBNOISE Analyses with .MEASURE on page 263).

Output Syntax

```
.PRINT PHASENOISE phnoise phnoise(element_name)
.PROBE PHASENOISE phnoise phnoise(element_name)
```

In this syntax, *phnoise* is the phase noise parameter.

The `.PHASENOISE` statement outputs raw data to the *.pn# and *.printpn# files. HSPICE RF outputs the *phnoise* data in decibels, relative to the carrier signal, per hertz, across the output nodes in the `.PHASENOISE` statement. The data plot is a function of the offset frequency. Units are in dBc/Hz.

- If you use the NLP algorithm (default), HSPICE RF calculates only the phase noise component.
- If you use the PAC algorithm, HSPICE RF sums both the phase and amplitude noise components to show the total noise at the output.
- If you use the BPN algorithm (`METHOD=2`), HSPICE RF adds both the phase and amplitude noise components together to show the total noise at the output. HSPICE RF outputs phnoise to the .pn# file if you set `.OPTION POST`.

Element phase noise can also be analyzed through the `.PRINT` and `.PROBE` statements, which the previous syntax shows. A single *phnoise* keyword specifies the phase noise for the whole circuit, and the `phnoise(`*element_name*`)` specifies the phase-noise value of the specified element.

Example 1

```
.HBOSC TONE=900MEG NHARMS=9
+ PROBENODE=gate,gnd,0.65
.PHASENOISE V(gate,gnd) DEC 10 100 1.0e7
+ METHOD=0 CARRIERINDEX=1 $use NLP algorithm
```

This example performs an oscillator analysis, searching for frequencies in the vicinity of 900 MHz, followed by a phase noise analysis at frequency offsets from 100 Hz to 10 MHz.

Example 2

```
.HBOSC TONE=2400MEG NHARMS=11
+ PROBENODE=drainP,drainN,1.0
+ FSPTS=20,2100MEG,2700MEG
+ SWEEP Vtune 0.0 5.0 0.2
.PHASENOISE V(drainP,drainN) DEC 10 100 1.0e7
+ METHOD=1 CARRIERINDEX=1 $use NLP algorithm
```

This example performs a VCO analysis, searching for frequencies in the vicinity of 2.4 GHz. This example uses eleven harmonics, and sweeps the VCO tuning voltage from 0 to 5 V. HSPICE RF uses the nonlinear perturbation (NLP) algorithm to perform a phase noise analysis about the fundamental frequency for each tuning voltage value.

Phase Noise Analysis Options

Table x lists the control options specific to PHASENOISE applications.

Table 20 PHASENOISE Analysis Options

Parameter	Description
BPNMATCHTOL=val	Determines the minimum required match between the NLP and PAC phase noise algorithms. An acceptable range is 0.05dB to 5dB. The default is 0.5dB.

Table 20 PHASENOISE Analysis Options (Continued)

Parameter	Description
PHASENOISEKRYLOVDIM	Specifies the dimension of the Krylov subspace that the Krylov solver uses. This must be an integer greater than zero. The default is 500.
PHASENOISEKRYLOVITER	Specifies the maximum number of Krylov iterations that the phase noise Krylov solver takes. Analysis stops when the number of iterations reaches this value. The default is 1000.
PHASENOISETOL	Specifies the error tolerance for the phase noise solver. This must be a real number greater than zero. The default is 1e-8.
PHNOISELORENTZ=val	Turns on a Lorentzian model for the phase noise analysis. ▪ val=0: uses a linear approximation to a lorentzian model ▪ val=1 (default): applies a lorentzian model to all noise sources ▪ val=2: applies a lorentzian model to all non-frequency dependent noise sources

Timing Jitter Analysis

Timing jitter is a measurement of oscillator uncertainty in the time domain. For clock applications, time domain measurements are preferable, since most specifications of concern involve time domain values.

Timing jitter is the standard deviation of the timing uncertainty, which is a function of the auto correlation function in the power spectrum of the phase variations. The following equation shows this function:

$$\sigma^2(\tau) = \frac{2}{\omega_o^2}[R_\phi(0) - R_\phi(\tau)]$$

The Weiner-Khintchine Theorem [1] relates the auto correlation function to the power spectrum of phase variations as in the following equation:

$$R_\phi(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_\phi(\omega)e^{j\omega\tau}d\omega$$

The $S_\phi(\omega)$ is written as a double-sided power spectrum. Using a single-sided spectra would result in an additional factor of two.

The following equation shows the relationship between mean-square timing jitter and the power spectrum of phase variations:

$$\sigma^2(\tau) = \frac{4}{\pi\omega_o^2}\int_0^{\infty} S_\phi(\omega)sin^2\left(\frac{\omega\tau}{2}\right)d\omega$$

For reasonably large offset frequencies, such as a narrowband FM assumption that holds for phase modulation, the assumption is that $L(f) \cong S_\phi(f)$, which creates the following equation:

$$\sigma^2(\tau) \cong \frac{8}{\omega_o^2}\int_0^{\infty} L(f)sin^2(\pi f\tau)df$$

In the more common notation for timing jitter, the following equation applies:

$$\sigma_\tau \cong \sqrt{\frac{8}{\omega_o^2}\int_0^{\infty} L(f)sin^2(\pi f\tau)df}$$

This integral assumes a continual roll-off in $L(f)$ and is easily evaluated for an $L(f)$ with f^2 behavior (the “White FM region”) since the following equation is true:

$$\int_0^{\infty}\frac{sin^2(\pi f\tau)}{f^2}df = \frac{\pi^2\tau}{2}$$

Given an $L(f)$ that is written (in non-dB form) as

$$L(f) = \frac{L_{1HZ}}{f^2}$$

The following timing jitter expression becomes apparent with the expected square root delay dependence:

$$\sigma_\tau = \frac{\sqrt{L_{1HZ}}}{f_0}\sqrt{\tau}$$

In the general case, you must carefully set the limits of integration for the timing jitter calculation.

Timing Jitter Syntax

The timing jitter calculations are derived from the results of phase noise analysis. The phase noise output syntax supports the `JITTER` keyword as an output keyword in addition to the `PHNOISE` keyword.

```
.PRINT PHASENOISE PHNOISE JITTER
.PROBE PHASENOISE PHNOISE JITTER
```

If the `JITTER` keyword is present, the `.PHASENOISE` statement also outputs the raw jitter data to *.jt0 and *.printjt0 data files. These data are plotted as a function of time in units of seconds. Timing jitter data itself is unitless. The timing jitter calculations make use of some of the parameters given in the `.PHASENOISE` syntax. See Input Syntax on page 235 for the syntax and examples.

The timing jitter calculations make use of the phase noise frequency sweep specification. The resulting values for type, nsteps, start, and stop result in an array of frequency points given by:

$$f0, f1, \ldots fn$$

The output of timing jitter information uses a corresponding time sampling derived via:

$$\tau_0 = \frac{1}{f_N}, \tau_1 = \frac{1}{f_{N-1}}, \ldots, \tau_N = \frac{1}{f_0}$$

RMS JITTER Measurement

Based on the phase noise data, the syntax of the `RMS JITTER` measurement is provided, where word is in units of sec (seconds), rad (radiens), or iu (interval units). The default is sec.

```
.MEASURE phasenoise integralOutMag RMSJITTER phnoise
+ <FROM start_frequency> <TO end_frequency> <UNITS=word>
```

Example

```
.meas phasenoise rj RMSJITTER phnoise from 1K to 100K
+ units = rad
```

The `RMSJITTER` is calculated as

$$rms1 = \sum_{k = startfrequency}^{endfrequency} (2.0 \cdot 10.0^{0.1 \cdot phasenoise})$$

With sec units, the `RMSJITTER` is calculated as

$$RMSJITTER = \frac{\sqrt{rms1}}{2.0 \cdot \pi \cdot f0}$$

in which PI = 3.1415926 and f0 is the tone frequency of the oscillator.

With rad units, the `RMSJITTER` is calculated as

$$RMSJITTER = \sqrt{rms1}$$

With iu units, the `RMSJITTER` is calculated as

$$RMSJITTER = \frac{\sqrt{rms1}}{2.0 \cdot \pi}$$

References

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[2] C.R. Chang, M.B. Steer, S. Martin, E. Reese, “Computer-Aided Analysis of Free-Running Microwave Oscillators,” *IEEE Trans. on Microwave Theory and Techniques*, Volume 39, No. 10, pages 1735-1745, October 1991.

[3] G.D. Vendelin, *Design of Amplifiers and Oscillators by the S-Parameter Method*, John Wiley & Sons, 1982

[4] A. Demir, A. Mehrotra, J. Roychowdhury, “Phase Noise in Oscillators: A Unifying Theory and Numerical Methods for Characterization” in Proc. IEEE DAC, pages 26-31, June 1998.

[5] A. Demir, A. Mehrotra, and J. Roychowdhury, “Phase Noise in Oscillators: A Unifying Theory and Numerical Methods for Characterization,” *IEEE Trans. Circuits System I*, Volume 47, pages 655–674, May 2000.

10

Power-Dependent S Parameter Extraction

Describes how to use periodically driven nonlinear circuit analyses as well as noise parameter calculation.

HBLSP Analysis

An HBLSP analysis provides three kinds of analyses for periodically-driven nonlinear circuits, such as those that employ power amplifiers and filters:

- Two-port power-dependant (large-signal) S parameter extraction
- Two-port small-signal S parameter extraction
- Two-port small-signal noise parameter calculation

Unlike small-signal S parameters, which are based on linear analysis, power-dependent S parameters are based on harmonic balance simulation. Its solution accounts for nonlinear effects such as compression and variation in power levels.

The definition for power-dependent S parameters is similar to that for small-signal parameters. Power-dependent S parameters are defined as the ratio of reflected and incident waves by using this equation:

b = S * a ;   S[i, j]=b[i,n]/a[j,n]   when a[k,n](k!=j)=0

The incident waves, a[i, n], and reflected waves, b[i, n], are defined by using these equations:

a[i, n] = (V[i](n*W_0) + Z_o[i] * I[i](n*W_0)) / (2 * sqrt(Z_o[i]))

b[i, n] = (V[i](n*W_0) - Z_o[i] * I[i](n*W_0)) / (2 * sqrt(Z_o[i]))

Where:

- W_0 is the fundamental frequency (tone).
- n is a signed integer.

- i is the port number.
- a[i, n] is the input wave at the frequency n*W_0 on the i^{th} port.
- b[i, n] is the reflected wave at the frequency n*W_0 on the i^{th} port.
- V[i](n*W_0) is the Fourier coefficient at the frequency n*W_0 of the voltage at port i.
- I[i](n*W_0) is the Fourier coefficient at the frequency n*W_0 of the current at port i.
- Z_o[i] is the reference impedance at port i.

An HBLSP analysis only extracts the S parameters on the first harmonic (that is, n=1).

Limitations

The HBLSP analysis has these known limitations:

- Power-dependent S parameter extraction is a 2-port analysis only. Multiport power-dependent S parameters are not currently supported.
- The intermodulation data block (`IMTDATA`) in the .p2d# file is not supported.
- The internal impedance of the P (port) Element can only be a real value. Complex impedance values are not supported.

Input Syntax

```
.HBLSP NHARMS=nh <POWERUNIT=[dbm | watt]>
+ <SSPCALC=[1|0|YES|NO]> <NOISECALC=[1|0|YES|NO]>
+ <FILENAME=file_name> <DATAFORMAT=[ri | ma | db]>
+ FREQSWEEP freq_sweep POWERSWEEP power_sweep
```

Parameter	Description
NHARMS	Number of harmonics in the HB analysis triggered by the `.HBLSP` statement.
POWERUNIT	Power unit. Default is watt.

Parameter	Description
SSPCALC	Extract small-signal S parameters. Default is 0 (NO).
NOISECALC	Perform small-signal 2-port noise analysis. Default is 0 (NO).
FILENAME	Output data .p2d# filename. Default is the netlist name or the object name after the -o command-line option.
DATAFORMAT	Format of the output data file. Default is ma (magnitude, angle).
FREQSWEEP	Frequency sweep specification. A sweep of type LIN, DEC, OCT, POI, or SWEEPBLOCK. Specify the *nsteps*, *start*, and *stop* times using the following syntax for each type of sweep: ■ LIN *nsteps start stop* ■ DEC *nsteps start stop* ■ OCT *nsteps start stop* ■ POI *nsteps freq_values* ■ SWEEPBLOCK=*blockname* This keyword must appear before the POWERSWEEP keyword.
POWERSWEEP	Power sweep specification. A sweep of type LIN, DEC, OCT,POI, or SWEEPBLOCK. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ■ LIN *nsteps start stop* ■ DEC *nsteps start stop* ■ OCT *nsteps start stop* ■ POI *nsteps power_values* ■ SWEEPBLOCK=*blockname* This keyword must follow the FREQSWEEP keyword.

Note:

The `FREQSWEEP` and `POWERSWEEP` keywords must appear at the end of an `.HBLSP` statement.

Example

This example does 2-port single-tone, power-dependent S parameter extraction, without frequency translation:

- Frequency sweep: The fundamental tone is swept from 0 to 1G
- Power sweep: The power input at port 1 is swept from 6 to 10 Watts.
- Five harmonics are required for the HB analysis. Large-signal S parameters are extracted on the first harmonic.

- Five harmonics are required in the HBLSP triggered HB analysis.
- The DC value in p1 statement is used to set DC bias, which is used to perform small-signal analyses.
- Small-signal S parameters are required extracted.
- Small-signal two-port noise analysis is required.
- The data will be output to the ex1.p2d file.

```
p1 1 0 port=1 dc=1v
p2 2 0 port=2
.hblsp nharms=5 powerunit = watt
+ sspcalc=1 noisecalc=1 filename=ex1
+ freqsweep lin 5 0 1G powersweep lin 5 6 10
```

Output Syntax

This section describes the syntax for the `HBLSP .PRINT` and `.PROBE` statements. These statements only support S and noise parameter outputs. Node voltage, branch current, and all other parameters are not supported in `HBLSP .PRINT` and `.PROBE` statements.

.PRINT and .PROBE Statements

```
.PRINT HBLSP Smn | Smn(TYPE) | S(m, n) | S(m, n)(TYPE)
+ ...small signal 2-port noise params...
.PROBE HBLSP Smn | Smn(TYPE) | S(m, n) | S(m, n)(TYPE)
+ ...small signal 2-port noise params...
```

Parameter	Description

Smn | Smn(TYPE) | S(m,n) | S(m,n)(TYPE)	Complex 2-port parameters. Where:
	▪ m = 1 or 2
	▪ n = 1 or 2
	▪ TYPE = R, I, M, P, PD, D, DB, or DBM
	R = real
	I = imaginary
	M = magnitude
	P = PD = phase in degrees
	D = DB = decibels
	DBM = decibels per 1.0e-3

Parameter	Description
... small signal 2-port noise parameters ...	G_AS | NF | RN | YOPT | GAMMA_OPT | NFMIN | VN2 | ZCOR | GN | RHON | YCOR | ZOPT | IN2 For a description of these parameters, see Linear Network Parameter Analysis in the *HSPICE Simulation and Analysis User Guide*.

Output Data Files

An HBLSP analysis produces these output data files:

- The large-signal S parameters from the `.PRINT` statement are written to a .printls# file.
- The small-signal S parameters from the `.PRINT` statement are written to a .printss# file.
- The large-signal S parameters from the `.PROBE` statement are written to a .ls# file.
- The small-signal S parameters from the `.PROBE` statement are written to a .ss# file.
- The extracted large- and small-signal S and noise parameters are written to a .p2d# file.

The large- and small-signal S parameters from the `.PROBE` statement are viewable in CosmosScope.

11

Harmonic Balance-Based AC and Noise Analyses

Describes how to use harmonic balance-based AC analysis as well as nonlinear, steady-state noise analysis.

Multitone Harmonic Balance AC Analysis (.HBAC)

You use the `.HBAC` (Harmonic Balance AC) statement for analyzing linear behavior in large-signal periodic systems. The `.HBAC` statement uses a periodic AC (PAC) algorithm to perform linear analysis of autonomous (oscillator) or nonautonomous (driven) circuits, where the linear coefficients are modulated by a periodic, steady-state signal.

Multitone HBAC analysis extends single-tone HBAC to quasi-periodic systems with more than one periodic, steady-state tone. One application of multitone HBAC is to more efficiently determine mixer conversion gain under the influence of a strong interfering signal than is possible by running a swept three-tone HB simulation.

Prerequisites and Limitations

The following prerequisites and limitations apply to HBAC:

- Requires one and only one `.HBAC` statement. If you use multiple `.HBAC` statements, HSPICE RF uses only the last `.HBAC` statement.
- Requires one and only one `.HB` statement.
- Supports arbitrary number of tones.
- Requires placing the parameter sweep in the `.HB` statement.
- Requires at least one HB source.
- Requires at least one HBAC source.

- Supports unlimited number of HB and HBAC sources.
- The requested maximum harmonic in a `.PROBE` or `.PRINT` statement must be less than or equal to half the number of harmonics specified in harmonic balance (that is, max_harm <= num_hb_harms / 2).

Input Syntax

```
.HBAC <frequency_sweep>
```

Parameter	Description
frequency_sweep	Frequency sweep range for the input signal (also referred to as the input frequency band (IFB) or fin). You can specify LIN, DEC, OCT, POI, or SWEEPBLOCK. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ■ LIN *nsteps start stop* ■ DEC *nsteps start stop* ■ OCT *nsteps start stop* ■ POI *nsteps freq_values* ■ SWEEPBLOCK *nsteps freq1 freq2 ... freqn* ■ DATA=*dataname*

HBAC Analysis Options

The following options directly relate to a HBAC analysis and override the corresponding PAC options if specified in the netlist:

- `.OPTION HBACTOL`, default = 1x10-8, Range = 1x10-14 to Infinity
- `.OPTION HBACKRYLOVDIM`, default = 300, Range = 1 to Infinity
- `.OPTION HBACKRYLOVITR`, default = 1000, Range = 1 to Infinity

If these parameters are not specified in the netlist, then the following conditions apply:

- If `HBACTOL` > `HBTOL`, then `HBACTOL` = `HBTOL`
- If `HBACKRYLOVDIM` < `HBKRYLOVDIM`, then `HBACKRYLOVDIM` = `HBKRYLOVDIM`

Output Syntax

This section describes the syntax for the HBAC `.PRINT` and `.PROBE` statements. These statements are similar to those used for HB analysis.

.PRINT and .PROBE Statements

```
.PRINT HB TYPE(NODES | ELEM)[INDICES]
.PROBE HB TYPE(NODES | ELEM)[INDICES]
```

Parameter	Description
TYPE	Specifies a harmonic type node or element. TYPE can be one of the following: ■ Voltage type – V = voltage magnitude and phase in degrees VR = real component VI = imaginary component VM = magnitude VP - Phase in degrees VPD - Phase in degrees VPR - Phase in radians VDB - dB units VDBM - dB relative to 1 mV ■ Current type – I = current magnitude and phase in degrees IR = real component II = imaginary component IM = magnitude IP - Phase in degrees IPD - Phase in degrees IPR - Phase in radians IDB - dB units IDBM - dB relative to 1 mV ■ Power type – P ■ Frequency type – hertz[index], hertz[index1, index2, ...] You must specify the harmonic index for the hertz variable. The frequency of the specified harmonics is dumped.

Parameter	Description
NODES | ELEM	NODES or ELEM can be one of the following: ■ Voltage type – a single node name (n1), or a pair of node names, (n1,n2) ■ Current type – an element name (elemname) ■ Power type – a resistor (resistorname) or port (portname) element name ■ Frequency type – the harmonic index for the hertz variable. The frequency of the specified harmonics is dumped.
INDICES	Index to tones in the form [n1, n2, ..., nK, +/-1]. ■ nj is the index of the j-th HB tone and the .HB statement contains K tones ■ +/-1 is the index of the HBAC tone Wildcards are not supported if this parameter is used. You can transform HB data into the time domain and output by using the following syntax:.PRINT HBTRAN ov1 [ov2 ... ovN].PROBE HBTRAN ov1 [ov2 ... ovN]. See TYPE above for voltage and current type definitions.

Output Data Files

An HBAC analysis produces these output data files:

- Output from the `.PRINT` statement is written to a .printhb# file. This data is against the IFB points.
  - The header contains the large-signal fundamental and the range of small-signal frequencies.
  - The columns of data are labeled as F(Hz), followed by the output variable names. Each variable name has the associated mixing pair value appended.

    All *N* variable names and all *M* mixing pair values are printed for each swept small-signal frequency value (a total of N*M for each frequency value).
- Output from the `.PROBE` statement is written to a .hb# file. This data is against the IFB points.

- Reported performance log statistics are written to a .lis file:
  - Number of nodes
  - Number of FFT points
  - Number of equations
  - Memory in use
  - CPU time
  - Maximum Krylov iterations
  - Maximum Krylov dimension
  - Target GMRES residual
  - GMRES residual
  - Actual Krylov iterations taken
  - Frequency (swept input frequency values).

Errors and Warnings

The following error and warning messages are used when HSPICE encounters a problem with a HBAC analysis.

Error Messages

HBAC frequency sweep includes negative frequencies. HBAC allows only frequencies that are greater than or equal to zero.

No HB statement is specified (error at parser). HBAC requires an HB statement to generate the steady-state solution.

Warning Messages

More than one HBAC statement (warning at parser). HSPICE RF uses only the last HBAC statement in the netlist.

No HBAC sources are specified (error at parser). HBAC requires at least one HBAC source.

GMRES Convergence Failure. When GMRES (Generalized Minimum Residual) reaches the maximum number of iterations and the residual is greater than the specified tolerance. The HBAC analysis generates a warning and then continue as if the data were valid. This warning reports the following information:

- Final GMRES Residual
- Target GMRES Residual
- Maximum Krylov Iterations
- Actual Krylov Iterations taken

Multitone Nonlinear Steady-State Analysis (.HBNOISE)

An HBNOISE (Harmonic Balance noise) analysis simulates the noise behavior in periodic systems. It uses a Periodic AC (PAC) algorithm to perform noise analysis of nonautonomous (driven) circuits under periodic, steady-state tone conditions. This can be extended to quasi-periodic systems having more than one periodic, steady-state tone. One application for a multitone HBNOISE analysis is determining mixer noise figures under the influence of a strong interfering signal.

The PAC method simulates noise assuming that the stationary noise sources and/or the transfer function from the noise source to a specific output are periodically modulated.

- The modulated noise source (thermal, shot, or flicker) is modeled as a cyclostationary noise source.
- A PAC algorithm solves the modulated transfer function.
- You can also use the HBNOISE PAC method with correlated noise sources, including the MOSFET level 9 and level 11 models, and the behavioral noise source in the G Element (Voltage Dependent Current Source).

You use the `.HBNOISE` statement to perform a Periodic Noise Analysis.

Supported Features

HBNOISE supports the following features:

- All existing HSPICE RF noise model.
- Uses more than one single-tone, harmonic balance to generate the steady-state solution.

- Unlimited number of HB sources (using the same tone, possibly multiple harmonics).
- Includes stationary, cyclostationary, frequency-dependent, and correlated noise effects.
- Swept parameter analysis.
- Results are independent of the number of HBAC sources in the netlist.

Prerequisites and Limitations

The following prerequisites and limitations apply to HBNOISE:

- Requires one `.HB` statement (which determines the steady-state solution).
- Requires at least one HB source.
- Requires placing the parameter sweep in the `.HB` statement.
- The requested maximum harmonic in `.HBNOISE` must be less than or equal to half the number of harmonics used in harmonic balance (that is, *max_harm* <= *num_hb_harms*/2).

Input Syntax

```
.HBNOISE [output] [insrc] [parameter_sweep]
+ <[n1, n2, ..., nk,+/-1]>
+ <listfreq=(frequencies|none|all)> <listcount=val>
+ <listfloor=val> <listsources=on|off>
```

Parameter	Description
output	Output node, pair of nodes, or 2-terminal element. HSPICE RF references equivalent noise output to this node (or pair of nodes). Specify a pair of nodes as V(n+,n-). If you specify only one node, V(n+), then HSPICE RF assumes that the second node is ground. You can also specify a 2-terminal element name that refers to an existing element in the netlist.
insrc	An input source. If this is a resistor, HSPICE RF uses it as a reference noise source to determine the noise figure. If the resistance value is 0, the result is an infinite noise figure.

Parameter	Description
parameter_sweep	Frequency sweep range for the input signal. Also referred to as the input frequency band (IFB) or *fin*). You can specify LIN, DEC, OCT, POI, SWEEPBLOCK, DATA, MONTE, or OPTIMIZE sweeps. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ■ LIN *nsteps start stop* ■ DEC *nsteps start stop* ■ OCT *nsteps start stop* ■ POI *nsteps freq_values* ■ SWEEPBLOCK *nsteps freq1 freq2 ... freqn*
n1,n2,...,nk, +/-1	Index term defining the output frequency band (OFB or *fout*) at which the noise is evaluated. Generally, fout=ABS(n1*f+n2*f2+...+nk*fk+/-fin) Where: ■ f1,f2,...,fk are the first through k-th steady-state tones determined from the harmonic balance solution ■ n1,n2,...,nk are the associated harmonic multipliers ■ fin is the IFB defined by *parameter_sweep*. The default index term is [1,1,...1,-1]. For a single tone analysis, the default mode is consistent with simulating a low-side, down conversion mixer where the RF signal is specified by the IFB and the noise is measured at a down-converted frequency that the OFB specifies. In general, you can use the [n1,n2,...,nk,+/-1] index term to specify an arbitrary offset. The noise figure measurement is also dependent on this index term.

listfreq	Prints the element noise value to the .lis file. You can specify at which frequencies the element noise value is printed. The frequencies must match the sweep_frequency values defined in the *parameter_sweep*, otherwise they are ignored.
	In the element noise output, the elements that contribute the largest noise are printed first. The frequency values can be specified with the NONE or ALL keyword, which either prints no frequencies or every frequency defined in *parameter_sweep*. Frequency values must be enclosed in parentheses. For example:`listfreq=(none)`
	`listfreq=(all)`
	`listfreq=(1.0G)`
	`listfreq=(1.0G, 2.0G)` The default value is NONE.

Parameter	Description
listcount	Prints the element noise value to the .lis file, which is sorted from the largest to smallest value. You do not need to print every noise element; instead, you can define `listcount` to print the number of element noise frequencies. For example, `listcount=5` means that only the top 5 noise contributors are printed. The default value is 1.
listfloor	Prints the element noise value to the .lis file and defines a minimum meaningful noise value (in V/Hz$^{1/2}$ units). Only those elements with noise values larger than `listfloor` are printed. The default value is 1.0e-14 V/Hz$^{1/2}$.
listsources	Prints the element noise value to the .lis file when the element has multiple noise sources, such as a FET, which contains the thermal, shot, and 1/f noise sources. You can specify either ON or OFF: ON Prints the contribution from each noise source and OFF does not. The default value is OFF.

Output Syntax

This section describes the syntax for the HBNOISE `.PRINT` and `.PROBE` statements.

.PRINT and .PROBE Statements

```
.PRINT HBNOISE <ONOISE> <NF> <SSNF> <DSNF>
.PROBE HBNOISE <ONOISE> <NF> <SSNF> <DSNF>
```

Parameter	Description
ONOISE	Outputs the voltage noise at the output frequency band (OFB) across the output nodes in the .HBNOISE statement. The data is plotted as a function of the input frequency band (IFB) points. Units are in V/Hz$^{1/2}$. Simulation ignores ONOISE when applied to autonomous circuits.

Parameter	Description
NF SSNF	NF and SSNF both output a single-side band noise figure as a function of the IFB points: NF = SSNF = 10 Log(SSF) Single side-band noise factor, SSF = {(Total Noise at output, at OFB, originating from all frequencies) - (Load Noise originating from OFB)} / (Input Source Noise originating from IFB).
DSNF	DSNF outputs a double side-band noise figure as a function of the IFB points. DSNF = 10 Log(DSF) Double side-band noise factor, DSF = {(Total Noise at output, at the OFB, originating from all frequencies) - (Load Noise originating from the OFB)} / (Input Source Noise originating from the IFB and from the image of IFB).

Output Data Files

An HBNOISE analysis produces these output data files:

- Output from the `.PRINT` statement is written to a .printpn# file.
- Output from the `.PROBE` statement is written to a .pn# file.

  Both the *.printpn# and *.pn# files output data against the input frequency band points.
- Standard output information is written to a .lis file:
  - simulation time
  - HBNOISE linear solver method
  - HBNOISE simulation time
  - total simulation time

Measuring HBNOISE Analyses with .MEASURE

Note:

A `.MEASURE HBNOISE` statement cannot contain an expression that uses a `HBNOISE` variable as an argument. Also, you cannot use a `.MEASURE HBNOISE` statement for error measurement and expression evaluation of `HBNOISE`.

The `.MEASURE HBNOISE` syntax supports four types of measurements:

- Find-when

```
.MEASURE HBNOISE result FIND out_var1
+ At = Input_Frequency_Band value
```

  The previous measurement yields the result of a variable value at a specific IFB point.

```
.MEASURE HBNOISE result FIND out_var1
+ WHEN out_var2 = out_var3
```

  The previous measurement yields the result at the input frequency point when *out_var2* == *out_var3*.

```
.MEASURE HBNOISE result WHEN out_var2 = out_var3
```

  The previous measurement yields the input frequency point when *out_var2* == *out_var3*.

- Average, RMS, min, max, and peak-to-peak

```
.MEASURE HBNOISE result <RMS> out_var < FROM = IFB1 >
+ < TO = IFB2 >
```

- Integral evaluation

```
.MEASURE HBNOISE result INTEGRAL out_var
+ < FROM = IFB1 > < TO = IFB2 >
```

  This measurement integrates the *out_var* value from the IFB1 frequency to the IFB2 frequency.

- Derivative evaluation

```
.MEASURE HBNOISE result DERIVATIVE out_var AT = IFB1
```

  This measurement finds the derivative of *out_var* at the IFB1 frequency point.

Note:

> `.MEASURE HBNOISE` cannot contain an expression that uses an *hbnoise* variable as an argument. You also cannot use `.MEASURE HBNOISE` for error measurement and expression evaluation of `HBNOISE`.

The HSPICE RF optimization flow can read the measured data from a `.MEASURE HBNOISE` analysis. This flow can be combined in the HSPICE RF optimization routine with a `.MEASURE HBTR` analysis (see Using .MEASURE with .HB Analyses on page 219) and a `.MEASURE PHASENOISE` analysis (see Measuring PHASENOISE Analyses with .MEASURE on page 239).

Errors and Warnings

HBNOISE Errors

See the list of HBAC Errors and Warnings on page 257.

Example

This example performs an HB analysis, then runs an HBNOISE analysis over a range of frequencies, from 9.0e8 to 8.8e8 Hz. Simulation outputs the output noise at V(out) and the single side-band noise figure versus IFB, from 1e8 to 1.2e8 Hz, to the *.pn0 file. The netlist for this example is shown immediately following.

```
.hb tones=1e9 nharms=16
.hbnoise V(out) Rin lin 10 1e8 1.2e8
.probe hbnoise onoise nf

$$*-Ideal mixer + noise source
$ prints total noise at the output (2.47e-20 V^2/Hz),
$ single-sideband noise figure, (3.01 dB)
$ double-sideband noise figure. (0 dB)
.OPTION PROBE
.OPTION POST=2
vlo lo 0 0.0 hb 1.0 0 1 1$ Periodic, HB Input
Ilo lo 0 0
rsrc rfin rf1 1.0$ Noise source
g1 0 if cur='1.0*v(lo)*v(rfin)'  $ mixer element
rout if 0 1.0
vrf rf1 0 $ hbac 2.0 0.0
.hb tones=1.0g nharms=4 $ sweep mval 1 2 1
.HBNOISE rout rsrc lin 11 0.90g 0.92g
.print HBNOISE onoise ssnf dsnf
.end
```

Frequency Translation S-Parameter (HBLIN) Extraction

Frequency translation scattering parameter (S-parameter) extraction is used to describe N-port circuits that exhibit frequency translation effects, such as mixers. The analysis is similar to the existing LIN analysis, except that the circuit is first linearized about a periodically varying operating point instead of a simple DC operating point. After the linearization, the S-parameters between circuit ports that convert signals from one frequency band to another are calculated.

You use the `.HBLIN` statement to extract frequency translation S-parameters and noise figures.

Frequency translation S-parameter describes the capability of a periodically linear time varying systems to shift signals in frequency. The S-parameters for a frequency translation system are similar to the S-parameters of a linear-time-varying system, it is defined as:

$$b = S \cdot a \qquad S_{\mathrm{i,j;m,n}}(w) = \left.\frac{b_{\mathrm{i,m}}(w)}{a_{\mathrm{j,n}}(w)}\right|_{a_{\mathrm{k}\neq j,\, p\neq n}(w) = 0}$$

The incident waves, $a_{i,n}(w)$, and reflected waves, $b_{i,n}(w)$, are defined by using these equations:

$$a_{i,n}(w) = \frac{V_i(w+nw_0) + Z_{0i}I_i(w+nw_0)}{2\sqrt{Z_{0i}}}$$

$$b_{i,n}(w) = \frac{V_i(w+nw_0) - Z_{0i}I_i(w+nw_0)}{2\sqrt{Z_{0i}}}$$

Where,

- w_0 is the fundamental frequency (tone).
- n is a signed integer.
- i is the port number.
- $a_{i,n}(w)$ is the input wave at the frequency $w + nw_0$ on the ith port.
- $b_{i,n}(w)$ is the reflected wave at the frequency $w + nw_0$ on the ith port.

- $V_i(w + nw_0)$ is the Fourier coefficient at the frequency $w + nw_0$ of the voltage at port i.
- $I_i(w + wn_0)$ is the Fourier coefficient at the frequency $w + nw_0$ of the current at port i.
- Z_{0i} is the reference impedance at port i.
- V and I definitions are Fourier coefficients rather than phasors.

For a multi-tone analysis, it can be expressed as:

$$b = S \cdot a \qquad S_{i,j;m_1\ldots m_N,n_1,n_2\ldots n_N}(w) = \left.\frac{b_{i,m_1,m_2\ldots m_N}(w)}{a_{j,n_1,n_2\ldots n_N}(w)}\right|_{a_{k,p_1,p_2\ldots p_N|k \neq j, \nabla p_q \neq n_q}(w) = 0}$$

$$a_{i,n_1,n_2\ldots n_N}(w) = \frac{V_i\left(w + \sum_{j=1}^{N} n_j w_j\right) + Z_{0i} I_i\left(w + \sum_{j=1}^{N} n_j w_j\right)}{2\sqrt{Z_{oi}}}$$

$$b_{i,n_1,n_2\ldots n_N}(w) = \frac{V_i\left(w + \sum_{j=1}^{N} n_j w_j\right) - Z_{0i} I_i\left(w + \sum_{j=1}^{N} n_j w_j\right)}{2\sqrt{Z_{oi}}}$$

Where,

- w_j is the ith tone.

The frequency translate S-parameters are calculated by applying different $n_j(j = 1 \sim N)$ to different ports.

Limitations

The HBLIN analysis has these known limitations:

- Noise parameters are not calculated for mixed-mode operation.
- Only the S-parameters corresponding to the set of frequencies specified at each port are extracted.

- Multiple small-signal tones are not supported.
- The port (P) element impedance cannot be specified as complex.

HB Analysis

An HB analysis is required prior to an HBLIN analysis. To extract the frequency translation S-parameters, a sweep of the small-signal tone is necessary. You can identify the small-signal tone sweep in the `.HBLIN` command or in the `.HB` command together with a `SS_TONE` specification.

For additional information regarding HB analysis, see Harmonic Balance Analysis on page 206.

Port Element

You must use a port (P) element as the termination at each port of the system. To indicate the frequency band that the S-parameters are extracted from, it is necessary to specify a harmonic index for each P element.

Port Element Syntax

Without `SS_TONE`

```
Pxxx p n <n_ref> <PORT=portnumber >
+ <HBLIN = [H1, H2, ... HN, +/-1]> ...
```

With `SS_TONE`

```
Pxxx p n <n_ref> <PORT=portnumber >
+ <HBLIN = [H1, H2, ... +/-1 ... HN]> ...
```

Parameter	Description
n_ref	Reference node used when a mixed-mode port is specified.
PORT	The port number. Numbered sequentially beginning with 1 with no shared port numbers.
HBLIN	Integer vector that specifies the harmonic index corresponding to the tones defined in the .HB command. The +/-1 term corresponds to the small-signal tone specified by SS_TONE in the .HB command. If there is no SS_TONE in the .HB command, the +/-1 term must be at the last entry of HBLIN vector.

HBLIN Analysis

You use the `.HBLIN` statement to extract frequency translation S-parameters and noise figures.

Input Syntax

Without `SS_TONE`

```
.HBLIN <frequency_sweep>
+ <NOISECALC = [1|0|yes|no]> <FILENAME=file_name>
+ <DATAFORMAT = [ri|ma|db]>
+ <MIXEDMODE2PORT = [dd|cc|cd|dc|sd|sc|cs|ds]>
```

With `SS_TONE`

```
.HBLIN <NOISECALC = [1|0|yes|no]> <FILENAME=file_name>
+ <DATAFORMAT = [ri|ma|db]>
+ <MIXEDMODE2PORT = [dd|cc|cd|dc|sd|sc|cs|ds]>
```

Parameter	Description
frequency_sweep	Frequency sweep range for the input signal (also referred to as the input frequency band (IFB) or fin). You can specify LIN, DEC, OCT, POI, or SWEEPBLOCK. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ▪ LIN *nsteps start stop* ▪ DEC *nsteps start stop* ▪ OCT *nsteps start stop* ▪ POI *nsteps freq_values* ▪ SWEEPBLOCK *nsteps freq1 freq2 ... freqn* ▪ DATA=*dataname*
NOISECALC	Enables calculating the noise figure. The default is no (0).
FILENAME	Specifies the output file name for the extracted S-parameters or the object name after the -o command-line option. The default is the netlist file name.

Parameter	Description
DATAFORMAT	Specifies the format of the output data file. ▪ dataformat=RI, real-imaginary. ▪ dataformat=MA, magnitude-phase. This is the default format for Touchstone files. ▪ dataformat=DB, DB(magnitude)-phase.
MIXEDMODE2PORT	Describes the mixed-mode data map of output mixed mode S parameter matrix. The availability and default value for this keyword depends on the first two port (P element) configuration as follows: ▪ case 1: p1=p2=single-ended (standard-mode P element) available: ss default: ss ▪ case 2: p1=p2=balanced (mixed-mode P element) available: dd, cd, dc, cc default: dd ▪ case 3: p1=balanced p2=single-ended available: ds, cs default: ds ▪ case 4: p1=single p2=balanced available: sd, sc default: sd

Example 1

Single-tone analysis with frequency translation. In this example, the 2-port S-parameters from RF (1G-del_f) to IF (del_f) are extracted. The LO signal is specified by normal voltage source Vlo. The frequency on port 1 is in the RF band, 1G-del_f, and the frequency on port 2 is in the IF band, del_f. The IF band is swept from 0- to 100-MHz. The results are output to file ex1.s2p.

```
p1 RFin gnd port=1 HBLIN=(1,-1)
p2 IFout gnd port=2 HBLIN=(0,1)
Vlo LOin gnd DC 0 HB 2.5 0 1 1
.HB tones=1G harms=5
.HBLIN lin 5 0 100meg noisecalc=no filename=ex1
+ dataformat=ma
```

Example 2

Another single-tone analysis with frequency translation example. In this example, the 3-port S-parameters are extracted. Port 3 provides the periodic large signal. The frequency on port 1 is del_f, the frequency on port 2 is 1G*2-del_f, and the frequency on port 3 is 1G*1+del_f. The small-signal frequency is swept from 0 to 100MHz. HBNOISE calculation is required. The results are output to file ex2.s3p.

```
p1 1 0 port=1 HBLIN=(0, 1)
p2 2 0 port=2 HBLIN=(2, -1)
p3 3 0 port=3 hb 0.5 0 1 1 HBLIN=(1, 1)
.HB tones=1G harms=5
.HBLIN lin 5 0 100meg noisecalc=yes filename=ex2
```

Output Syntax

This section describes the syntax for the `HBLIN .PRINT` and `.PROBE` statements.

.PRINT and .PROBE Statements

```
.PRINT HBLIN Smn | Smn(TYPE) | S(m,n) | S(m,n)(TYPE)
.PROBE HBLIN Smn | Smn(TYPE) | S(m, n) | S(m, n)(TYPE)
.PRINT HBLIN SXYmn | SXYmn(TYPE) | SXY(m,n) | SXY(m,n)(TYPE)
.PROBE HBLIN SXYmn | SXYmn(TYPE) | SXY(m, n) | SXY(m, n)(TYPE)
.PRINT HBLIN <NF> <SSNF> <DSNF>
.PROBE HBLIN <NF> <SSNF> <DSNF>
```

Parameter	Description

Smn | Smn(TYPE) | S(m,n) | S(m,n)(TYPE) SXYmn | SXYmn(TYPE) | SXY(m,n) | SXY(m,n)(TYPE)	Complex 2-port parameters. Where:
	▪ m = 1 or 2
	▪ n = 1 or 2
	▪ X and Y are used for mixed-mode S-parameter output. The values for X and Y can be D (differential), C (common), or S (single-end).
	▪ TYPE = R, I, M, P, PD, D, DB, or DBM
	R = real
	I = imaginary
	M = magnitude
	P = PD = phase in degrees
	D = DB = decibels
	DBM = decibels per 1.0e-3

Parameter	Description
NF SSNF	NF and SSNF both output a single-side band noise figure as a function of the IFB points: NF = SSNF = 10 Log(SSF) Single side-band noise factor, SSF = {(Total Noise at output, at OFB, originating from all frequencies) - (Load Noise originating from OFB)} / (Input Source Noise originating from IFB).
DSNF	DSNF outputs a double side-band noise figure as a function of the IFB points. DSNF = 10 Log(DSF) Double side-band noise factor, DSF = {(Total Noise at output, at the OFB, originating from all frequencies) - (Load Noise originating from the OFB)} / (Input Source Noise originating from the IFB and from the image of IFB).

Output Data Files

An HBLIN analysis produces these output data files:

- The S-parameters from the `.PRINT` statement are written to a .printhl# file.
- The extracted S parameters from the `.PROBE` statement are written to a .hl# file.

Computing Transfer Functions (.HBXF)

The `.HBXF` command calculates the transfer function from a given source in the circuit to a designated output. Frequency conversion is calculated from the input frequencies to a single output frequency that is specified with the command. The relationship between the `.HBXF` command and the input/output is expressed in the following equation:

$$Y_m(j\omega_0) = \sum_{\omega \varepsilon W} HBXF_{m,n}(j\omega_0, j(\omega + \Delta\omega)) \cdot X_n(j(\omega + \Delta\omega))$$

Where:

- $HBXF_{m,n}(j\omega_0, j(\omega + \Delta\omega))$ is the transfer function from input port n to the output port m
- W is the set of all possible harmonics
- $\omega + \Delta\omega$ is the input frequency
- $\Delta\omega$ is the offset frequency
- m is the output node number
- n is the input node number
- ω_0 is the output frequency
- Y is the output (voltage or current)
- X is the input (voltage or current)

Supported Features

The `.HBXF` command supports the following features:

- All existing HSPICE RF models and elements
- Sweep parameter analysis
- Unlimited number of HB sources

Prerequisites and Limitations

The following prerequisites and limitations apply to the `.HBXF` command:

- Only one `.HBXF` statement is required. If you use multiple `.HBXF` statements, HSPICE RF only uses the last `.HBXF` statement.
- At least one `.HB` statement is required, which determines the steady-state solution.
- Parameter sweeps must be placed in `.HB` statements.

Input Syntax

```
.HBXF out_var <freq_sweep>
```

Parameter	Description
out_var	Specify `i(2`*_port_elem*`)` or `V(`*n1*`<,`*n2*`>)`
freq_sweep	Frequency sweep range for the input signal (also referred to as the input frequency band (IFB or fin)). A sweep of type LIN, DEC, OCT, POI, or SWEEPBLOCK. Specify the nsteps, start, and stop frequencies using the following syntax for each type of sweep: ▪ LIN *nsteps start stop* ▪ DEC *nsteps start stop* ▪ OCT *nsteps start stop* ▪ POI *nsteps freq_values* ▪ SWEEPBLOCK = *BlockName* Specify the frequency sweep range for the output signal. HSPICE RF determines the offset frequency in the input sidebands; for example, f1 = abs(fout - k*f0) s.t. f1<=f0/2 The f0 is the steady-state fundamental tone, and f1 is the input frequency.

Output Syntax

This section describes the syntax for the HBXF `.PRINT` and `.PROBE` statements.

.PRINT and .PROBE Statements

```
.PRINT HBXF TYPE(NODES | ELEM)
.PROBE HBXF TYPE(NODES | ELEM)
```

Parameter	Description
TYPE	TYPE can be one of the following: ■ TFV = existing source ■ TFI = placeholder value for the current source attached to the given node. The transfer function is computed on the output variables and input current or voltage.
NODES | ELEM	NODES or ELEM can be one of the following: ■ Voltage type – a single node name (n1), or a pair of node names, (n1,n2) ■ Current type – an element name (elemname) ■ Power type – a resistor (resistorname) or port (portname) element name.

Output Data Files

An HBXF calculation produces these output data files:

- Output from the `.PRINT` statement is written to a .printxf# file.
  - The output is in ohms, siemens, or undesignated units, and the header in the output file is Z(..). Y(..) or GAIN(..).
- Output from the `.PROBE` statement is written to a .xf# file.
- Reported performance log statistics are written to a .lis file:
  - HBXF CPU time
  - HBXF peak memory usage

Example

Based on the HB analysis, the following example computes the trans-impedance from `isrc` to `v(1)`.

```
.hb tones=1e9 nharms=4
.hbxf  v(1) lin 10 1e8 1.2e8
.print hbxf tfv(isrc)  tfi(n3)
```

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12
Envelope Analysis

Describes how to use envelope simulation.

Envelope Simulation

Envelope simulation combines features of time- and frequency-domain analysis. Harmonic Balance (HB) solves for a static set of phasors for all the circuit state variables, as shown in this equation:

$$v(t) = a_0 + \sum_{i=1}^{N} [a_i cos\, \omega_i t + b_i sin\, \omega_i t]$$

In contrast, envelope analysis finds a dynamic, time-dependent set of phasors, as this equation shows:

$$v(t) = a_0(\hat{t}) + \sum_{i=1}^{N} [a_i(\hat{t}) \cos \omega_i t + b_i(\hat{t}) \sin \omega_i t]$$

Thus, in envelope simulation, each signal is described by the evolving spectrum. Envelope analysis is generally used on circuits excited by signals with significantly different timescales. An HB simulation is performed at each point in time of the slower-moving ($\hat{t}$) timescale. In this way, for example, a 2-tone HB simulation can be converted into a series of related 1-tone simulations where the transient analysis proceeds on the ($\hat{t}$) timescale, and 1-tone HB simulations are performed with the higher frequency tone as the fundamental frequency.

In HSPICE RF, any voltage or current source identified as a HB source either in a V or I element statement, or by an `.OPTION TRANFORHB` command, is used for HB simulations at each point in $\hat{t}$ time. All other sources are associated with the transient timescale. Also, the input waveforms can be represented in the frequency domain as RF carriers modulated by an envelope by identifying a VMRF signal source in a V or I element statement. The amplitude and phase values of the sampled envelope are used as the input signal for HB analysis.

Some typical applications for envelope simulation are amplifier spectral regrowth, adjacent channel power ration (ACPR), and oscillator startup and shutdown analyses.

Envelope Analysis Commands

This section describes those commands specific to envelope analysis. These commands are:

- Standard envelope simulation (`.ENV`)
- Oscillator simulation, both startup and shutdown (`.ENVOSC`)
- Envelope Fast Fourier Transform (`.ENVFFT`)

Nonautonomous Form

```
.ENV TONES=f1<f2...fn> NHARMS=h1<h2...hn>
+ ENV_STEP=tstep ENV_STOP=tstop
```

Parameter	Description
TONES	Carrier frequencies, in hertz.
NHARMS	Number of harmonics.
ENV_STEP	Envelope step size, in seconds.
ENV_STOP	Envelope stop time, in seconds.

Description

You use the `.ENV` command to do standard envelope simulation. The simulation proceeds just as it does in standard transient simulation, starting at `time=0` and continuing until `time=env_stop`. An HB analysis is performed at each step in time. You can use Backward-Euler (BE), trapezoidal (TRAP), or level-2 Gear (GEAR) integration.

Recommended option settings are:

- For BE integration, set `.OPTION SIM_ORDER=1`.
- For TRAP, set `.OPTION SIM_ORDER=2` (default) `METHOD=TRAP` (default).
- For GEAR, set `.OPTION SIM_ORDER=2` (default) `METHOD=GEAR`.

Example

```
.env tones=1e9 nharms=6 env_step=10n env_stop=1u
```

Oscillator Analysis Form

```
.ENVOSC TONE=f1 NHARMS=h1 ENV_STEP=tstep ENV_STOP=tstop
+ PROBENODE=n1,n2,vosc <FSPTS=num, min, max>
```

Parameter	Description
TONE	Carrier frequencies, in hertz.
NHARMS	Number of harmonics.
ENV_STEP	Envelope step size, in seconds.
ENV_STOP	Envelope stop time, in seconds.
PROBENODE	Defines the nodes used for oscillator conditions and the initial probe voltage value.
FSPTS	Specifies the frequency search points used in the initial small-signal frequency search. Usage depends on oscillator type.

Description

You use the `.ENVOSC` command to do envelope simulation for oscillator startup or shutdown.

Oscillator startup or shutdown analysis with this command must be helped along by converting a bias source from a DC description to a PWL description that either:

- Starts at a low value that supports oscillation and ramps up to a final value (startup simulation)
- Starts at the DC value and ramps down to zero (shutdown simulation).

In addition to solving for the state variables at each envelope time point, the `.ENVOSC` command also solves for the frequency. This command is intended to be applied to high-Q oscillators that take a long time to reach steady-state. For these circuits, standard transient analysis is too costly. Low-Q oscillators, such as typical ring oscillators, are more efficiently simulated with standard transient analysis.

Example

```
.envosc tone=250Meg nharms=10 env_step=20n env_stop=10u
+ probenode=v5,0,1.25
```

Fast Fourier Transform Form

```
.ENVFFT <output_var> <NP=value> <FORMAT=keyword>
+ <WINDOW=keyword> <ALFA=value>
```

Parameter	Description
output_var	Any valid output variable.
NP	The number of points to use in the FFT analysis. NP must be a power of 2. If not a power of 2, then it is automatically adjusted to the closest higher number that is a power of 2. The default is 1024.

FORMAT	Specifies the output format:
	NORM= normalized magnitude
	UNORM=unnormalized magnitude (default)

WINDOW	Specifies the window type to use:
	RECT=simple rectangular truncation window (default)
	BART=Bartlett (triangular) window
	HANN=Hanning window
	HAMM=Hamming window
	BLACK=Blackman window
	HARRIS=Blackman-Harris window
	GAUSS=Gaussian window
	KAISER=Kaiser-Bessel window

ALFA	Controls the highest side-lobe level and bandwidth for GAUSS and KAISER windows. The default is 3.0.

Description

You use the `.ENVFFT` command to perform Fast fourier Transform (FFT) on envelope output. This command is similar to the `.FFT` command. The only difference is that transformation is performed on real data with the `.FFT` command, and with the `.ENVFFT` command, the data being transformed is complex. You usually want to do this for a specific harmonic of a voltage, current, or power signal.

Example

```
.envfft v(out)[1]
```

Output Syntax

The results from envelope simulation can be made available through the `.PRINT`, `.PROBE`, and `.MEASURE` commands. This section describes the basic syntax you can use for this purpose.

.PRINT or .PROBE

You can print or probe envelope simulation results by using the following commands:

```
.PRINT ENV ov1 <ov2... >
.PROBE ENV ov1 <ov2... >
```

Where `ov1...` are the output variables to print or probe.

.MEASURE

In HSPICE RF, the independent variable for envelope simulation is the first tone. Otherwise and except for the analysis type, the `.MEASURE` statement syntax is the same as the syntax for HB; for example,

```
.MEASURE ENV result ...
```

Envelope Output Data File Format

The results of envelope simulations are written to *.ev# data files by the `.PROBE` statement. The format of an *.ev# data file is equivalent to an *.hb# data file with the addition of one fundamental parameter sweep that represents the slowly-varying time-envelope variation $\hat{t}$ of the Fourier coefficients and frequencies. You can recognize this swept parameter” in the *.ev# file by the keyword `env_time`.

Each row in the tabulated data of an *.ev# file includes values for identifying frequency information, the complex data for the output variables, and information on the envelope time sweep. For example, the header for a data file dump for output variables v(in) and v(out) that follow a 2-tone envelope analysis, have entries for:

```
hertz  v(in)  v(out)  n0  f0  n1  f1  sweep  env_time  $&%#
```

Which result in data blocks with floating point values following:

```
env_time[0]
f[0]  a[0]{v(in)} b[0] {v(in)} a[0] {v(out)} b[0] {v(out)} n0 f0 n1 f1
f[1]  a[1]{v(in)} b[1] {v(in)} a[1] {v(out)} b[1] {v(out)} n0 f0 n1 f1
...
f[N]  a[N]{v(in)} b[N] {v(in)} a[N] {v(out)} b[N] {v(out)} n0 f0 n1 f1

env_time[1]
f[0]  a[0]{v(in)} b[0] {v(in)} a[0] {v(out)} b[0] {v(out)} n0 f0 n1 f1
f[1]  a[1]{v(in)} b[1] {v(in)} a[1] {v(out)} b[1] {v(out)} n0 f0 n1 f1
...
f[N]  a[N]{v(in)} b[N] {v(in)} a[N] {v(out)} b[N] {v(out)} n0 f0 n1 f1

...

env_time[M-1]
f[0]  a[0]{v(in)} b[0] {v(in)} a[0] {v(out)} b[0] {v(out)} n0 f0 n1 f1
f[1]  a[1]{v(in)} b[1] {v(in)} a[1] {v(out)} b[1] {v(out)} n0 f0 n1 f1
...
f[N]  a[N]{v(in)} b[N] {v(in)} a[N] {v(out)} b[N] {v(out)} n0 f0 n1 f1
```

Where there are M data blocks corresponding to M envelope time points, with each block containing N+1 rows for the frequency data. The units for the `env_time` sweep are seconds.

13

Post-Layout Analysis

Describes the post-layout analysis flow, including post-layout back-annotation, DSPF and SPEF files, linear acceleration, check statements, and power analysis.

Post-Layout Back-Annotation

A traditional, straightforward, “brute-force” flow runs an RC extraction tool that produces a detailed standard parasitic format (DSPF) file. DSPF is the standard format for transferring RC parasitic information. This traditional flow then feeds this DSPF file into the circuit simulation tool for post-layout simulation.

A key problem is that the DSPF file is flat. Accurately simulating a complete design, such as an SRAM or an on-chip cache, is a waste of workstation memory, disc space usage, and simulation runtime. Because this DSPF file is flat, control and analysis are limited.

- How do you set different options for different blocks for better trade-off between speed and accuracy?
- How do you perform a power analysis on a flat netlist to check the power consumption?
- This traditional flow flattens all nodes after extraction so it is more difficult to compare the delay before and after extraction.
- This traditional flow can also stress the limits of an extraction tool so reliability also becomes an issue.

HSPICE RF provides a flow that solves all of these problems.

- Star-RCXT generates a hierarchical Layout Versus Schematic (LVS) ideal netlist, and flat information about RC parasitics in a DSPF or (standard parasitic exchange format (SPEF) file.
- HSPICE RF uses the hybrid flat-hierarchical approach to back-annotate the RC parasitics, from the DSPF or SPEF file, into the hierarchical LVS ideal netlist.

Using the hierarchical LVS ideal netlist cuts simulation runtime and CPU memory usage. Because HSPICE RF uses the hierarchical LVS ideal netlist as the top-level netlist, you can fully control the netlist. For example:

- You can set different modes to different blocks for better accuracy and speed trade-off.
- You can run power analysis, based on the hierarchical LVS ideal netlist, to determine the power consumption of each block. If you use the hierarchical LVS ideal netlist, you can reuse all post-processing statements from the pre-layout simulation for the post-layout simulation. This saves time, and the capacity of the verification tool is not stressed so reliability is higher.

HSPICE RF supports only the XREF:COMPLETE flow and the XREF:NO flow from Star-RCXT. Refer to the *Star-RCXT User Guide* for more information about the XREF flow.

To generate a hierarchical LVS ideal netlist with Star-RCXT, include the following options in the Star-RCXT command file.

```
*** for XREF:NO flow ***
NETLIST_IDEAL_SPICE_FILE: ideal_spice_netlist.sp
NETLIST_IDEAL_SPICE_TYPE: layout
NETLIST_IDEAL_SPICE_HIER:YES

*** for XREF:COMPLETE flow ***
NETLIST_IDEAL_SPICE_FILE: ideal_spice_netlist.sp
NETLIST_IDEAL_SPICE_TYPE: schematic
NETLIST_IDEAL_SPICE_HIER:YES
```

Note:

Before version 2002.2, Star-RCXT used `NETLIST_IDEAL_SPICE_SKIP_CELLS` to generate the hierarchical ideal SPICE netlist. HSPICE RF can still simulate post-layout designs using the brute-force flow, but the post-layout flow is preferable in HSPICE RF.

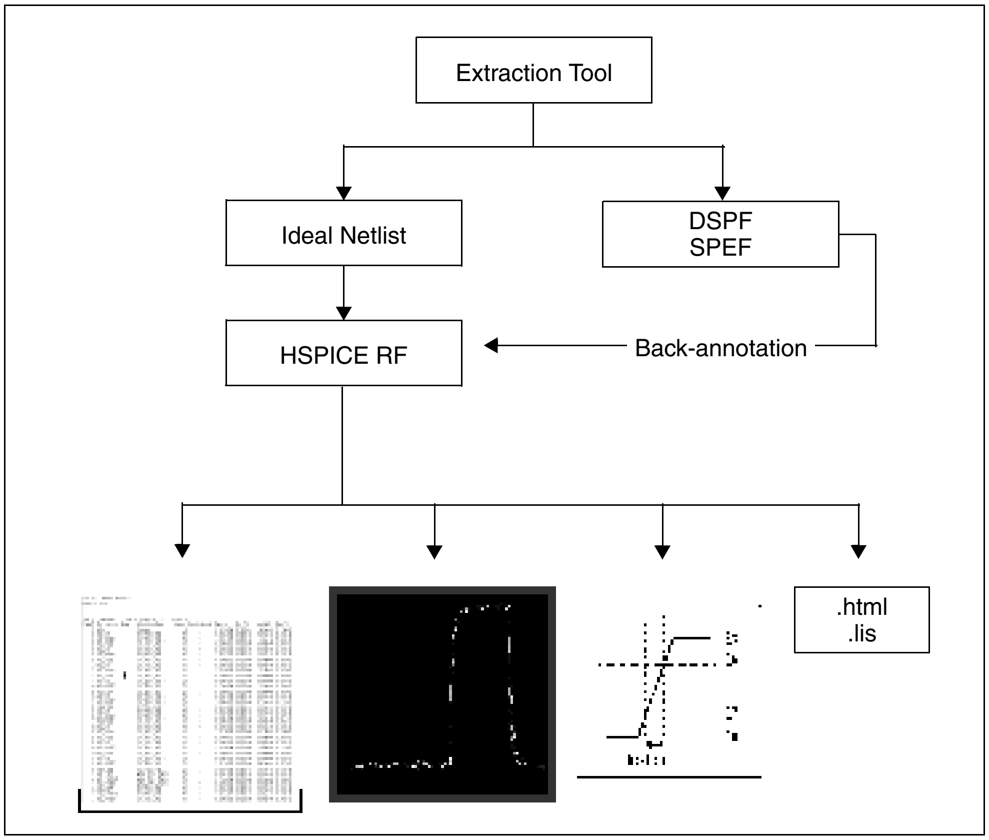
HSPICE RF supports these post-layout flows to address your post-layout simulation needs.

- Standard Post-Layout Flow
- Selective Post-Layout Flow
- Additional Post-Layout Options

Standard Post-Layout Flow

Use this flow mainly for analog or mixed signal design, and high-coverage verification runs when you need to back-annotate RC parasitics into the hierarchical LVS ideal netlist. In this flow, HSPICE RF expands all nets from the DSPF or SPEF file. To expand only selected nets, use see Selective Post-Layout Flow on page 288.

Figure 20 Standard Post-Layout Flow



Standard Post-Layout Flow Control Options

The standard post-layout flow options are `SIM_DSPF` and `SIM_SPEF`. Include one of these options in your netlist. For example,

```
.OPTION SIM_DSPF="[scope] dspf_filename"
.OPTION SIM_SPEF="spec_filename"
```

In the `SIM_DSPF` syntax, `scope` can be a subcircuit definition or an instance. If you do not specify `scope`, it defaults to the top-level definition. HSPICE RF requires both a DSPF file and an ideal netlist. Only flat DSPF files are supported; hierarchy statements, such as `.SUBCKT` and .x1, are ignored.

Very large circuits generate very large DSPF files; this is when using either the `SIM_DSPF` or the `SIM_DSPF_ACTIVE` option can really improve performance.

You can specify a DSPF file in the `SIM_SPEF` option, or a SPEF file in the `SIM_DSPF` option. The `scope` function is not supported in the SPEF format.

For descriptions and usage examples, see .OPTION SIM_DSPF and .OPTION SIM_SPEF in the *HSPICE and HSPICE RF Command Reference*.

Example

```
$  models
.MODEL p pmos
.MODEL n nmos
.INCLUDE add4.dspf
.OPTION SIM_DSPF="add4.dspf"
.VEC "dspf_adder.vec"
.TRAN 1n 5u
vdd vdd 0 3.3
.OPTION POST
.END
```

SIM_DSPF With SIM_LA Option

The `SIM_DSPF` option accelerates the simulation by more than 100%. By using the `SIM_LA` option at the same time, you can further reduce the total CPU time:

```
$  models
.MODEL p pmos
.MODEL n nmos
.INCLUDE add4.dspf
.OPTION SIM_DSPF="add4.dspf"
.OPTION SIM_LA=PACT
.VEC "dspf_adder.vec"
.TRAN 1n 5u
vdd vdd 0 3.3
.OPTION POST
.END
```

To expand only active nodes, such as those that move, include the `SIM_DSPF_ACTIVE` option in your netlist. For example:

```
.OPTION SIM_DSPF_ACTIVE="active_net_filename"
```

This option is most effective when used with a large design—for example, over 5K transistors. Smaller designs lose some of the performance gain, due to internal overhead processing.

For syntax and description of `SIM_DSPF_LA` option, see .OPTION SIM_DSPF_LA in the *HSPICE and HSPICE RF Command Reference*.

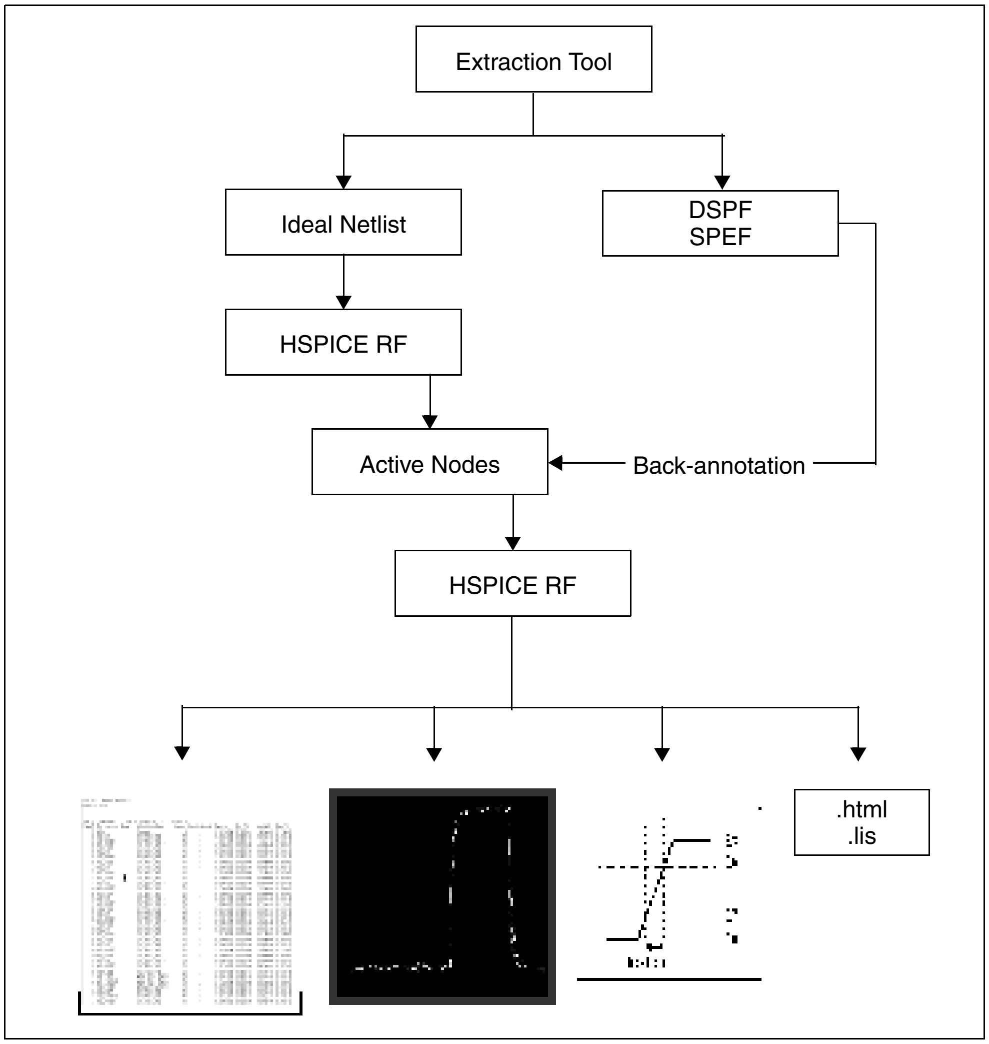
When you have included the appropriate control option, run HSPICE RF, using the ideal netlist.

The structure of a DSPF file is:

```
*|DSPF 1.0
*|DESIGN "demo"
*|Date "October 6, 1998"
...
.SUBCKT < name > < pins >
* Net Section
C1 ...
R1 ...
...
* Instance Section
...
.ENDS
```

Selective Post-Layout Flow

Figure 21 Selective Post-Layout Flow



You can use the selective post-layout flow to simulate a post-layout design for a memory or digital circuit, and for a corner-point verification run. Instead of back-annotating all RC parasitics into the ideal netlist, the selective post-layout flow automatically detects and back-annotates only active parasitics, into the hierarchical LVS ideal netlist. For a high-latency design, the selective post-layout flow is an order of magnitude faster than the standard post-layout flow.

Note:

The selective post-layout flow applies only to RF transient analyses and cannot be used with other analyses such as DC, AC, or HB.

Selective Post-Layout Flow Control Options

To invoke the selective post-layout flow, include one of the options listed in Table 21 in your netlist.

Table 21 Selective Post-Layout Flow Options

Syntax	Description
SIM_DSPF_ACTIVE -or- SIM_SPEF_ACTIVE	HSPICE RF performs a preliminary verification run to determine the activity of the nodes and generates two ASCII files: active_node.rc and active_node.rcxt. These files save all active node information in both Star-RC format and Star-RCXT format. By default, a node is considered active if the voltage varies by more than 0.1V. To change this value, use the SIM_DSPF_VTOL or SIM_SPEF_VTOL option. For descriptions and usage examples, see .OPTION SIM_DSPF_ACTIVE and .OPTION SIM_SPEF_ACTIVE in the *HSPICE and HSPICE RF Command Reference*.
SIM_DSPF_VTOL -or- SIM_SPEF_VTOL	HSPICE RF performs a second simulation run by using the *active_node* file, the DSPF or SPEF file, and the hierarchical LVS ideal netlist to back-annotate only active portions of the circuit. If a net is latent, then HSPICE RF does not expand the net. This saves simulation runtime and memory. ■ *value* is the tolerance of the voltage change. ■ *scopen* can be a subcircuit definition (which has an @ prefix), or a subcircuit instance. By default, HSPICE RF performs only one iteration of the second simulation run. Use the SIM_DSPF_MAX_ITER or SIM_SPEF_MAX_ITER option to change it. For descriptions and usage examples, see .OPTION SIM_DSPF_VTOL and .OPTION SIM_SPEF_VTOL in the *HSPICE and HSPICE RF Command Reference*.

Table 21 Selective Post-Layout Flow Options (Continued)

Syntax	Description
SIM_DSPF_MAX_ITER -or- SIM_SPEF_MAX_ITER	value is the maximum number of iterations for the second simulation run. Some of the latent nets might turn active after the first iteration of the second run. In this case: ▪ Resimulate the netlist to ensure the accuracy of the post-layout simulation. ▪ Use SIM_DSPF_MAX_ITER or SIM_SPEF_MAX_ITER to set the maximum number of iterations for the second run. If the active_node remains the same after the second simulation run, HSPICE RF ignores these options. For descriptions and usage examples, see .OPTION SIM_DSPF_MAX_ITER and .OPTION SIM_SPEF_MAX_ITER in the *HSPICE and HSPICE RF Command Reference*.

Additional Post-Layout Options

Other post-layout options are listed in Table 22.

Table 22 Additional Post-Layout Options

Syntax	Description
SIM_DSPF_RAIL -or- SIM_SPEF_RAIL	By default, HSPICE RF does not back-annotate parasitics of the power-net. To back-annotate power-net parasitics, include one of these options in the netlist. Default=OFF. ON expands nets in a power rail as it expands all nets.
SIM_DSPF_SCALER SIM_SPEF_SCALER -or- SIM_DSPF_SCALEC SIM_SPEF_SCALEC	Scales the resistance or capacitance values. ▪ scaleR is the scale factor for resistance ▪ scaleC is the scale factor for capacitance.

Table 22 Additional Post-Layout Options (Continued)

Syntax	Description
SIM_DSPF_LUMPCAPS -or- SIM_SPEF_LUMPCAPS	If HSPICE RF cannot back-annotate an instance in a net because one or more instances are missing in the hierarchical LVS ideal netlist, then by default HSPICE RF does not evaluate the net. Instead of ignoring all parasitic information for this net, HSPICE RF includes these options to connect a lumped capacitor with a value equal to the net capacitance to this net. Default = ON adds lumped capacitance; ignores other net contents.
SIM_DSPF_INSERROR -or- SIM_SPEF_INSERROR	HSPICE RF supports options to skip the unmatched instance, and continue the evaluation of the next instance. The default is OFF. ON skips unmatched instances and continues the evaluation.
SIM_SPEF_PARVALUE	This option affects only values in a SPEF file that have triplet format: *float:float:float*, which this option interprets as *best:average:worst*. In such cases: ■ If SIM_SPEF_PARVALUE=1, HSPICE RF uses best. ■ If SIM_SPEF_PARVALUE=2 (default), HSPICE RF uses average. ■ If SIM_SPEF_PARVALUE=3, HSPICE RF uses worst.

Unsupported SPEF Options

HSPICE RF does not yet support the following IEEE-481 SPEF options:

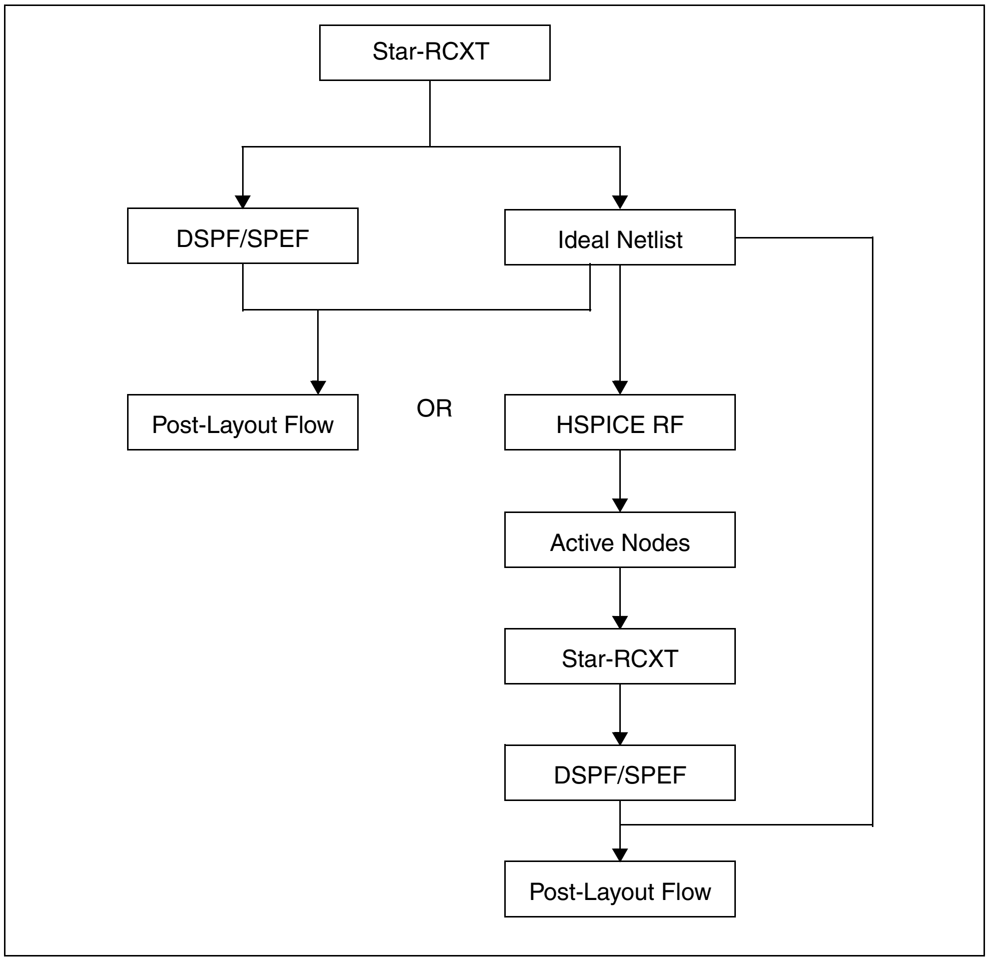
- Hierarchical SPEF definition (multiple SPEF files connected with a hierarchical definition):
- `*DEFINE` and `*PDEFINE`
- `*R_NET` and `*R_PNET` definition
- `*D_PNET` definition.

Selective Extraction Flow

Use the selective extraction flow if disk space is limited. Especially use this option when simulating a full-chip post-layout design, where block latency is high. HSPICE RF feedbacks the active net information to Star-RCXT to extract only the active parasitic.

The major advantage of this flow is a smaller DSPF or SPEF file, which saves disk space.

Figure 22 Selective Extraction Flow



Note:

HSPICE RF generates an active node file in both Star-RC and Star-RCXT format. It then expands the active node file to the Star-RCXT command file to extract only active parasitics.

Overview of DSPF Files

In general, an SPF (Standard Parasitic Format) file describes interconnect delay and loading, due to parasitic resistance and capacitance. DSPF (Detailed Standard Parasitic Format) is a specific type of SPF file that describes the actual parasitic resistance and capacitance components of a net. DSPF is a standard output format commonly used in many parasitic extraction tools, including Star-RCXT. The HSPICE RF circuit simulator can read DSPF files.

DSPF File Structure

The DSPF standard is published by Open Verilog International (OVI). For information about how to obtain the complete DSPF specification, or any other documents from OVI, see:

http://www.ovi.org/document.html

The OVI DSPF specification requires the following file structure in a DSPF file. Parameters in {braces} are optional:

```
DSPF_file : :=

*|DSPF{version}
{*|DESIGN design_name}
{*|DATE date}
{*|VENDOR vendor}
{*|PROGRAM program_name}
{*|VERSION program_version}
{*|DIVIDER divider}
{*|DELIMITER delimiter}

.SUBCKT
   *|GROUND_NET
      {path divider} net_name
   *|NET {path divider} net_name ||
         {path divider} instance_name ||
         pin_name
      net_capacitance

      *|P (pin_name pin_type
         pinCap
            {resistance {unit} {O}
            capacitance {unit} {F}}
         {x_coordinate y_coordinate})

      ||
      *|I {path divider} instance_name
            delimiter pin_name
         {path divider} instance_name
         pin_name pin_type
         pinCap
            {resistance {unit} {O}
            capacitance {unit}{F}}
         {x_coordinate y_coordinate}

      *|S ({path divider} net_name ||
         {path divider} instance_name
            delimiter pin_name ||
         pin_name
         instance_number
         {x_coordinate y_coordinate})
      capacitor_statements
      resistor_statements
   subcircuit_call_statements
.ENDS

{.END}
```

Table 23   DSPF Parameters

Parameter	Definition
*|DSPF	Specifies that the file is in DSPF format.
{version}	Version number of the DSPF specification (optional).
*|	Words that start with *| are keywords.
||	Or (use the option either preceding or following ||). For example, *|P || *|I means you can use either the *|P option or the *|I option.
design_name	Name of your circuit design (optional).
date	Date and time when a parasitic extraction tool (such as Star-RCXT) generated the DSPF file (optional).
vendor	Name of the vendor (such as Synopsys) whose tools you used to generate the DSPF file (optional).
program_name	Name of the program (such as Star-RCXT) that generated the DSPF file (optional).

Table 23 DSPF Parameters (Continued)

Parameter	**Definition**
program_version	Version number of the program that generated the DSPF file (optional).
divider	Character that divides levels of hierarchy in a circuit path (optional). If you do not define this parameter, the default hierarchy divider is a slash (/). For example, X1/X2 indicates that X2 is a subcircuit of the X1 circuit.
delimiter	Character used to separate the name of an instance and a pin in a concatenated instance pin name, or a net name and a sub-node number in a concatenated sub-node name. If you do not define this parameter, the default delimiter is a colon (:).
path	Hierarchical path to a net, instance, or pin, within a circuit.
net_name	Name of a net in a circuit or subcircuit.
instance_name	Name of an instance of a subcircuit.
pin_name	Name of a pin on an instance of a subcircuit.
pinCap	Capacitance of a pin.
pin_type	▪ I (input) ▪ O (output) ▪ B (bidirectional) ▪ X (don’t care) ▪ S (switch) ▪ J (jumper)

Table 23 DSPF Parameters (Continued)

Parameter	Definition
resistance	Resistance on a pin in ohms for input (I), output (O), or bidirectional (B) pins. You can use resistance-capacitance (RC) pairs to model pin characteristics by using a higher-order equivalent RC ladder circuit than a single capacitor model. For example: C0 {R1 C1 R2 C2...}. Attaching RC pairs increases the order of the equivalent circuit from the first (C0) order. For X, S, and J pin types, simulation ignores this generalized capacitance value, but you should insert a 0 value as a place-holder for format integrity. The resistance value can be a real number or an exponent (optionally followed by a real number). You can enter an O (ohms) after the value.
capacitance	Capacitance on a pin in farads for input (I), output (O), or bidirectional (B) pins. Use as part of a resistance-capacitance (RC) pair. Optionally enter an F (farads) after the value.
unit	▪ K (kilo) ▪ M (milli) ▪ U (micro) ▪ N (nano) ▪ P (pico) ▪ F (femto)
x_coordinate	Location of a pin relative to the x (horizontal) axis.
y_coordinate	Location of a pin relative to the y (vertical) axis.
capacitor_ statements	SPICE-type statements that define capacitors in the subcircuit.
resistor_ statements	SPICE-type statements that define resistors in the subcircuit.
subcircuit_call_ statements	Statements that call the subcircuit from higher-level circuits.
.END	Marks the end of the file (optional).

DSPF File Example

```
*|DSPF 1.0
*|DESIGN "my_circuit"
*|DATE June 15, 2002 14:12:43
*|VENDOR "Synopsys"
*|PROGRAM "Star-RC"
*|VERSION "Star-RCXT 2002.2"
*|DIVIDER /
*|DELIMITER :
.SUBCKT BUFFER OUT IN
* Description of Nets
*GROUND_NET VSS
*|NET IN 1.221451PF
*|P(IN 1 0.0 0 10)
*|I(DF1:A DF1 A I 0.0PF 10.0 10.0)
*|I(DF1:B DF1 B I 0.0PF 10 0 20.0)
*|S(IN:1 5.0 10.0)(IN:2 5.0 20.0)
   C1 IN VSS 0.117763PF
   C2 IN:1 VSS 0.276325PF
   C3 IN:2 VSS 0.286325PF
   C4 DF1:A VSS 0.270519PF
   C5 DF1:B VSS 0.270519PF
   R20 IN N:1 1.70333E00
   R21 IN:1 DF1:A 1.29167E-01
   R22 IN:1 IN:2 1.29167E-01
   R23 IN:2 DF1:B 1.70333E-01
*|NET BF 0.287069PF
*|I(DF1:C DF1 C O 0.0PF 12.0 15.0)
*|I(INV1:IN INV1 IN I 0.0PF 30.0 15.0)
   C6 DF1:C VSS 0.208719PF
   C7 INV1:IN VSS 0.783500PF
   R24 DF1:C INV1:IN 1.80833E-01
*|NET OUT 0.148478PF
*|S(OUT:1 45.0 15.0)
*|P(OUT O 0.0PF 50.0 5.0)
*|I(INV1:OUT INV1 OUT O 0.0PF 40.0 15.0)
   C8 INV1:OUT VSS 0.147069PF
   C9 OUT:1 VSS 0.632813PF
   C10 OUT VSS 0.776250PF
   R25 INV1:OUT OUT:1 3.11000E00
   R26 OUT:1 OUT 3.03333E00

* Description of Instances
XDF1 DF1:A DF1:B DF1:C DFF
XINV1 INV1:IN INV1:OUT INV
.ENDS
.END
```

Overview of SPEF Files

The Standard Parasitics Exchange Format (SPEF) file structure is described in IEEE standard *IEEE-1481*. For information about how to obtain the complete SPEC (*IEEE-1481*) specification, or any other documents from IEEE, see:

http://www.ieee.org/products/onlinepubs/stand/standards.html

SPEF File Structure

The IEEE-1481 specification requires the following file structure in a SPEF file. Parameters in [brackets] are optional:

```
SPEF_file : :=

*SPEF version
*DESIGN design_name
*DATE date
*VENDOR vendor
*PROGRAM program_name
*VERSION program_version
*DESIGN_FLOW flow_type {flow_type}
*DIVIDER divider
*DELIMITER delimiter
*BUS_DELIMITER bus_prefix bus_suffix
*T_UNIT time_unit NS|PS
*C_UNIT capacitance_unit FF|PF
*R_UNIT resistance_unit OHM|KOHM
*L_UNIT inductance_unit HENRY|MH|UH

[*NAME_MAP name_index name_id|bit|path|name|physical_ref]
[*POWER_NETS logical_power_net physical_power_net ...]
[*GROUND_NETS ground_net ...]
[*PORTS logical_port I|B|O
   *C coordinate ...
   *L par_value
   *S rising_slew falling_slew [low_threshold high_threshold]
   *D cell_type]
[*PHYSICAL_PORTS [physical_instance delimiter]
   physical_port I|B|O
   *C coordinate ...
   *L par_value
   *S rising_slew falling_slew [low_threshold high_threshold]
   *D cell_type]

[*DEFINE logical_instance design_name |
 *PDEFINE physical_instance design_name]
```

```
*D_NET net_path total_capacitance
   [*V routing_confidence]
   [*CONN
      *P [logical_instance delimiter] logical_port|physical_port
         I|B|O
         *C coordinate ...
         *L par_value
         *S rising_slew falling_slew
            [low_threshold high_threshold]
         *D cell_type
      |
      *I [physical_instance delimiter] logical_pin|physical_node
         I|B|O
         *C coordinate ...
         *L par_value
         *S rising_slew falling_slew
            [low_threshold high_threshold]
         *D cell_type
      *N net_name delimiter net_number coordinate
   [*CAP cap_id node1 [node2] capacitance]
   [*RES res_id node1 node2 resistance]
   [*INDUC induc_id node1 node2 inductance]
*END
```

Table 24 SPEF Parameters

Parameter	Definition
*SPEF	Specifies that the file is in SPEF format.
{version}	Version number of the SPEF specification, such as “IEEE 1481-1998”.
*	Words that start with an asterisk (*) are keywords.
|	Or. For example, NS|PS means choose either nanoseconds or picoseconds as the time units.
design_name	Name of your circuit design.
date	Date and time when a parasitic extraction tool (such as Star-RCXT) generated the SPEF file.
vendor	Name of the vendor (such as Synopsys) whose tools you used to generate the SPEF file (optional).
program_name	Name of the program (such as Star-RCXT) that generated the SPEF file.
program_version	Version number of the program that generated the SPEF file.

Table 24 SPEF Parameters (Continued)

Parameter	Definition
flow_type	One or more of the following flow types: ■ EXTERNAL_LOADS: The SPEF file defines all external loads (if any). If you do not specify this flow type, then some or all external loads are not defined in this SPEF file. If HSPICE RF cannot find external load data outside the SPEF file, it reports an error. ■ EXTERNAL_SLEWS: The SPEF file defines all external slews (if any). If you do not specify this flow type, then some or all external slews are not defined in this SPEF file. If HSPICE RF cannot find external slew data outside the SPEF file, it reports an error. ■ FULL_CONNECTIVITY: A SPEF file defines all net connectivity. If you do not specify this flow type, then some or all net connectivity is not defined in this SPEF file. If HSPICE RF cannot find connectivity data outside the SPEF file, it issues an error. This flow does not look for presence or absence of power and ground nets, or any other nets that do not correspond to the logical netlist. If a SPEC file includes FULL_CONNECTIVITY and MISSING_NETS, HSPICE RF reports an error. ■ MISSING_NETS: If any logical nets are not defined in the netlist, HSPICE RF merges missing parasitic data from another source. If it does not find another source, HSPICE RF rereads the netlist and estimates the missing parasitics. This flow does not look for presence or absence of power and ground nets, or any other nets that do not correspond to the logical netlist. If you use FULL_CONNECTIVITY and MISSING_NETS in the same SPEF file, HSPICE RF reports an error. ■ NETLIST_TYPE_VERILOG, NETLIST_TYPE_VHDL87, NETLIST_TYPE_VHDL93, or NETLIST_TYPE_EDIF: Specifies the type of naming conventions used in the SPEF file. If you specify more than one format in one SPEF file, HSPICE RF reports an error. ■ ROUTING_CONFIDENCE *positive_integer*: Specifies a default routing confidence value for all nets in the SPEF file. ■ ROUTING_CONFIDENCE_ENTRY *positive_integer* character_string: Specifies one or more characters that represent additional routing confidence values, which you can assign to nets in the SPEF file.

Table 24 SPEF Parameters (Continued)

Parameter	Definition
flow_type (continued)	▪ NAME_SCOPE LOCAL|FLAT: Specifies whether paths in the SPEF file are LOCAL (relative to the current SPEF file) or FLAT (relative to the top level of your circuit design). ▪ SLEW_THRESHOLDS low high: Specifies low and high default input slew thresholds for your circuit design as a percentage of the voltage level for the input pin. ▪ PIN_CAP NONE|INPUT_OUTPUT|INPUT_ONLY: Specifies the type of pin capacitance to include when calculating the total capacitance for all nets in the SPEF file, either no capacitance, all input and output capacitances, or only input capacitances.
divider	Character used to divide levels of hierarchy in a circuit path name. Must be one of the following characters: . / : | For example, X1/X2 means that X2 is a subcircuit of the X1 circuit.
delimiter	Character used to separate the name of an instance and a pin in a concatenated instance pin name. Must be one of these characters: . / : |
bus_prefix bus_suffix	Delimiter characters that precede and follow a bus bit or an arrayed instance number. If these characters are not matching pairs, HSPICE RF reports an error. Valid bus delimiter prefix and suffix character pairs are brackets “[ ]”, braces “{ }”, parentheses “( )”, or angle brackets “< >”>
time_unit	A positive number. For example, 10 PS means use time units of 10 picoseconds. 5 NS means use time units of 5 nanoseconds.
capacitance_unit	A positive number. For example, 10 PF means capacitance units of 10 picofarads. 5 FF means use capacitance units of 5 femtoseconds.
resistance_unit	Positive number. For example, 10 OHM sets resistance units to 10 ohms. 5 KOHM sets resistance units to 5 kilo ohms.
inductance_unit	A positive number. For example, 10 HENRY means use inductance units of 10 henries. 5 MH means use inductance units of 5 millihenries. 2 UH means use inductance units of 2 micro-henries.
name_index	Name used throughout a SPEF file. To reduce file space, you can map other names to this name.

Table 24 SPEF Parameters (Continued)

Parameter	Definition
name_id|bit|path|name| physical_ref	A name identifier, bit, path, name, or physical reference to map to the name_index.
logical_power_net	Logical path (or logical path index) to a power net.
physical_power_net	Physical path (or physical path index) to a power net. You can specify multiple *logical_power_net physical_power_net* pairs.
ground_net	Name of a net to use as a ground net. You can specify multiple ground net names.
logical_port	Logical name of an input, output, or bidirectional port.
coordinate	Geometric location of a logical or physical port.
par_value	Either a single float value, or a triplet in float:float:float form.
rising_slew	Rising slew of the waveform for the port. T_UNIT defines the time unit for the waveform.
falling_slew	Rising slew of the waveform for the port. T_UNIT defines the time unit for the waveform.
low_threshold	Low voltage threshold as a percentage of the port's input voltage. Can bed one float value or a triplet in float:float:float form.
high_threshold	High voltage threshold as a percentage of the input voltage for the port. Either a single *float* value or a triplet in *float*:*float*:*float* form.
cell_type	Type of cell that drives the port. If you do not know the cell type, use the reserved word UNKNOWN_DRIVER as the cell type.
physical_port	Physical name of an input, output, or bidirectional port.
logical_instance	Logical name of a subcircuit in your *design_name* circuit design. You can specify more than one logical_instance. Whenever you specify a logical instance name, you must set NAME_SCOPE to FLAT. If you connect a logical net to a physical port, HSPICE RF reports an error.

Table 24 SPEF Parameters (Continued)

Parameter	Definition
physical_instance	Physical name of a subcircuit in your *design_name* circuit design. You can specify more than one physical_instance. Whenever you specify a physical instance name, you must set NAME_SCOPE to FLAT. If you connect a physical net to a logical port, HSPICE RF reports an error.
routing_confidence	One of the following positive integers: ▪ 10: Statistical wire load model. ▪ 20: Physical wire load model. ▪ 30: Physical partitions with locations, no cell placement. ▪ 40: Estimated cell placement with Steiner tree-based route. ▪ 50: Estimated cell placement with global route. ▪ 60: Final cell placement with Steiner route. ▪ 70: Final cell placement with global route. ▪ 80: Final cell placement, final route, 2d extraction. ▪ 90: Final cell placement, final route, 2.5d extraction. ▪ 100: Final cell placement, final route, 3d extraction.
logical_pin	Logical name of a pin.
physical_node	Physical name of a node.
net_name	Name of a net in a circuit or subcircuit.
cap_id	Unique identifier for capacitance between two specific nodes.
res_id	Unique identifier for resistance between two specific nodes.
induc_id	Unique identifier for inductance between two specific nodes.
node1	First of two nodes, between which you are specifying a capacitance, resistance, or inductance value.
node2	Second of two nodes, between which you are specifying a capacitance, resistance, or inductance value. For a capacitance value, if you do not specify a second node name, HSPICE RF assumes that the second node is ground.

Table 24 SPEF Parameters (Continued)

Parameter	Definition
capacitance	Specifies the capacitance value assigned to a *cap_id* identifier. *capacitance_unit* defines the units of capacitance. For example, if you set capacitance to 5 and capacitance_unit to 10 PF, then the actual capacitance value is 50 picoFarads.
resistance	Specifies the resistance value assigned to a *res_id* identifier. *resistance_unit* defines the units of resistance. For example, if you set *resistance* to 5 and *resistance_unit* to 5 KOHM, then the actual resistance value is 25 kilo ohms.
inductance	Specifies the resistance value assigned to an *induc_id* identifier. *inductance_unit* defines the units of inductance. For example, if you set *inductance* to 6 and *inductance_unit* to 2 UH, then the actual inductance value is 12 microhenries.

SPEF File Example

```
*SPEF "IEEE 1481-1998"
*DESIGN   "My_design"
*DATE   "11:26:34 Friday June 28, 2002"
*VENDOR   "Synopsys, Inc."
*PROGRAM   "Star-RCXT"
*VERSION   "2002.2."
*DESIGN_FLOW   "EXTERNAL_LOADS" "EXTERNAL_SLEWS" "MISSING_NETS"
*DIVIDER   /
*DELIMITER   :
*BUS_DELIMITER   [ ]
*T_UNIT   1 NS
*C_UNIT   1 PF
*R_UNIT   1 OHM
*L_UNIT   1 HENRY

*POWER_NETS   VDD
*GND_NETS   VSS

*PORTS
CONTROL O *L 30 *S 0 0
FARLOAD O *L 30 *S 0 0
INVX1FNTC_IN I *L 30 *S 5 5
NEARLOAD O *L 30 *S 0 0
TREE O *L 30 *S 0 0
```

If you use triplet format, the above section would look like this:

```
*PORTS
CONTROL O *L 30:30:30 *S 0:0:0 0:0:0
FARLOAD O *L 30:30:30 *S 0:0:0 0:0:0
INVX1FNTC_IN I *L 30:30:30 *S 5:5:5 5:5:5
NEARLOAD O *L 30:30:30 *S 0:0:0 0:0:0
TREE O *L 30:30:30 *S 0:0:0 0:0:0
```

This triplet formatting principle applies to the rest of this example.

```
*D_NET INVX1FNTC_IN 0.033
*CONN
*P INVX1FNTC_IN I
*I FL_1281:A *L 0.033
*END
*D_NET INVX1FNTC 2.033341

*CONN
*I FL_1281:X O *L 0.0
*I I1184:A I *L 0.343
*I FL_1000:A I *L 0.343
*I NL_1000:A I *L 0.343
*I TR_1000:A I *L 0.343

*CAP
216 FL_1000:A 0.346393
217 I1184:A 0.344053
218 INVX1FNTC_IN 0
219 INVX1FNTC_IN:10 0.154198
220 INVX1FNTC_IN:11 0.117827
221 INVX1FNTC_IN:12 0.463063
222 INVX1FNTC_IN:13 0.0384381
223 INVX1FNTC_IN:14 0.00246845
224 INVX1FNTC_IN:15 0.00350198
225 INVX1FNTC_IN:16 0.00226712
226 INVX1FNTC_IN:17 0.0426184
227 INVX1FNTC_IN:18 0.0209701
228 INVX1FNTC_IN:2 0.0699292
229 INVX1FNTC_IN:20 0.019987
230 INVX1FNTC_IN:21 0.0110279
231 INVX1FNTC_IN:24 0.0192603
232 INVX1FNTC_IN:25 0.0141824
233 INVX1FNTC_IN:3 0.0520437
234 INVX1FNTC_IN:4 0.0527105
235 INVX1FNTC_IN:5 0.1184749
236 INVX1FNTC_IN:6 0.0468458
237 INVX1FNTC_IN:7 0.0391578
238 INVX1FNTC_IN:8 0.0113856
```

```
239 INVX1FNTC_IN:9 0.0142528
240 NL_1000:A 0.344804
241 TR_000:A 0.34506

*RES
152 INVX1FNTC_IN INVX1FNTC_IN:18 8.39117
153 INVX1FNTC_IN INVX1FNTC_IN:5 25.1397
154 INVX1FNTC_IN:11 INVX1FNTC_IN:20 4.59517
155 INVX1FNTC_IN:12 INVX1FNTC_IN:13 3.688
156 INVX1FNTC_IN:13 INVX1FNTC_IN:17 25.102
157 INVX1FNTC_IN:14 INVX1FNTC_IN:16 0.0856444
158 INVX1FNTC_IN:14 NL_1000:A 0.804
159 INVX1FNTC_IN:15 INVX1FNTC_IN:16 1.73764
160 INVX1FNTC_IN:15 INVX1FNTC_IN:24 0.307175
161 INVX1FNTC_IN:17 INVX1FNTC_IN:25 5.65517
162 INVX1FNTC_IN:18 FL_1000:A 1/36317
163 INVX1FNTC_IN:2 INVX1FNTC_IN:4 6.95371
164 INVX1FNTC_IN:2 INVX1FNTC_IN:5 50.9942
165 INVX1FNTC_IN: INVX1FNTC_IN:21 4.71035
166 INVX1FNTC_IN: I1184:A 0.403175
167 INVX1FNTC_IN: TR_1000:A 0.923175
168 INVX1FNTC_IN: INVX1FNTC_IN:12 31.7256
169 INVX1FNTC_IN: INVX1FNTC_IN:4 11.9254
170 INVX1FNTC_IN: INVX1FNTC_IN:7 25.3618
171 INVX1FNTC_IN: INVX1FNTC_IN:6 23.3057
172 INVX1FNTC_IN: INVX1FNTC_IN:24 8.64717
173 INVX1FNTC_IN: INVX1FNTC_IN:8 7.46529
174 INVX1FNTC_IN: INVX1FNTC_IN:10 2.04729
175 INVX1FNTC_IN: INVX1FNTC_IN:10 10.8533
176 INVX1FNTC_IN: INVX1FNTC_IN:11 1.05164

*END

*D_NET NE_794 1.98538

*CONN
*I NL_1039:X O *L 0 *D INVX
*I NL_2039:A I *L 0.343
*I NL_1040:A I *L 0.343

*CAP
3387 NE_794 0
3388 NE_794:1 0.0792492
3389 NE_794:10 0.0789158
3390 NE_794:11 0.0789991
3391 NE_794:12 0.0789991
3392 NE_794:13 0.0792992
3393 NE_794:14 0.00093352
```

```
3394 NE_794:15 0.00063346
3395 NE_794:16 0.0792992
3396 NE_794:17 0.80116
3397 NE_794:18 0.80116
3398 NE_794:19 0.00125452
3399 NE_794:2 0.0789158
3400 NE_794:20 0.00336991
3401 NE_794:21 0.00668512
3402 NE_794:23 0.00294932
3403 NE_794:25 0.00259882
3404 NE_794:26 0.00184653
3405 NE_794:3 0.0789158
3406 NE_794:4 0.0796826
3407 NE_794:5 0.0796826
3408 NE_794:6 0.0789991
3409 NE_794:7 0.0789991
3410 NE_794:8 0.0793992
3411 NE_794:9 0.0789158
3412 NL_1039:X 0.00871972
3413 NL_1040:A 0.344453
3414 NL_2039:A 0.343427

*RES
2879 NE_794:1 NE_794:13 66.1953
2880 NE_794:1 NE_794:2 0.311289
2881 NE_794:11 NE_794:12 0.311289
2882 NE_794:13 NE_794:14 0.353289
2883 NE_794:14 NE_794:19 0.365644
2884 NE_794:15 NE_794:16 0.227289
2885 NE_794:15 NE_794:20 0.239644
2886 NE_794:17 NE_794:18 0.14
2887 NE_794:19 NE_794:21 0.0511746
2888 NE_794:2 NE_794:9 65.9153
2889 NE_794:20 NE_794:23 1.15117
2890 NE_794:21 NL_1039:X 3.01917
2891 NE_794:25 NE_794:26 0.166349
2892 NE_794:26 NL_1040:A 0.651175
2893 NE_794:3 NE_794:10 65.9153
2894 NE_794:3 NE_794:4 0.311289
2895 NE_794:4 NE_794:17 66.5437
2896 NE_794:5 NE_794:18 66.5437
2897 NE_794:5 NE_794:6 0.311289
2898 NE_794:6 NE_794:11 65.98853
2899 NE_794:7 NE_794:12 65.9853
2900 NE_794:7 NE_794:8 0.311289
2901 NE_794:8 NE_794:16 66.3213
2902 NE_794:9 NE_794:10 0.311289
2903 NL_1039:X NE_794:25 1.00317
```

```
2904 NL_2039:A NE_794:23 0.171175

*END
```

Linear Acceleration

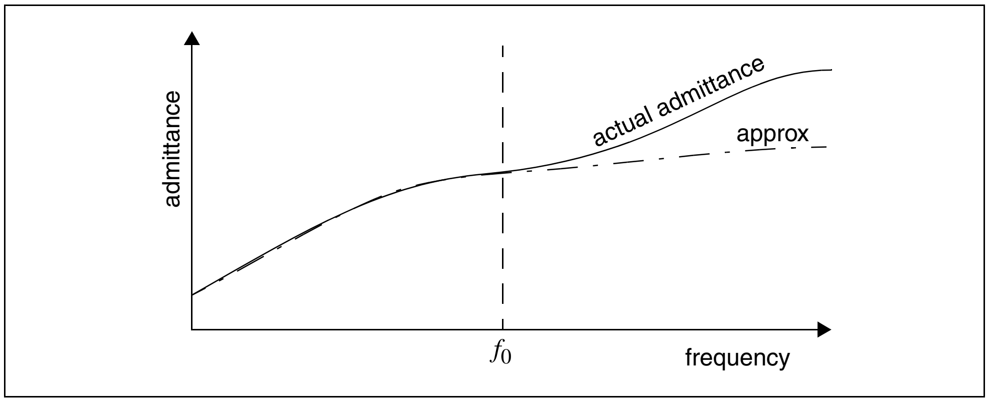
Linear acceleration, by using the `SIM_LA` option, accelerates the simulation of circuits that include large linear RC networks. To achieve this acceleration, HSPICE RF reduces all matrices that represent RC networks. The result is a smaller matrix that maintains the original port behavior, yet achieves significant savings in memory and computation. Thus, the `SIM_LA` option is ideal for circuits with large numbers of resistors and capacitors, such as clock trees, power lines, or substrate networks.

In general, the RC elements are separated into their own network. The nodes shared by both main circuit elements (including `.PRINT`, `.PROBE`, and `.MEASURE` statements), and RC elements. are the port nodes of the RC network,. All other RC nodes are internal nodes. The currents flowing into the port nodes are a frequency-dependent function of the voltages at those nodes.

The multiport admittance of a network represents this relationship.

- The `SIM_LA` option formulates matrices to represent multiport admittance.
- Then, to eliminate as many internal nodes as possible, it reduces the size of these matrices, while preserving the admittance, otherwise known as port node behavior.
- The amount of reduction depends on the *f*0 upper frequency, the threshold frequency where `SIM_LA` preserves the admittance. This is shown graphically in Figure 23.

Figure 23 Multiport Admittance vs. Frequency



The `SIM_LA` option is very effective for post-layout simulation, because of the volume of parasitics. For frequencies below *f*0, the *approx* signal matches that of the original admittance. Above f_0, the two waveforms diverge, but presumably the higher frequencies are not of interest. The lower the *f*0 frequency, the greater the amount of reduction.

For the syntax and description of this control option, see .OPTION SIM_LA in the *HSPICE and HSPICE RF Command Reference*.

You can choose one of two algorithms, explained in the following sections:

- PACT Algorithm
- PI Algorithm

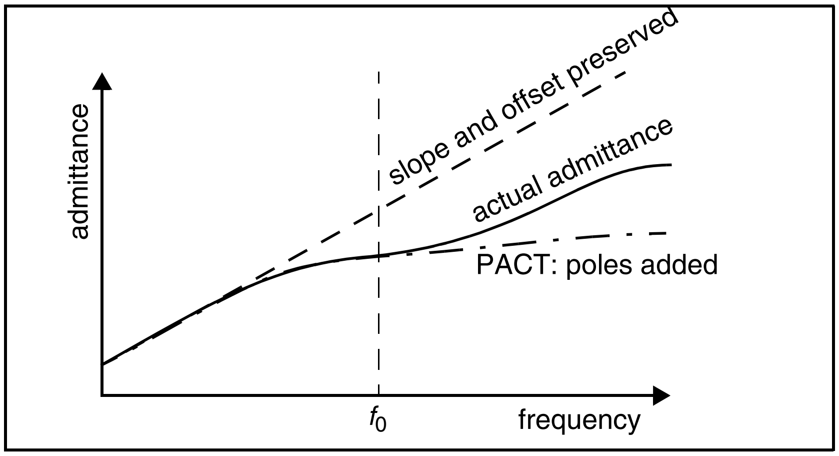
PACT Algorithm

The `PACT` (Pole Analysis via Congruence Transforms) algorithm reduces the RC networks in a well-conditioned manner, while preserving network stability.

- The transform preserves the first two moments of admittance at DC (slope and offset), so that DC behavior is correct (see Figure 24).
- The algorithm preserves enough low-frequency poles from the original network to maintain the circuit behavior up to a specified maximum frequency *f*0, within the specified tolerance.

This approach is the most accurate of the two algorithms, and is the default.

Figure 24 PACT Algorithm



PI Algorithm

This algorithm creates a *pi* model of the RC network.

- For a two-port, the *pi* model reduced network consists of:
  - a resistor connecting the two ports, and
  - a capacitor connecting each port to ground

    The result resembles the Greek letter pi.
- For a general multiport, `SIM_LA` preserves the DC admittance between the ports, and the total capacitance that connects the ports to ground. All floating capacitances are lumped to ground.

Linear Acceleration Control Options Summary

In addition to `.OPTION SIM_LA`, other options are available to control the maximum resistance and minimum capacitance values to preserve, and to limit the operating parameters of the PACT algorithm. Table 25 contains a summary of these control options. For the syntax and descriptions of these control options, see the respective section in the *HSPICE and HSPICE RF Command Reference*.

Table 25 PACT Options

Syntax	**Description**
.OPTION SIM_LA=PACT | PI	Activates linear matrix reduction and selects between four methods. If you set the entire netlist to ANALOG mode, linear matrix reduction does not occur.
.OPTION SIM_LA_FREQ=<value>	Upper frequency where you need accuracy preserved. *value* is the upper frequency for which the PACT algorithm preserves accuracy. If *value* is 0, PACT drops all capacitors, because only DC is of interest. The maximum frequency required for accurate reduction depends on both the technology of the circuit and the time scale of interest. In general, the faster the circuit, the higher the maximum frequency. The default is 1GHz.

Table 25 PACT Options (Continued)

Syntax	Description
.OPTION SIM_LA_MAXR=<value>	Maximum resistance for linear matrix reduction. *value* is the maximum resistance preserved in the reduction. SIM_LA assumes that any resistor greater than *value* has an infinite resistance, and drops the resistor after reduction finishes. The default is 1e15 ohms.
.OPTION SIM_LA_MINC=<value>	Minimum capacitance for linear matrix reduction. *value* is the minimum capacitance preserved in the reduction. After reduction completes, SIM_LA lumps any capacitor smaller than *value* to ground. The default is 1e-16 farads.
.OPTION SIM_LA_MINMODE= ON|OFF	Reduces the number of nodes instead of the number of elements.
.OPTION SIM_LA_TIME=<value>	Minimum time for which accuracy must be preserved. *value* is the minimum switching time for which the PACT algorithm preserves accuracy. HSPICE RF does not accurately represent waveforms that occur more rapidly than this time. SIM_LA_TIME is simply the dual of SIM_LA_FREQ. The default is equivalent to setting LA_FREQ=1 GHz. The default is 1ns.
.OPTION SIM_LA_TOL=<value>	Error tolerance for the PACT algorithm. *value* is the error tolerance for the PACT algorithm, is between 0.0 and 1.0. The default is 0.05.

Example

In this example, the circuit has a typical risetime of 1ns. Set the maximum frequency to 1 GHz, or set the minimum switching time to 1ns.

```
.OPTION SIM_LA_FREQ = 1GHz
-or-
.OPTION SIM_LA_TIME = 1ns
```

However, if spikes occur in 0.1ns, HSPICE will not accurately simulate them. To capture the behavior of the spikes, use:

```
.OPTION SIM_LA_FREQ = 10GHz
-or-
.OPTION SIM_LA_TIME = 0.1ns
```

Note:

Higher frequencies (smaller times) increase accuracy, but only up to the minimum time step used in HSPICE.

14

Using HSPICE with HSPICE RF

Describes how various analysis features differ in HSPICE RF as compared to standard HSPICE.

This first section of this chapter describes topics related to transient analysis and the other section describe other differences between HSPICE and HSPICE RF.

RF Numerical Integration Algorithm Control

In HSPICE RF, you can select either the Backward-Euler or Trapezoidal integration algorithm. Each of these algorithms has its own advantages and disadvantages for specific circuit types. For pre-charging simulation or timing critical simulation, the Trapezoidal algorithm usually improves accuracy.

You use the `SIM_ORDER` option to control the amount of Backward-Euler (BE) to mix with the Trapezoidal (TRAP) method for hybrid integration. For example,

```
.OPTION SIM_ORDER=x
```

Setting `SIM_ORDER` to its lowest value selects Backward-Euler integration algorithm, and setting it to its highest value selects Trapezoidal integration.

For the syntax and description of this control option, see .OPTION SIM_ORDER in the *HSPICE and HSPICE RF Command Reference*.

RF Transient Analysis Accuracy Control

The default time step method in HSPICE RF mixes timestep algorithms Trapezoidal and second-order Gear (Gear-2). This yields a more accurate scheme than Trapezoidal or Backward-Euler. Also, detection of numerical oscillations inserts fewer Backward-Euler steps than in previous HSPICE versions.

.OPTION SIM_ACCURACY

You use the `SIM_ACCURACY` option to modify the size of timesteps in HSPICE RF. For example,

```
.OPTION SIM_ACCURACY=<value>
```

A timestep is a time interval at which you evaluate a signal. HSPICE RF discretely expresses the time continuum as a series of points. At each point or timestep, a circuit simulator evaluates the corresponding voltage or current value of a signal. Thus, a resulting signal waveform is a series of individual data points; connecting these points results in a smooth curve.

You can apply different accuracy settings to different blocks or time intervals. The syntax to set accuracy on a block, instance, or time interval is similar to the settings used for a power supply.

Note:

An `.OPTION SIM_ACCURACY` takes precedence over an `.OPTION ACCURATE`.

For the syntax and description of this control option, see .OPTION SIM_ACCURACY in the *HSPICE and HSPICE RF Command Reference*.

Algorithm Control

In HSPICE RF, you can select the Backward-Euler, Trapezoidal, Gear, or hybrid method algorithms. Each of these algorithms has its own advantages and disadvantages for specific circuit types. These methods have tradeoffs related to accuracy, avoidance of numerical oscillations, and numerical damping of circuit oscillations. For pre-charging simulation or timing critical simulations, the Trapezoidal algorithm usually improves accuracy.

.OPTION METHOD

You use the `METHOD` option to select a numeric integration method for a transient analysis.

HSPICE RF supports three basic timestep algorithms: Trapezoidal (`TRAP`), second-order Gear (Gear-2), and Backward-Euler (BE). Backward-Euler is the same as first-order Gear. Also, HSPICE RF supports a hybrid algorithm (`TRAPGEAR`), which is a mixture of the three basic algorithms.

HSPICE RF contains an algorithm for auto-detection of numerical oscillations commonly encountered with trapezoidal integration. If HSPICE RF detects such oscillations, it inserts BE steps, but not more than one BE step for every 10 time steps. To turn off auto-detection, use the `PURETP` option.

The `TRAPGEAR` method, combining 90% trapezoidal with 10% Gear-2. HSPICE RF inserts BE steps, when the simulator encounters a breakpoint, or when the auto-detection algorithm finds numerical oscillations.

For the syntax and description of this control option, see .OPTION METHOD in the *HSPICE and HSPICE RF Command Reference*.

.OPTION MAXORD

You use the `MAXORD` option to select the maximum order of integration for the `GEAR` method. Either the first-order Gear (Backward-Euler), or the second-order Gear (Gear-2) integration method.

For the syntax and description of this control option, see .OPTION MAXORD in the *HSPICE and HSPICE RF Command Reference*.

.OPTION SIM_ORDER

You use the `SIM_ORDER` option to control the amount of Backward-Euler (BE) to mix with the Trapezoidal method for hybrid integration. This option affects time stepping when you set .OPTION METHOD to `TRAP` or `TRAPGEAR`.

For the syntax and description of this control option, see .OPTION SIM_ORDER in the *HSPICE and HSPICE RF Command Reference*.

.OPTION SIM_TG_THETA

You use the `SIM_TG_THETA` option to control the amount of Gear-2 method to mix with trapezoidal integration for the hybrid `TRAPGEAR` method.

For the syntax and description of this control option, see .OPTION SIM_TG_THETA in the *HSPICE and HSPICE RF Command Reference*.

.OPTION SIM_TRAP

You use the `SIM_TRAP` option to change the default `SIM_TG_THETA` to 0, so that method=trapgear acts like `METHOD=TRAP`.

For the syntax and description of this control option, see .OPTION SIM_TRAP in the *HSPICE and HSPICE RF Command Reference*.

.OPTION PURETP

You use the `PURETP` option to turn off insertion of Backward-Euler (BE) steps due to auto-detection of numerical oscillations.

For the syntax and description of this control option, see .OPTION PURETP in the *HSPICE and HSPICE RF Command Reference*.

.OPTION SIM_OSC_DETECT_TOL

You use the `SIM_OSC_DETECT_TOL` option to specify the tolerance for detecting numerical oscillations. If HSPICE RF detects numerical oscillations, it inserts Backward-Euler (BE) steps. Smaller values of this tolerance result in fewer BE steps.

For the syntax and description of this control option, see .OPTION SIM_OSC_DETECT_TOL in the *HSPICE and HSPICE RF Command Reference*.

RF Transient Analysis Output File Formats

The default output format for transient analysis in HSPICE RF is the same as in HSPICE: the .tr0 file format. See Transient Analysis in the *HSPICE Simulation and Analysis User Guide*. HSPICE RF supports these output formats, which are described in this section:

- Tabulated Data Output
- WDB Output Format
- XP Output Format
- NW Output Format
- VCD Output Format
- turboWave Output Format (tw)

- Undertow Output Format (ut)
- CSDF Output Format

If your netlist includes an unsupported output format, HSPICE RF prints a warning message, indicating that the selected format is unsupported. HSPICE RF then automatically defaults the output to TR0 format.

You can use the waveform viewer to view certain output formats:

- wdb: XP/CosmosScope (Recommended)
- nw: XP/AvanWaves
- xp: XP/AvanWaves/CosmosScope

  Note:

  > If your waveform file is larger than 2GB, use split waveforms.

Tabulated Data Output

HSPICE RF outputs all analog waveforms specified in a `.PRINT` statement. HSPICE RF saves these waveforms as ASCII tabulated data, into a file with the .PRINT extension.

To display waveforms graphically, CosmosScope can directly read the tabulated data. For more information about CosmosScope, see the *CosmosScope User's and Reference*.

Note:

> Tabulated data excludes waveforms specified in `.PROBE` statements.

WDB Output Format

You can use the waveform database (WDB) output format in `.OPTION POST`. It was developed for maximum efficiency. The output file is *.wdb#. For example, to output to a *.wdb# file, enter:

```
.OPTION POST=wdba
```

Signals across multiple hierarchies, that map to the same node, are named together. They also share the same waveform data.

You can also set up the database so that CosmosScope extracts one signal at a time. This means that CosmosScope does not need to read the entire output file to display a single waveform.

The WDB format was designed to make accessing waveform data faster and more efficient. It is a true database so the waveform browser does not have to load the complete waveform file for you to view a single signal. This feature is especially useful if the size of the waveform file is several gigabytes.

Furthermore, the WDB format is usually more compact than XP and NW (described later in this section). However, if the NW file is already very small, then WDB offers little advantage in size or speed.

You can compress WDB files. For additional information, see Compressing Analog Files on page 322.

TR Output Format

HSPICE RF stores simulation results for analysis by using the AvanWaves graphical interface method. For example, these commands output a *.tr# file in TR format:

- `.OPTION POST=1` saves the results in binary format
- `.OPTION POST=2` saves the results in ASCII format.

XP Output Format

HSPICE RF outputs XP binary format to a file with the .xp# extension. This format is compatible with the HSPICE TR binary format. For example, to output to a *.xp# file, enter:

```
.OPTION POST=xp
```

NW Output Format

HSPICE RF outputs the NW format to a file with the .nw# extension. Synopsys developed this format; you need a Synopsys waveform display tool to process a file in NW format. For example, to output to a *.nw# file, enter:

```
.OPTION POST=nw
```

You can compress NW files. For additional information, see Compressing Analog Files on page 322.

VCD Output Format

To output your waveforms from HSPICE RF in VCD (Value Change Dump) format, set the `VCD` option in conjunction with the `.LPRINT` statement. For example,

```
.OPTION VCD
.LPRINT (0.5 4.5) v(0) v(2) v(6)
```

.LPRINT Statement

You use the `.LPRINT` statement to produce output in VCD file format from transient analysis. For example,

```
.LPRINT (v1,v2) output_varable_list
```

For additional information, see .LPRINT in the *HSPICE and HSPICE RF Command Reference*.

turboWave Output Format

To use turboWave output format TW, enter:

```
.OPTION POST=tw
```

This format supports analog compression as described in Compressing Analog Files on page 322.

Undertow Output Format

To use Veritools Undertow output format UT, enter:

```
.OPTION POST=ut
```

This format supports analog compression as described in Compressing Analog Files on page 322.

The waveform list in UT format now displays in a hierarchical structure, rather than one flat level as in previous versions.

CSDF Output Format

To use CSDF output format CSDF, enter:

```
.OPTION POST=csdf
.OPTION csdf [overrides .OPTION POST setting]
```

Compressing Analog Files

Analog compression eliminates unnecessary data points from a HSPICE RF voltage or current waveform to reduce the size of the waveform file.

Eliminating Voltage Datapoints

You use the `SIM_DELTAV` option to determine the selection criteria for HSPICE RF voltage waveforms in WDB or NW format. For example,

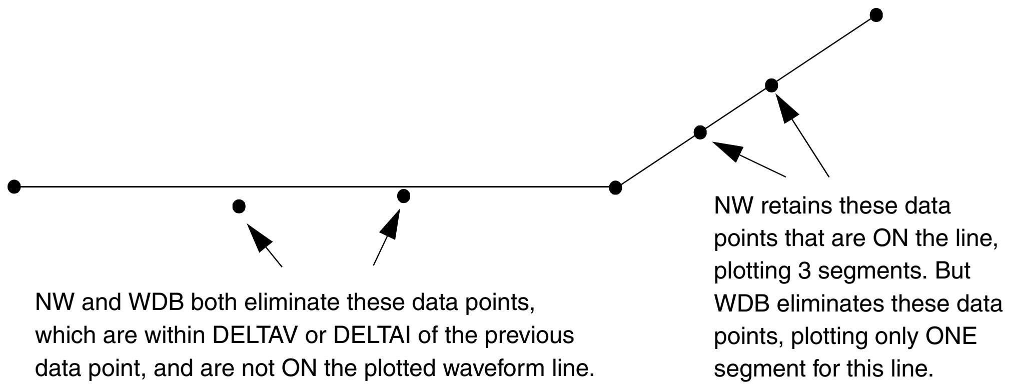
```
.OPTION SIM_DELTAV=<value>
```

During simulation, HSPICE RF checks whether the value of the *X* signal at the *n* timestep changes by more than the `SIM_DELTAV` option, from its previous value at the *n-1* timestep.

- If yes, then HSPICE RF saves the new data point.
- Otherwise, this new data point is lost.

Typically such an algorithm yields a reduced file size with minimal resolution loss as long as you set an appropriate `SIM_DELTAV` value. If a value for the `SIM_DELTAV` option is too large, the waveform degrades.

Figure 25 Analog Compression Formats


NW retains these data points that are ON the line, plotting 3 segments. But WDB eliminates these data points, plotting only ONE segment for this line.
NW and WDB both eliminate these data points, which are within DELTAV or DELTAI of the previous data point, and are not ON the plotted waveform line.

For a additional information, see .OPTION SIM_DELTAV in the *HSPICE and HSPICE RF Command Reference*.

Eliminating Current Datapoints

You use the `SIM_DELTAI` option to determine the selection criteria for HSPICE RF current waveforms in WDB or NW format. For example,

```
.OPTION SIM_DELTAI=<value>
```

For a additional information, see .OPTION SIM_DELTAI in the *HSPICE and HSPICE RF Command Reference*.

15

Statistical and Monte Carlo Analysis

Describes the features available in HSPICE RF for statistical analysis.

Overview

Described in this chapter are the features available in HSPICE RF for statistical analysis. These features are supported for HSPICE RF and differ from the enhanced statistical analysis features available for HSPICE (described in the *HSPICE Simulation and Analysis User Guide* in Chapter 13, Simulating Variability, Chapter 14, Variation Block, and Chapter 15, Monte Carlo Analysis).

The following subjects are described in this chapter:

- Application of Statistical Analysis
- Analytical Model Types
- Simulating Circuit and Model Temperatures
- Worst Case Analysis
- Monte Carlo Analysis
- Worst Case and Monte Carlo Sweep Example
- Simulating the Effects of Global and Local Variations with Monte Carlo

Application of Statistical Analysis

When you design an electrical circuit, it must meet tolerances for the specific manufacturing process. The electrical yield is the number of parts that meet the electrical test specifications. Overall process efficiency requires maximum yield. To analyze and optimize the yield, HSPICE RF supports statistical techniques and observes the effects of variations in element and model parameters.

Analytical Model Types

To model parametric and statistical variation in circuit behavior, use:

- `.PARAM` statement to investigate the performance of a circuit as you change circuit parameters. For details about the `.PARAM` statement, see the .PARAM statement in the *HSPICE and HSPICE RF Command Reference*.
- Temperature variation analysis to vary the circuit and component temperatures, and compare the circuit responses. You can study the temperature-dependent effects of the circuit, in detail.
- Monte Carlo analysis when you know the statistical standard deviations of component values to center a design. This provides maximum process yield, and determines component tolerances.
- Worst-case corner analysis when you know the component value limit to automate quality assurance for:
  - basic circuit function
  - process extremes
  - quick estimation of speed and power tradeoffs
  - best-case and worst-case model selection
  - parameter corners
  - library files
- Data-driven analysis for cell characterization, response surface, or Taguchi analysis. See “Performing Digital Cell Characterization” in the *HSPICE Applications Manual*. Automates characterization of cells and calculates the coefficient of polynomial delay for timing simulation. You can simultaneously vary any number of parameters and perform an unlimited number of analyses. This analysis uses an ASCII file format so HSPICE RF can automatically generate parameter values. This analysis can replace hundreds or thousands of HSPICE RF simulation runs.

Use yield analyses to modify:

- DC operating points
- DC sweeps
- AC sweeps
- Transient analysis.

CosmosScope can generate scatter plots from the operating point analysis or a family of curve plots for DC, AC, and transient analysis.

Use `.MEASURE` statements to save results for delay times, power, or any other characteristic extracted in a `.MEASURE` statement. HSPICE RF generates a table of results in an .mt# file in ASCII format. You can analyze the numbers directly or read this file into CosmosScope to view the distributions. Also, if you use `.MEASURE` statements in a Monte Carlo or data-driven analysis, then the HSPICE RF output file includes the following statistical results in the listing:

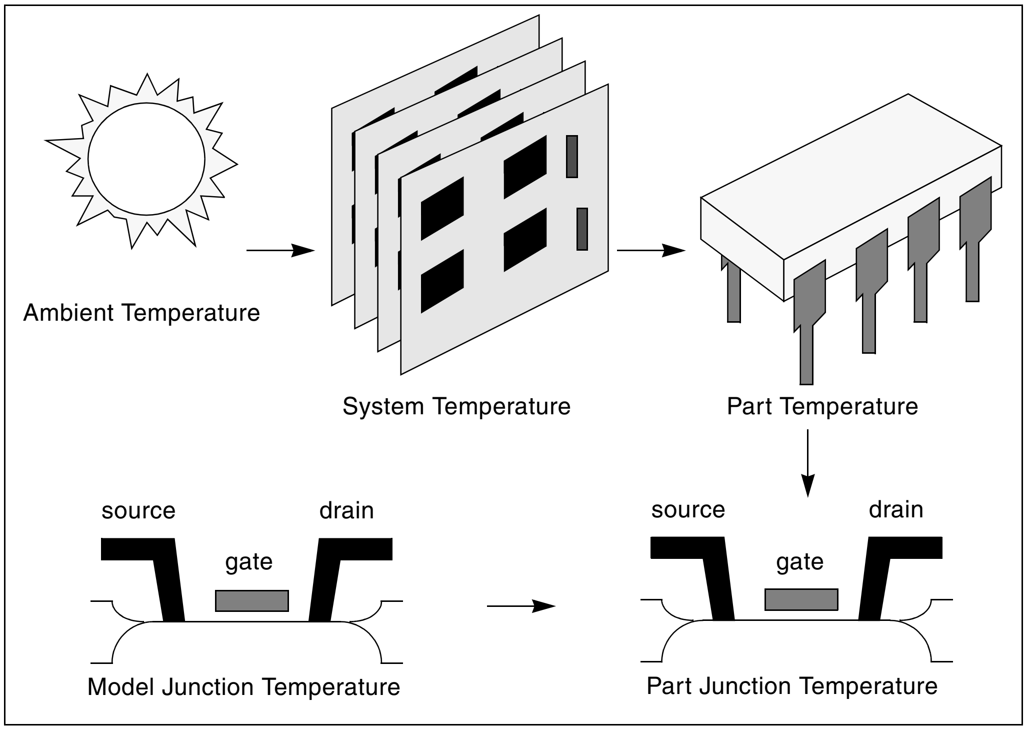
Mean	$\frac{x_1 + x_2 + \ldots + x_n}{N}$
Variance	$\frac{(x_1 - Mean)^2 + \ldots(x_n - Mean)^2}{N-1}$
Sigma	$\sqrt{Variance}$
Average Deviation	$\frac{\lvert x_1 - Mean\rvert + \ldots + \lvert x_n - Mean\rvert}{N-1}$

Simulating Circuit and Model Temperatures

Temperature affects *all* electrical circuits. Figure 26 shows the key temperature parameters associated with circuit simulation:

- Model reference temperature – you can model different models at different temperatures. Each model has a `TREF` (temperature reference) parameter.
- Element junction temperature – each resistor, transistor, or other element generates heat so an element is hotter than the ambient temperature.
- Part temperature – at the system level each part has its own temperature.
- System temperature – a collection of parts form a system, which has a local temperature.
- Ambient temperature – the ambient temperature is the air temperature of the system.

Figure 26 Part Junction Temperature Sets System Performance



HSPICE RF calculates temperatures as differences from the ambient temperature:

$$Tambient + \Delta system + \Delta part + \Delta junction = Tjunction$$

$$Ids = f(Tjunction, Tmodel)$$

Every element includes a DTEMP keyword, which defines the difference between junction and ambient temperature.

Example

The following example uses DTEMP in a MOSFET element statement:

```
M1 drain gate source bulk Model_name W=10u L=1u DTEMP=+20
```

Temperature Analysis

You can specify three temperatures:

- Model reference temperature specified in a `.MODEL` statement. The temperature parameter is usually `TREF`, but can be `TEMP` or `TNOM` in some models. This parameter specifies the temperature, in °C, at which HSPICE RF measures and extracts the model parameters. Set the value of `TNOM` in an `.OPTION` statement. Its default value is 25°C.
- Circuit temperature that you specify using a `.TEMP` statement or the `TEMP` parameter. This is the temperature, in °C, at which HSPICE RF simulates all elements. To modify the temperature for a particular element, use the `DTEMP` parameter. The default circuit temperature is the value of `TNOM`.
- Individual element temperature, which is the circuit temperature, plus an optional amount that you specify in the `DTEMP` parameter.

To specify the temperature of a circuit in a simulation run, use either the `.TEMP` statement, or the `TEMP` parameter in the `.DC`, `.AC`, or `.TRAN` statements. HSPICE RF compares the circuit simulation temperature that one of these statements sets against the reference temperature that the `TNOM` option sets. `TNOM` defaults to 25°C, unless you use the `SPICE` option, which defaults to 27°C. To calculate the derating of component values and model parameters, HSPICE RF uses the difference between the circuit simulation temperature, and the `TNOM` reference temperature.

Elements and models within a circuit can operate at different temperatures. For example, a high-speed input/output buffer that switches at 50 MHz is much hotter than a low-drive NAND gate that switches at 1 MHz). To simulate this temperature difference, specify both an element temperature parameter (`DTEMP`), and a model reference parameter (`TREF`). If you specify `DTEMP` in an element statement, the element temperature for the simulation is:

```
element temperature=circuit temperature + DTEMP
```

Specify the `DTEMP` value in the element statement (resistor, capacitor, inductor, diode, BJT, JFET, or MOSFET statement), or in a subcircuit element. Assign a parameter to `DTEMP`, then use the `.DC` statement to sweep the parameter. The `DTEMP` value defaults to zero.

If you specify `TREF` in the model statement, the model reference temperature changes (`TREF` overrides `TNOM`). Derating the model parameters is based on the difference between circuit simulator temperature and `TREF` (instead of `TNOM`).

.TEMP Statement

To specify the temperature of a circuit for a HSPICE RF simulation, use the `.TEMP` statement.

Worst Case Analysis

Circuit designers often use worst-case analysis when designing and analyzing MOS and BJT IC circuits. To simulate the worst case, set all variables to their 2- or 3-sigma worst-case values. Because several independent variables rarely attain their worst-case values simultaneously, this technique tends to be overly pessimistic and can lead to over-designing the circuit. However, this analysis is useful as a fast check.

Model Skew Parameters

The HSPICE RF device models include physically-measurable model parameters. The circuit simulator uses parameter variations to predict how an actual circuit responds to extremes in the manufacturing process. Physically-measurable model parameters are called *skew* parameters, because they skew from a statistical mean to obtain predicted performance variations.

Examples of skew parameters are the difference between the drawn and physical dimension of metal, postillion, or active layers, on an integrated circuit.

Generally, you specify skew parameters independently of each other, so you can use combinations of skew parameters to represent worst cases. Typical skew parameters for CMOS technology include:

- `XL` – polysilicon CD (critical dimension of the poly layer, representing the difference between drawn and actual size).
- $\mathtt{XW}_n$, $\mathtt{XW}_p$ – active CD (critical dimension of the active layer, representing the difference between drawn and actual size).
- `TOX` – thickness of the gate oxide.
- $\mathtt{RSH}_n$, $\mathtt{RSH}_p$ – resistivity of the active layer.
- $\mathtt{DELVTO}_n$, $\mathtt{DELVTO}_p$– variation in threshold voltage.

You can use these parameters in any level of MOS model, within the HSPICE RF device models. The `DELVTO` parameter shifts the threshold value. HSPICE

RF adds this value to `VTO` for the Level 3 model, and adds or subtracts it from `VFB0` for the BSIM model. Table 26 shows whether HSPICE RF adds or subtracts deviations from the average.

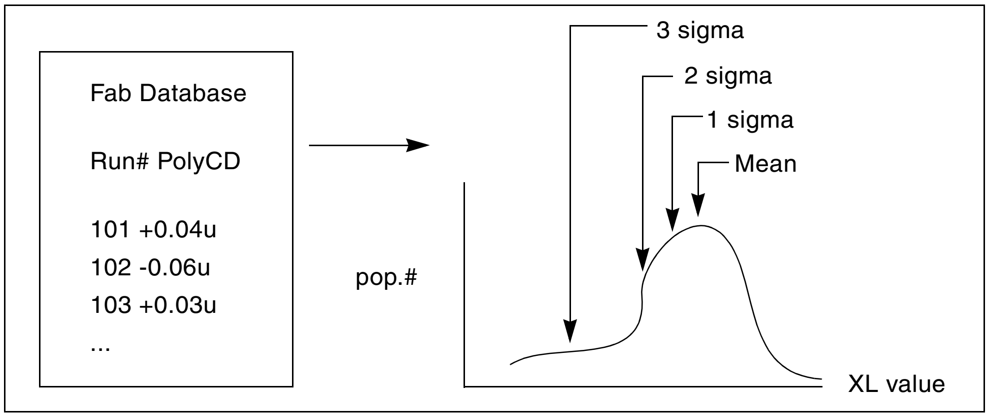
Table 26 Sigma Deviations

Type	**Parameter**	**Slow**	**Fast**
NMOS	XL	+	-
	RSH	+	-
	DELVTO	+	-
	TOX	+	-
	XW	-	+
PMOS	XL	+	-
	RSH	+	-
	DELVTO	-	+
	TOX	+	-
	XW	-	+

HSPICE RF selects skew parameters based on the available historical data that it collects either during fabrication or electrical test. For example, HSPICE RF collects the *XL skew* parameter for poly CD during fabrication. This parameter is usually the most important skew parameter for a MOS process.

Figure 27 is an example of data that historical records produce.

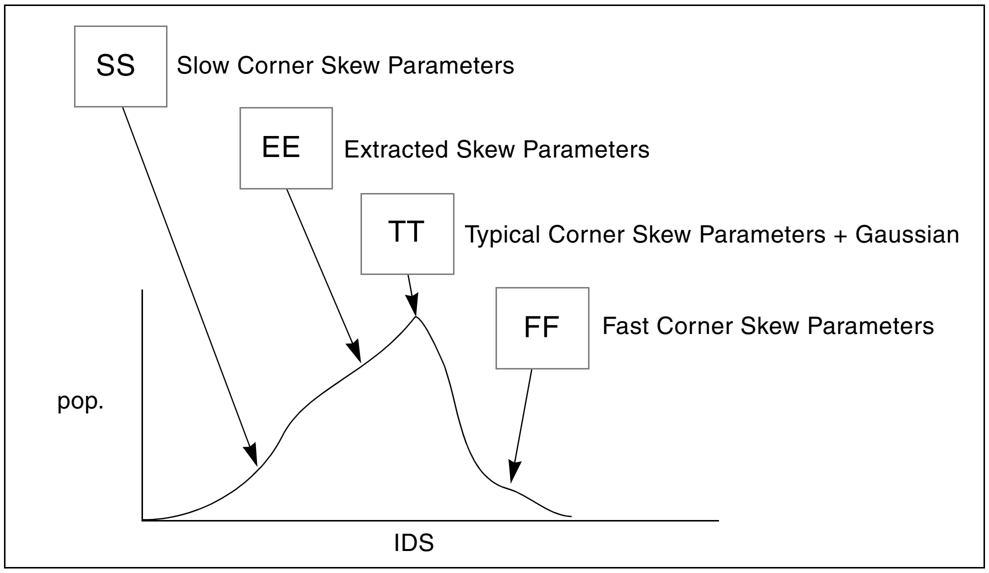
Figure 27 Historical Records for Skew Parameters in a MOS Process



Using Skew Parameters

Figure 28 shows how to create a worst-case corners library file for a CMOS process model. Specify the physically-measured parameter variations so that their proper minimum and maximum values are consistent with measured current (IDS) variations. For example, HSPICE can generate a 3-sigma variation in IDS from a 2-sigma variation in physically-measured parameters.

Figure 28 Worst Case Corners Library File for a CMOS Process Model


SS
Slow Corner Skew Parameters
EE
Extracted Skew Parameters
TT
Typical Corner Skew Parameters + Gaussian
FF
Fast Corner Skew Parameters
pop.
IDS

The `.LIB` (library) statement, and the `.INCLUDE` (include file) statement, access the models and skew. The library contains parameters that modify `.MODEL` statements. The following example of `.LIB` features both worst-case and statistical-distribution data by using model skew parameters. In statistical distribution, the median value is the default for all non-Monte Carlo analysis.

Example

```
.LIB TT
$TYPICAL P-CHANNEL AND N-CHANNEL CMOS LIBRARY DATE:3/4/91
$ PROCESS: 1.0U CMOS, FAB22, STATISTICS COLLECTED 3/90-2/91
$ following distributions are 3 sigma ABSOLUTE GAUSSIAN

.PARAM
$ polysilicon Critical Dimensions
+ polycd=agauss(0,0.06u,1) xl='polycd-sigma*0.06u'
$ Active layer Critical Dimensions
+ nactcd=agauss(0,0.3u,1) xwn='nactcd+sigma*0.3u'
+ pactcd=agauss(0,0.3u,1) xwp='pactcd+sigma*0.3u'
$ Gate Oxide Critical Dimensions (200 angstrom +/- 10a at 1
$ sigma)
+ toxcd=agauss(200,10,1) tox='toxcd-sigma*10'

$ Threshold voltage variation
+ vtoncd=agauss(0,0.05v,1) delvton='vtoncd-sigma*0.05'
+ vtopcd=agauss(0,0.05v,1) delvtop='vtopcd+sigma*0.05'


.INC '/usr/meta/lib/cmos1_mod.dat' $ model include file
.ENDL TT
.LIB FF
$HIGH GAIN P-CH AND N-CH CMOS LIBRARY 3SIGMA VALUES

.PARAM TOX=230 XL=-0.18u DELVTON=-.15V DELVTOP= 0.15V
.INC '/usr/meta/lib/cmos1_mod.dat' $ model include file

.ENDL FF
```

The /usr/meta/lib/cmos1_mod.dat include file contains the model.

```
.MODEL NCH NMOS LEVEL=2 XL=XL TOX=TOX DELVTO=DELVTON . .
.MODEL PCH PMOS LEVEL=2 XL=XL TOX=TOX DELVTO=DELVTOP . .
```

Note:

The model keyname (left) equals the skew parameter (right). Model keys and skew parameters can use the same names.

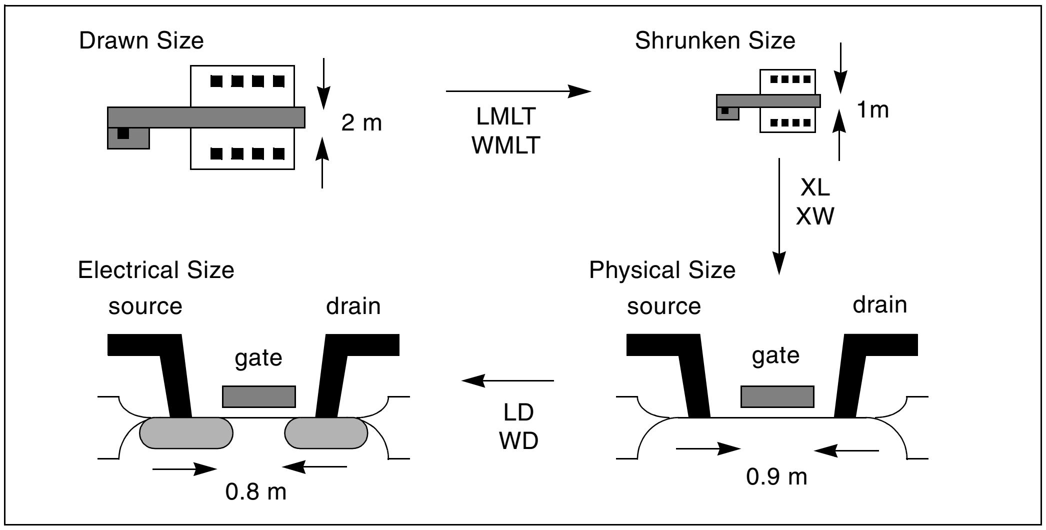
Skew File Interface to Device Models

Skew parameters are model parameters for transistor models or passive components. A typical device model set includes:

- MOSFET models for all device sizes by using an automatic model selector.
- RC wire models for polysilicon, metal1, and metal2 layers in the drawn dimension. Models include temperature coefficients and fringe capacitance.
- Single-diode and distributed-diode models for N+, P+, and well (includes temperature, leakage, and capacitance based on the drawn dimension).
- BJT models for parasitic bipolar transistors. You can also use these for any special BJTs, such as a BiCMOS for ECL BJT process (includes current and capacitance as a function of temperature).
- Metal1 and metal2 transmission line models for long metal lines.
- Models must accept elements. Sizes are based on a drawn dimension. If you draw a cell at 2μ dimension and shrink it to 1μ, the physical size is 0.9μ. The effective electrical size is 0.8μ. Account for the four dimension levels:
  - drawn size
  - shrunken size
  - physical size
  - electrical size

Most simulator models scale directly from *drawn* to *electrical* size. HSPICE MOS models support all four size levels as in Figure 29.

Figure 29 Device Model from Drawn to Electrical Size



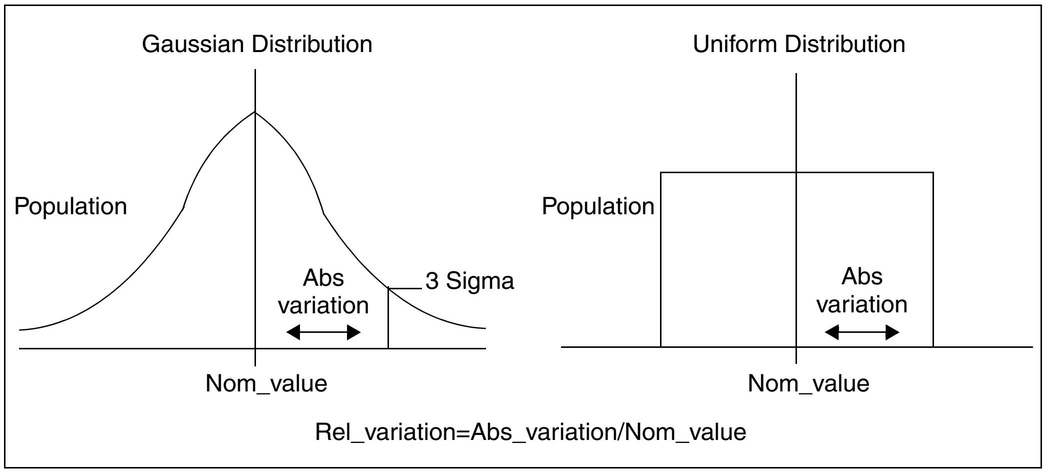
Monte Carlo Analysis

Monte Carlo analysis uses a random number generator to create the following types of functions.

- Gaussian parameter distribution
  - Relative variation—variation is a ratio of the average.
  - Absolute variation—adds variation to the average.
  - Bimodal–multiplies distribution to statistically reduce nominal parameters.
- Uniform parameter distribution
  - Relative variation—variation is a ratio of the average.
  - Absolute variation—adds variation to the average.
  - Bimodal–multiplies distribution to statistically reduce nominal parameters.
- Random limit parameter distribution
  - Absolute variation—adds variation to the average.
  - Monte Carlo analysis randomly selects the *min* or *max* variation.

The value of the `MONTE` analysis keyword determines how many times to perform operating point, DC sweep, AC sweep, or transient analysis.

Figure 30 Monte Carlo Distribution



Monte Carlo Setup

To set up a Monte Carlo analysis, use the following HSPICE statements:

- `.PARAM` statement—sets a model or element parameter to a Gaussian, Uniform, or Limit function distribution.
- `.DC`, `.AC`, or `.TRAN` analysis—enables `MONTE`.
- `.MEASURE` statement—calculates the output mean, variance, sigma, and standard deviation.
- `.MODEL` statement—sets model parameters to a Gaussian, Uniform, or Limit function distribution.

Select the type of analysis to run, such as operating point, DC sweep, AC sweep, or TRAN sweep.

Operating Point

```
.DC MONTE=<firstrun=num1>
```

-or-

```
.DC MONTE=list <(> <num1:num2> <num3> <num5:num6> <num7> <)>
```

DC Sweep

```
.DC vin 1 5 0.25 sweep MONTE=val <firstrun=num1>
```

-or-

```
.DC vin 1 5 0.25 sweep MONTE=list<(> <num1:num2> <num3>
+ <num5:num6> <num7> <)>
```

AC Sweep

```
.AC dec 10 100 1meg sweep MONTE=val <firstrun=num1>
```

-or-

```
.AC dec 10 100 1meg sweep MONTE=list<(> <num1:num2>
+ <num3> <num5:num6> <num7> <)>
```

TRAN Sweep

```
.TRAN 1n 10n sweep MONTE=val <firstrun=num1>
```

-or-

```
.TRAN 1n 10n sweep MONTE=list<(> <num1:num2> <num3>
+ <num5:num6> <num7> <)>
```

The *val* value specifies the number of Monte Carlo iterations to perform. A reasonable number is 30. The statistical significance of 30 iterations is quite high. If the circuit operates correctly for all 30 iterations, there is a 99% probability that over 80% of all possible component values operate correctly. The relative error of a quantity, determined through Monte Carlo analysis, is proportional to val$^{-1/2}$.

The *firstrun* values specify the desired number of iterations. HSPICE RF runs from num1 to num1+val-1. The number after *firstrun* can be a parameter. You can write only one number after *list*. The colon represents “from ... to ...". Specifying only one number makes HSPICE RF runs only a the one specified point.

Example 1

In this example, HSPICE RF runs from the 90th to 99th Monte Carlo iterations:

```
.tran 1n 10 sweep monte=10 firstrun=90
```

You can write more than one number after *list*. The colon represents “from ... to ...". Specifying only one number makes HSPICE RF run only at that single point.

Example 1

In this example, HSPICE RF begins running at the 10th iteration, then continues from the 20th to the 30th, at the 40th, and finally from the 46th to 72nd Monte Carlo iteration. The numbers after list can not be parameter.

```
.tran 1n 10n sweep monte=list(10 20:30 40 46:72)
```

Monte Carlo Output

- `.MEASURE` statements are the most convenient way to summarize the results.
- `.PRINT` statements generate tabular results, and print the values of all Monte Carlo parameters.
- `.MCBRIEF` determines the output types of the random parameters during Monte Carlo analysis to improve output performance.
- If one iteration is out of specification, you can obtain the component values from the tabular listing. A detailed resimulation of that iteration might help identify the problem.
- AvanWaves superimposes all iterations as a single plot so you can analyze each iteration individually.

.PARAM Distribution Function

This section describes how to use assign a `.PARAM` parameter in Monte Carlo analysis. For a general description of the `.PARAM` statement, see the .PARAM command in the *HSPICE and HSPICE RF Command Reference*.

You can assign a `.PARAM` parameter to the keywords of elements and models, and assign a distribution function to each `.PARAM` parameter. HSPICE RF recalculates the distribution function each time that and element or model keyword uses a parameter. When you use this feature, Monte Carlo analysis can use a parameterized schematic netlist without additional modifications.

Syntax

```
.PARAM xx=UNIF(nominal_val, rel_variation
+ <, multiplier>)

.PARAM xx=AUNIF(nominal_val, abs_variation <,
+ multiplier>)

.PARAM xx=GAUSS(nominal_val, rel_variation, sigma <,
+ multiplier>)

.PARAM xx=AGAUSS(nominal_val, abs_variation, sigma <,
+ multiplier>)
```

```
.PARAM xx=LIMIT(nominal_val, abs_variation)
```

Argument	Description
xx	Distribution function calculates the value of this parameter.
UNIF	Uniform distribution function by using relative variation.
AUNIF	Uniform distribution function by using absolute variation.
GAUSS	Gaussian distribution function by using relative variation.
AGAUSS	Gaussian distribution function by using absolute variation
LIMIT	Random-limit distribution function by using absolute variation. Adds +/- *abs_variation* to *nominal_val* based on whether the random outcome of a -1 to 1 distribution is greater than or less than 0.
nominal_val	Nominal value in Monte Carlo analysis and default value in all other analyses.
abs_variation	AUNIF and AGAUSS vary the nominal_val by +/- *abs_variation*.
rel_variation	UNIF and GAUSS vary the *nominal_val* by +/- (*nominal_val* · *rel_variation*).
sigma	Specifies *abs_variation* or *rel_variation* at the *sigma* level. For example, if *sigma*=3, then the standard deviation is *abs_variation* divided by 3.
multiplier	If you do not specify a multiplier, the default is 1. HSPICE RF recalculates many times and saves the largest deviation. The resulting parameter value might be greater than or less than *nominal_val*. The resulting distribution is bimodal.

Example 1

In this example, each R has an unique variation.

```
.param mc_var=agauss(0,1,3)    $ +/- 20% swing
.param val='1000*(1+mc_var)'
v_vin vin 0 dc=1 ac=.1
r1 vin 0  '1000*(1+mc_var)'
r2 vin 0  '1000*(1+mc_var)'
```

Example 2

In this example, each R has an identical variation.

```
.param mc_var=agauss(0,1,3)   $ +/- 20% swing
.param val='1+mc_var'
v_vin vin 0 dc=1 ac=.1
r1 vin 0  '1000*val'
r2 vin 0  '1000*val'
```

Example 3

In this example, local variations to an instance parameter are applied by assigning randomly-generated variations directly to each instance parameter. Each resistor r1 through r3 receives randomly different resistance values during each Monte Carlo run.

```
.param r_local=agauss(...)
r1 1 2 r=r_local
r2 3 4 r=r_local
r3 5 6 r=r_local
```

Example 4

In this example, global variations to an instance parameter are applied by assigning the variation to an intermediate parameter before assigning it to each instance parameter. Each resistor r1 through r3 receives the same random resistance value during each Monte Carlo run.

```
.param r_random=agauss(...)
.param r_global=r_random
r1 1 2 r=r_global
r2 3 4 r=r_global
r3 5 6 r=r_global
```

Monte Carlo Parameter Distribution

Each time you use a parameter, Monte Carlo calculates a new random variable.

- If you do not specify a Monte Carlo distribution, then HSPICE RF assumes the nominal value.
- If you specify a Monte Carlo distribution for only one analysis, HSPICE RF uses the nominal value for all other analyses.

You can assign a Monte Carlo distribution to all elements that share a common model. The actual element value varies according to the element distribution. If you assign a Monte Carlo distribution to a model keyword, then all elements that share the model, use the same keyword value. You can use this feature to create double element and model distributions.

For example, the MOSFET channel length varies from transistor to transistor by a small amount that corresponds to the die distribution. The die distribution is responsible for offset voltages in operational amplifiers, and for the tendency of flip-flops to settle into random states. However, all transistors on a die site vary according to the wafer or fabrication run distribution. This value is much larger than the die distribution, but affects all transistors the same way. You can specify the wafer distribution in the MOSFET model to set the speed and power dissipation characteristics.

Monte Carlo Examples

Gaussian, Uniform, and Limit Functions

You can find the sample netlist for this example in the following directory:$installdir/demo/hspice/apps/mont1.sp

Figure 31 Uniform Functions

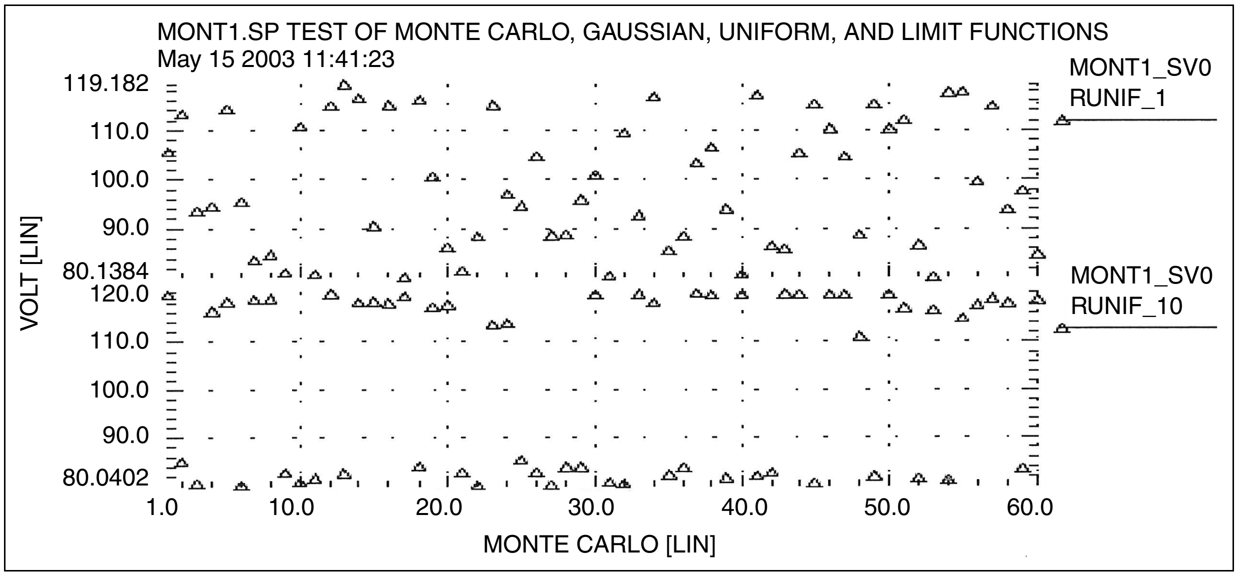


Figure 32 Gaussian Functions

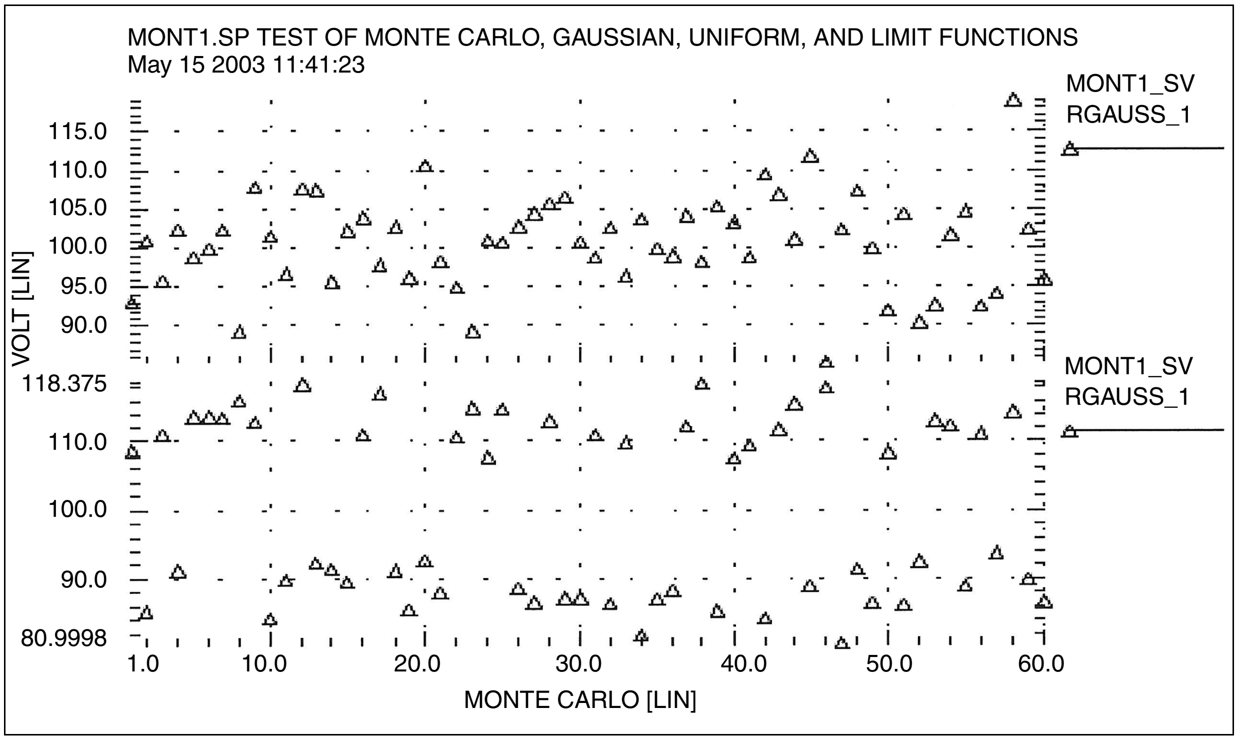
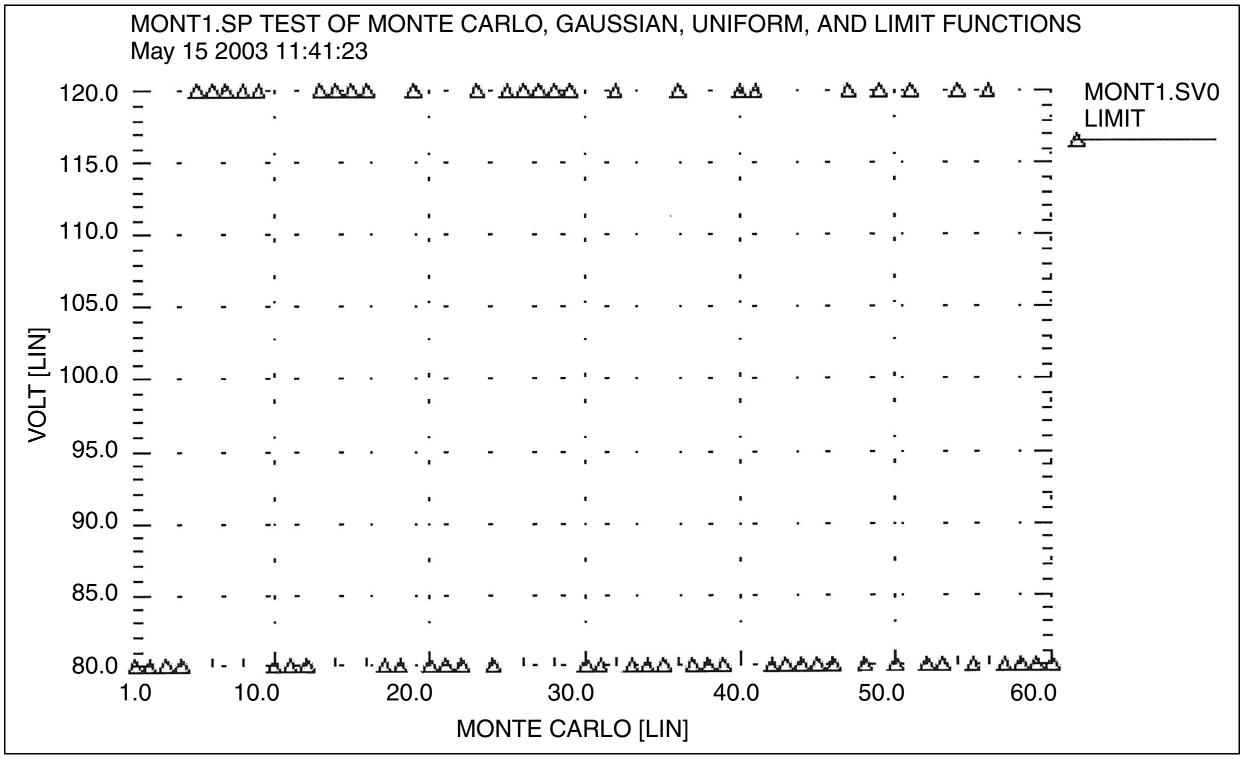


Figure 33 Limit Functions

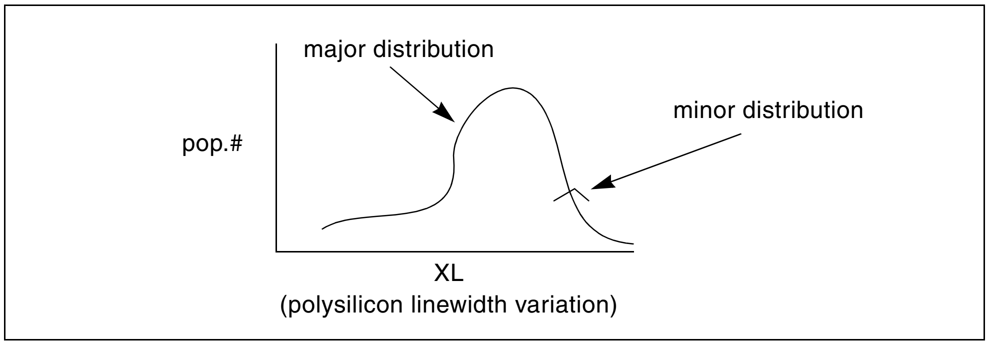


Major and Minor Distribution

In MOS IC processes, manufacturing tolerance parameters have both a major and a minor statistical distribution.

- The major distribution is the wafer-to-wafer and run-to-run variation. It determines electrical yield.
- The minor distribution is the transistor-to-transistor process variation. It is responsible for critical second-order effects, such as amplifier offset voltage and flip-flop preference.

Figure 34 Major and Minor Distribution of Manufacturing Variations



The following example is a Monte Carlo analysis of a DC sweep in HSPICE RF. Monte Carlo sweeps the VDD supply voltage from 4.5 volts to 5.5 volts.

You can find the sample netlist for this example in the following directory: $installdir/demo/hspice/apps/mondc_a.sp

- The M1 through M4 transistors form two inverters.
- The nominal value of the `LENGTH` parameter sets the channel lengths for the MOSFETs, which are set to 1u in this example.
- All transistors are on the same integrated circuit die. The `LEFF` parameter specifies the distribution—for example, a ±5% distribution in channel length variation at the ±3-sigma level.
- Each MOSFET has an independent random Gaussian value.

The `PHOTO` parameter controls the difference between the physical gate length and the drawn gate length. Because both n-channel and p-channel transistors use the same layer for the gates, Monte Carlo analysis sets `XPHOTO` distribution to the `PHOTO` local parameter.

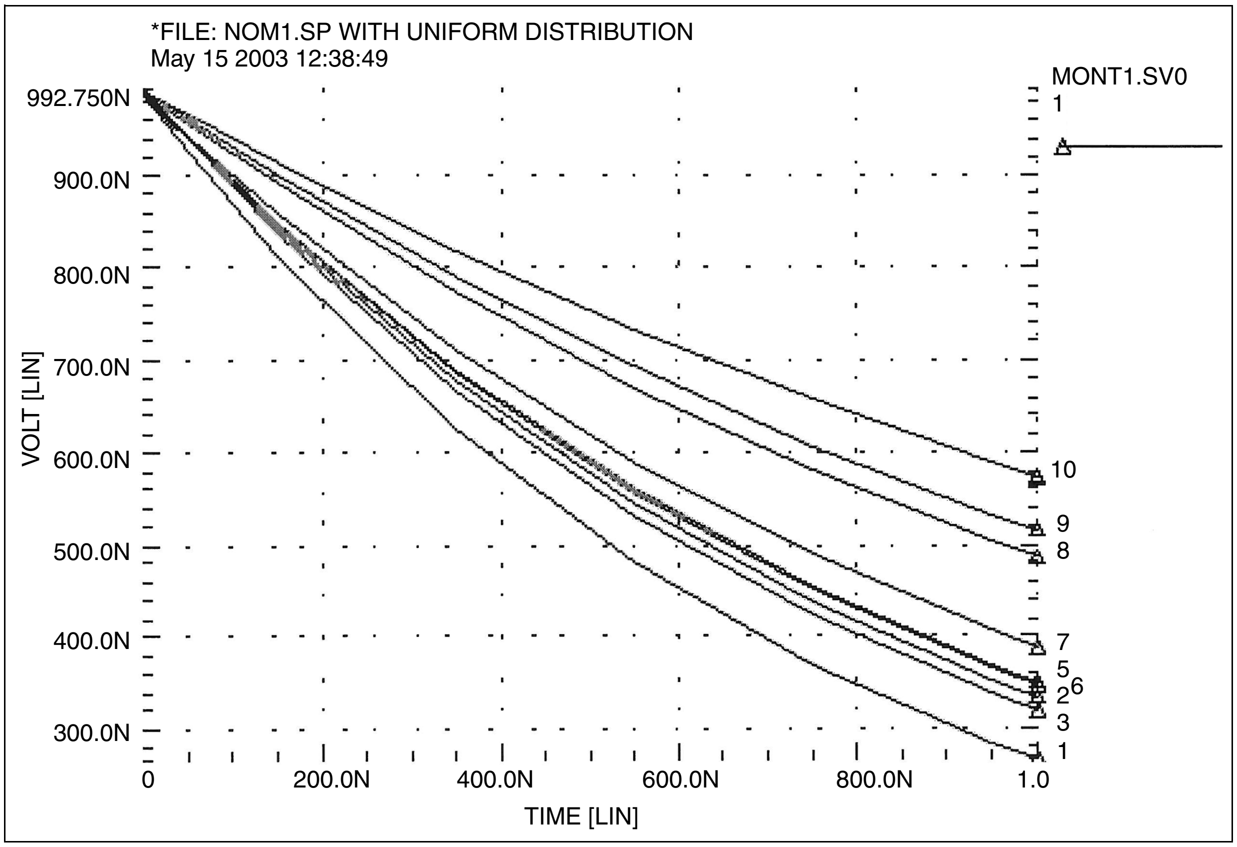
`XPHOTO` controls `PHOTO` lithography for both NMOS and PMOS devices, which is consistent with the physics of manufacturing.

RC Time Constant

This simple example shows uniform distribution for resistance and capacitance. It also shows the resulting transient waveforms for 10 different random values.

You can find the sample netlist for this example in the following directory: $installdir/demo/hspice/apps/rc_monte.sp

Figure 35 Monte Carlo Analysis of RC Time Constant

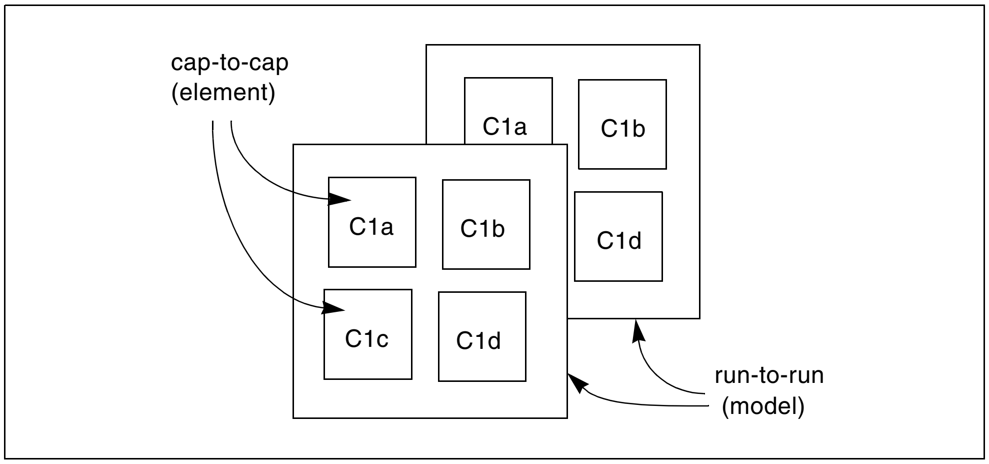


Switched Capacitor Filter Design

Capacitors used in switched-capacitor filters consist of parallel connections of a basic cell. Use Monte Carlo techniques in HSPICE RF to estimate the variation in total capacitance. The capacitance calculation uses two distributions:

- Minor (element) distribution of cell capacitance from cell-to-cell on a single die.
- Major (model) distribution of the capacitance from wafer-to-wafer or from manufacturing run-to-run.

Figure 36 Monte Carlo Distribution



You can approach this problem from physical or electrical levels.

- The physical level relies on physical distributions, such as oxide thickness and polysilicon line width control.
- The electrical level relies on actual capacitor measurements.

Physical Approach:

1. Since oxide thickness control is excellent for small areas on a single wafer, you can use a local variation in polysilicon to control the variation in capacitance for adjacent cells.
2. Next, define a local poly line-width variation and a global (model-level) poly line-width variation. In this example:
   - The local polysilicon line width control for a line 10 m wide, manufactured with process A, is ±0.02 m for a 1-sigma distribution.
   - The global (model level) polysilicon line-width control is much wider; use 0.1 m for this example.
3. The global oxide thickness is 200 angstroms with a ±5 angstrom variation at 1 sigma.
4. The cap element is square with local poly variation in both directions.
5. The cap model has two distributions:
   - poly line-width distribution
   - oxide thickness distribution.

   The effective length is:

```
Leff=Ldrawn - 2 · DEL
```

The model poly distribution is half the physical per-side values:

```
C1a 1 0 CMOD W=ELPOLY L=ELPOLY
C1b 1 0 CMOD W=ELPOLY L=ELPOLY
C1C 1 0 CMOD W=ELPOLY L=ELPOLY
C1D 1 0 CMOD W=ELPOLY L=ELPOLY
$ 10U POLYWIDTH,0.05U=1SIGMA
$ CAP MODEL USES 2*MODPOLY  .05u= 1 sigma
$ 5angstrom oxide thickness AT 1SIGMA
.PARAM ELPOLY=AGAUSS(10U,0.02U,1)
+ MODPOLY=AGAUSS(0,.05U,1)
+ POLYCAP=AGAUSS(200e-10,5e-10,1)
.MODEL CMOD C THICK=POLYCAP DEL=MODPOLY
```

Electrical Approach:

The electrical approach assumes no physical interpretation, but requires a local (element) distribution and a global (model) distribution. In this example:

- You can match the capacitors to ±1% for the 2-sigma population.
- The process can maintain a ±10% variation from run to run for a 2-sigma distribution.

```
C1a 1 0 CMOD SCALE=ELCAP
C1b 1 0 CMOD SCALE=ELCAP
C1C 1 0 CMOD SCALE=ELCAP
C1D 1 0 CMOD SCALE=ELCAP
.PARAM ELCAP=Gauss(1,.01,2) $ 1% at 2 sigma
+ MODCAP=Gauss(.25p,.1,2) $10% at 2 sigma
.MODEL CMOD C CAP=MODCAP
```

Worst Case and Monte Carlo Sweep Example

The following example measures the delay and the power consumption of two inverters. Additional inverters buffer the input and load the output.

This netlist contains commands for two sets of transient analysis: parameter sweep from -3 to +3-sigma, and a Monte Carlo analysis. It creates one set of output files (mt0 and tr0) for the sigma sweep, and one set (mt1 and tr1) for Monte Carlo.

```
$ inv.sp sweep mosfet -3 sigma to +3 sigma, use measure output
.param vref=2.5 sigma=0
.global 1
vcc  1 0  5.0
```

```
vin  in 0 pwl 0,0 0.2n,5
x1 in 2 inv
x2 2 3 inv
x3 3 out inv
x4 out 4 inv
.macro inv in out
  mn out in 0 0 nch w=10u l=1u
  mp out in 1 1 pch w=10u l=1u
.eom
.param mult1=1
+ polycd=agauss(0,0.06u,1)   xl='polycd-sigma*0.06u'
+ nactcd=agauss(0,0.3u,1)  xwn='nactcd+sigma*0.3u'
+ pactcd=agauss(0,0.3u,1)  xwp='pactcd+sigma*0.3u'
+ toxcd=agauss(200,10,1)   tox='toxcd-sigma*10'
+ vtoncd=agauss(0,0.05v,1) delvton='vtoncd-sigma*0.05'
+ vtopcd=agauss(0,0.05v,1) delvtop='vtoncd+sigma*0.05'
+ rshncd=agauss(50,8,1)   rshn='rshncd-sigma*8'
+ rshpcd=agauss(150,20,1)   rshp='rshpcd-sigma*20'
* level=28 example model
.model nch nmos
+ level=28 lmlt=mult1 wmlt=mult1 wref=22u lref=4.4u
+ xl=xl  xw=xwn tox=tox delvto=delvton rsh=rshn
...
.model pch pmos
+ level=28 lmlt=mult1 wmlt=mult1 wref=22u lref=4.4u
+ xl=xl  xw=xwp tox=tox delvto=delvtop rsh=rshp
+ ld=0.08u wd=0.2u acm=2 ldif=0 hdif=2.5u
+ rs=0 rd=0 rdc=0 rsc=0 rsh=rshp js=3e-04 jsw=9e-10
...
* transient with sweep
.tran 20p 1.0n   sweep sigma -3 3 .5
.meas s_delay trig v(2) val=vref fall=1
+           targ v(out) val=vref fall=1
.meas s_power rms power
* transient with Monte Carlo
.tran 20p 1.0n   sweep monte=100
.meas m_delay trig v(2) val=vref fall=1
+           targ v(out) val=vref fall=1
.meas m_power rms power
.probe tran v(in) v(1) v(2) v(3) v(4)
.end
```

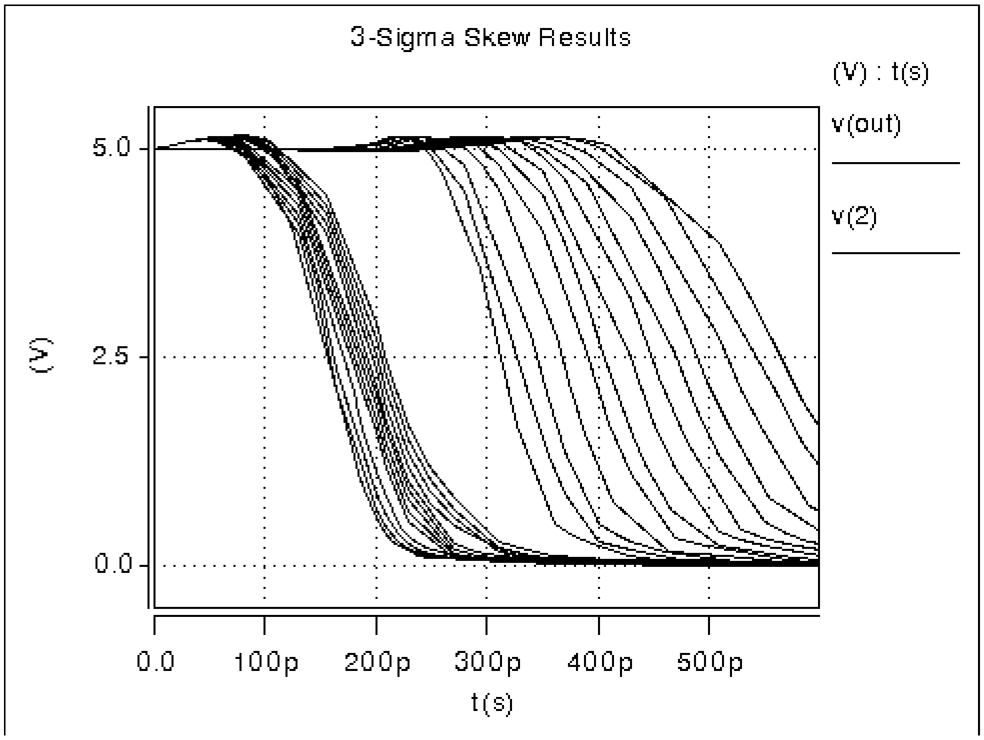
Transient Sigma Sweep Results

The plot in Figure 37 shows the family of transient analysis curves for the transient sweep of the sigma parameter from -3 to +3 from the file inv.tr0. In the sweep, HSPICE RF uses the values of sigma to update the skew parameters, which in turn modify the actual NMOS and PMOS models.

Operating-Point Results in Transient Analysis

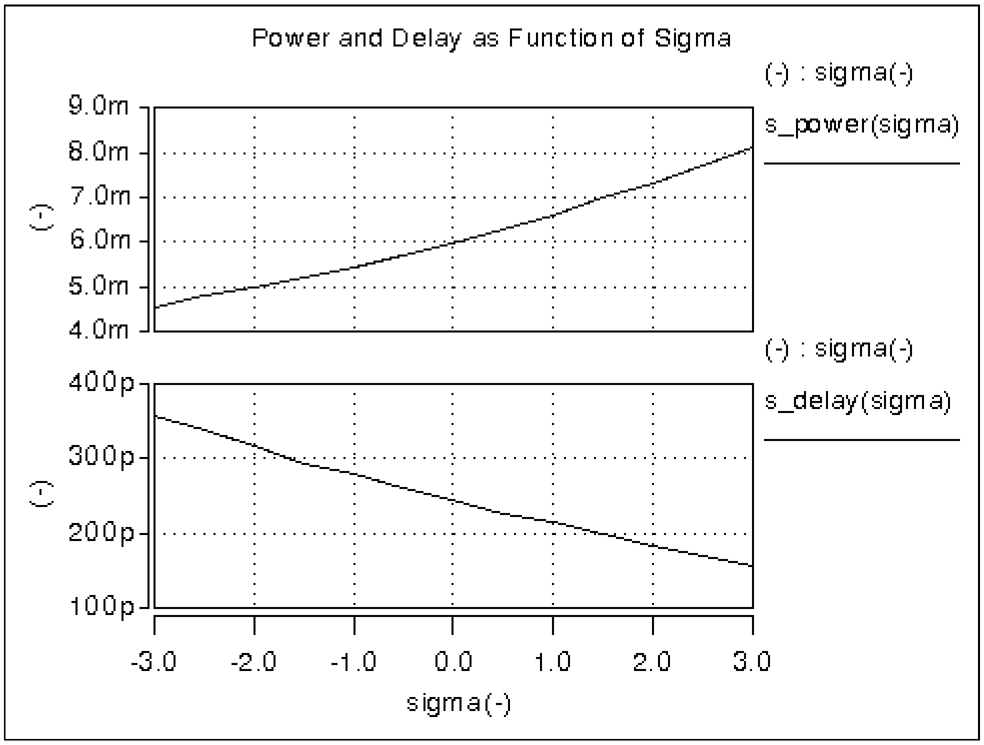
If you want to get OP results after every Monte Carlo simulation in transient analysis, you can add the option `opfile` to the netlist. OP results will all output to the file *.dp0.

Figure 37 Sweep of Skew Parameters from -3 Sigma to +3 Sigma



To view the measured results, plot the inv.mt0 output file. The plot in Figure 38 shows the measured pair delay and the total dissipative power, as a function of the parameter sigma.

Figure 38 Sweep MOS Inverter, Pair Delay and Power: -3 Sigma to 3 Sigma



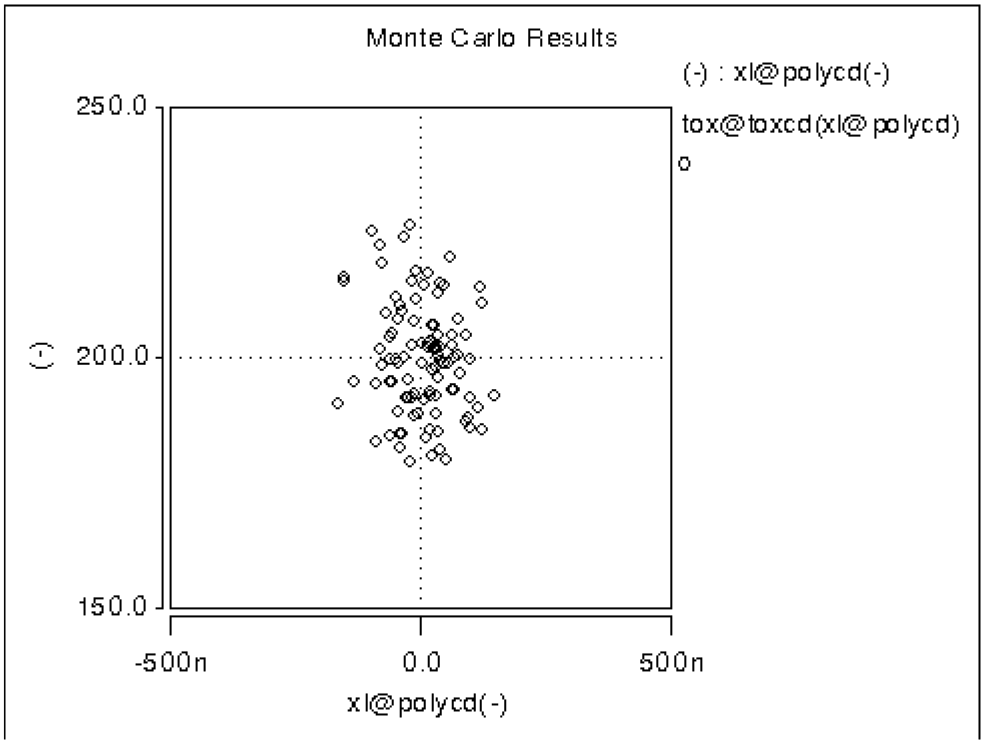
Monte Carlo Results

This section describes the output of the Monte Carlo analysis in HSPICE RF. The plot in Figure 39 shows that the relationship between `TOX` against `XL` (polysilicon width=transistor length)) is completely random, as set up in the input file.

To generate this plot in CosmosScope:

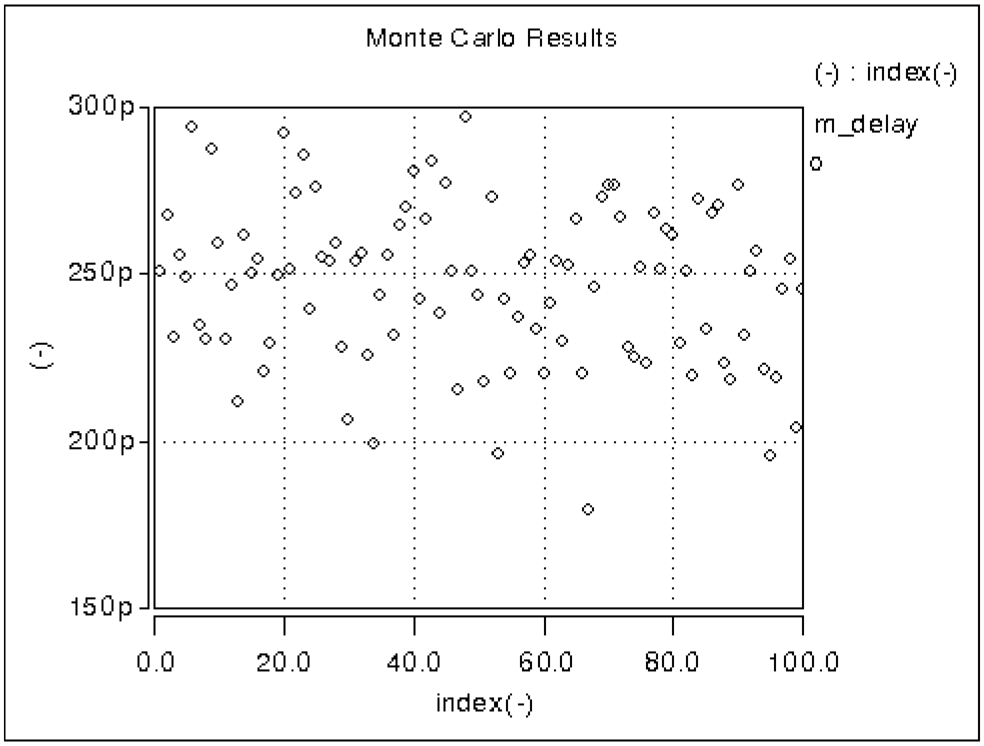
1. Read in the file inv.mt1.
2. Open the Calculator, select TOX (left mouse button), transfer to calculator (middle mouse button), and then select and transfer XL.
3. On the WAVE pulldown in the calculator, select f(x), and then click the plot icon.
4. Using the right mouse button on the plotted waveform, select Attributes to change from the line plot to symbols.

Figure 39   Scatter Plot, XL and TOX



The next graph (see Figure 40) is a standard scatter plot showing the measured delay for the inverter pair against the Monte Carlo index number.

Figure 40 Scatter Plot of Inverter Pair Delay



If a particular result looks interesting; for example, if the simulation 68 (monte carlo index=68) produces the smallest delay, then you can obtain the Monte Carlo parameters for that simulation.

```
*** monte carlo  index =    68 ***
   MONTE CARLO PARAMETER DEFINITIONS
 polycd  xl              = -1.6245E-07
 nactcd  xwn             =  3.4997E-08
 pactcd  xwp             =  3.6255E-08
 toxcd   tox             =   191.0
 vtoncd  delvton         = -2.2821E-02
         delvtop         =  4.1776E-02
 vtopcd
 rshncd  rshn            =   45.16
 rshpcd  rshp            =   166.2
 m_delay=  1.7929E-10  targ=  3.4539E-10   trig=  1.6610E-10
 m_power=  6.6384E-03  from=  0.0000E+00     to=  1.0000E-09
```

In the preceding listing, the m_delay value of 1.79e-10 seconds is the fastest pair delay. You can also examine the Monte Carlo parameters that produced this result.

The information on shortest delay and so forth is also available from the statistics section at the end of the output listing. While this information is useful to determine whether the circuit meets specification, it is often desirable to understand the relationship of the parameters to circuit performance. Plotting the results against the Monte Carlo index number does not help for this purpose. You need to generate plots that display a Monte Carlo result as a function of a parameter. For example, Figure 41 shows the inverter pair delay to channel as a function of poly width, which relates directly to device length.

Figure 41 Delay as a function of Poly width (XL)

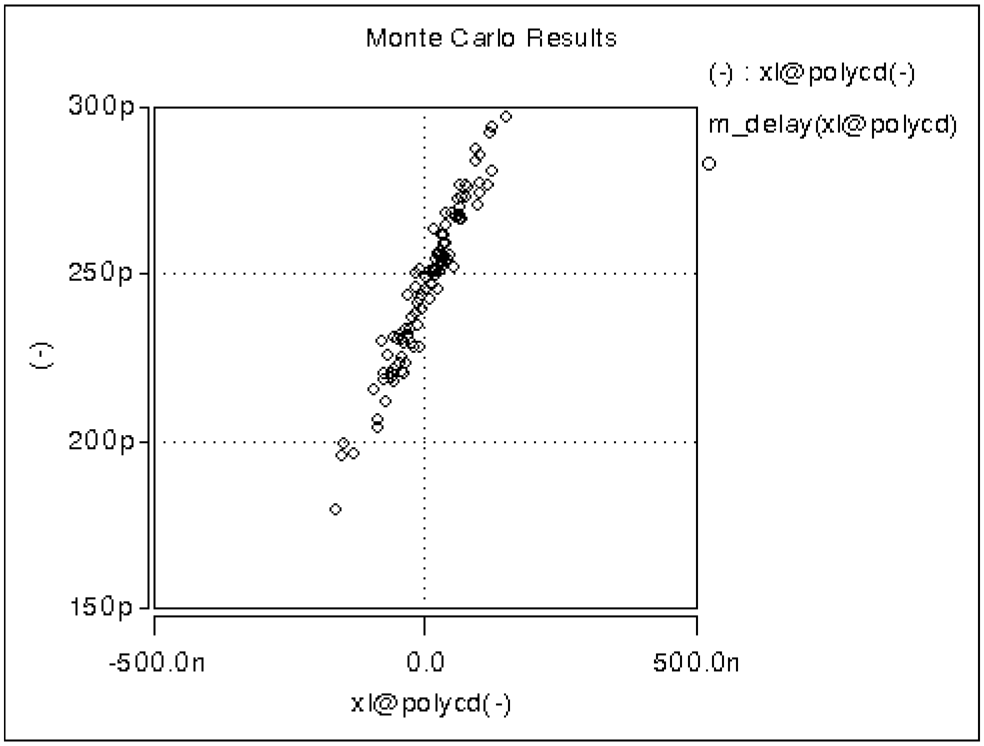
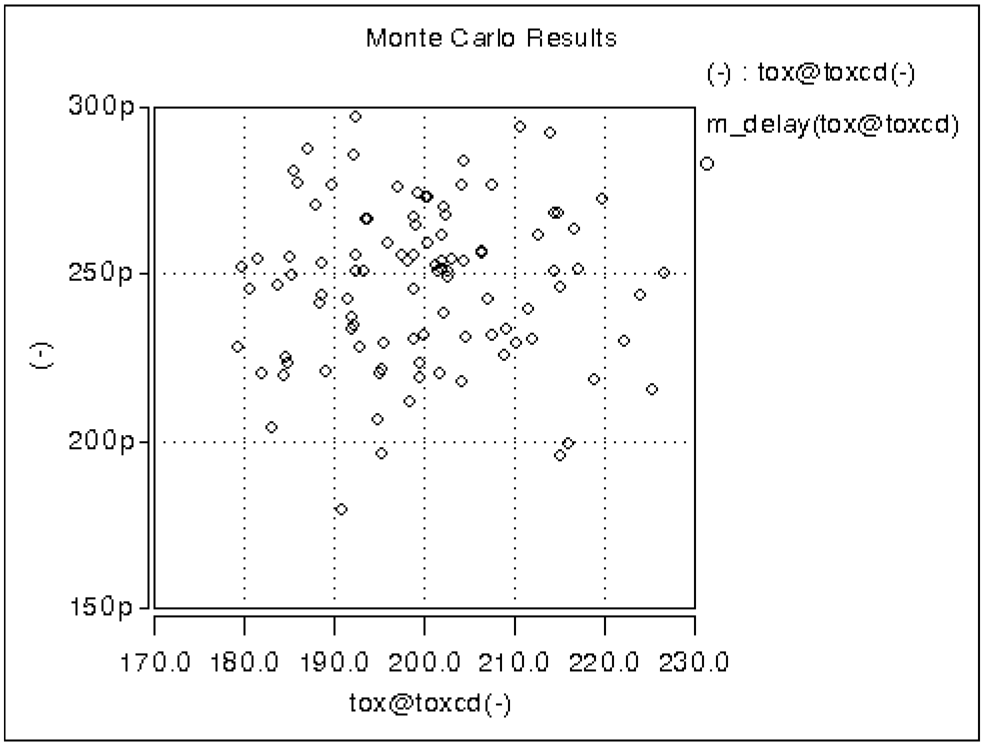


Figure 42 shows the pair delay against the `TOX` parameter. The scatter plot shows no obvious dependence, which means that the effect of `TOX` is much smaller than `XL`. To explore this in more detail, set the `XL` skew parameter to a constant and run a simulation.

Figure 42 Sensitivity of Delay with TOX



The plot in Figure 43 overlays the skew result with the ones from Monte Carlo. The skew simulation traverses the design space with all parameters changing in parallel and then produces a relationship between power and delay, which shows as a single line. Monte Carlo exercises a variety of independent parameter combinations, and shows that there is no simple relationship between the two results. Since the distributions were defined as Gaussian in the netlist, parameter values close to the nominal are more often exercised than the ones far away. With the relatively small number of samples, the chance of hitting a combination at the extremes is very small. In other words, designing for 3-sigma extreme for every parameter is probably not a good solution from the point of view of economy.

Figure 43 Superimposing Sigma Sweep Over Monte Carlo

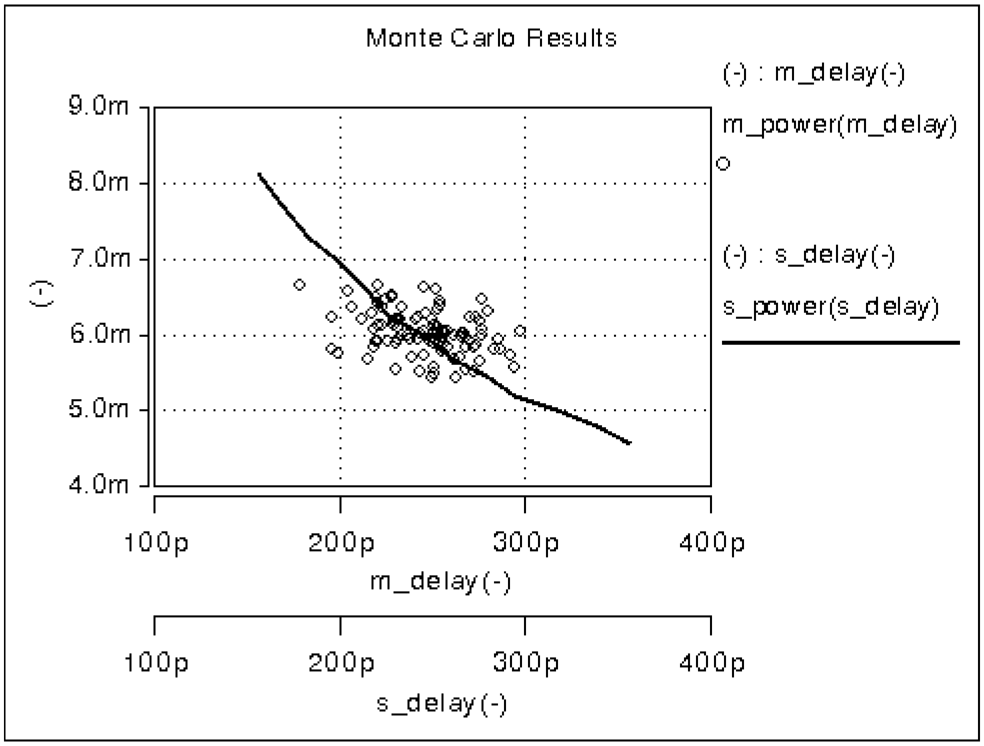
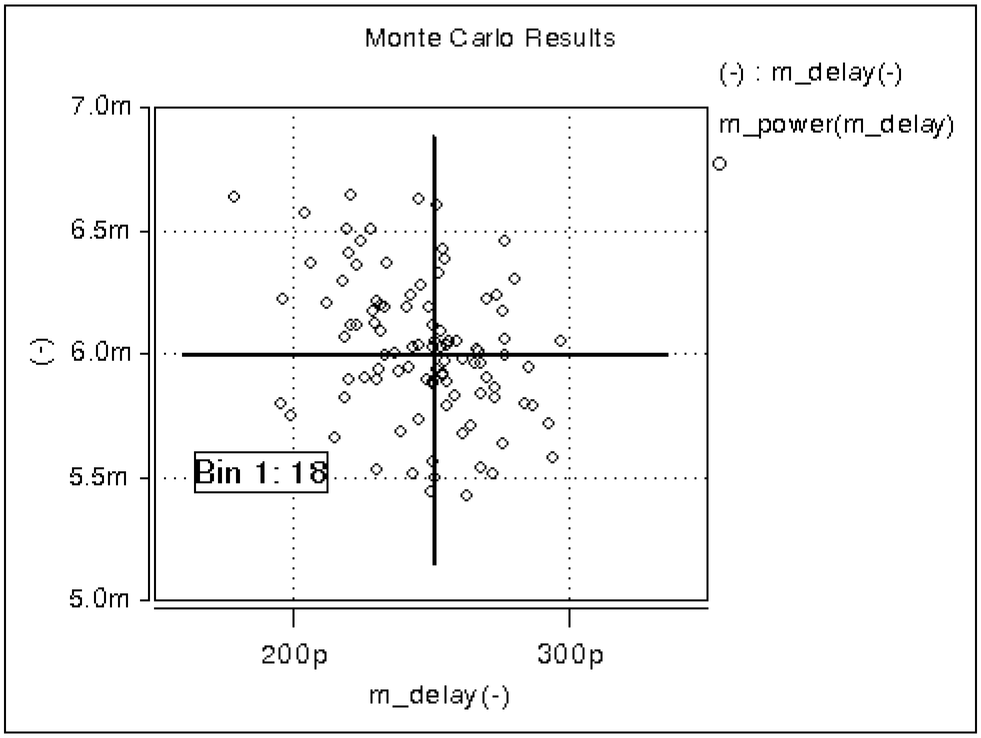


Figure 44 superimposes the required part grades for product sales onto the Monte Carlo plot. This example uses a 250 ps delay and 6.0 mW power dissipation to determine the four binning grades.

Figure 44 Speed/Power Yield Estimation



Sorting the results from inv.mt1 yields:

- Bin1 - 18%
- Bin2 - 30%
- Bin3 - 31%
- Bin4 - 21%

If this circuit is representative of the entire chip, then the present yield should be 18% for the premium Bin 1 parts, assuming variations in process parameters as specified in the netlist. Of course this example only shows the principle on how to analyze the Monte Carlo results; there is no market for a device with two of these inverters.

Simulating the Effects of Global and Local Variations with Monte Carlo

Monte Carlo analysis is dependent on a method to describe variability. Four different approaches are available in HSPICE RF:

- specify distributions on parameters and apply these to instance parameters
- specify distributions on parameters and apply these to model parameters
- specify distributions on model parameters using `DEV`/`LOT` construct
- specify distributions on model parameters in a variation block.

While the first three methods are still supported in HSPICE RF, the method based on the variation block emphasized here for improvements and future developments. The variation block is described in Chapter 14, Variation Block, and Monte Carlo analysis controlled by the variation block is described in Chapter 15, Monte Carlo Analysis.

In the following sections, the first three methods are described. The description relies on test cases, which can be found in the tar file monte_test.tar in directory $<installdir>/demo/hspice/apps.

Variations Specified on Geometrical Instance Parameters

This method consists of defining parameters with variation using the distribution functions `UNIF`, `AUINF`, `GAUSS`, `AGAUSS`, and `LIMIT`. These parameters are then used to generate dependent parameters or in the place of instance parameters. In a Monte Carlo simulation, at the beginning of each sample, new random values are calculated for these parameters. For each reference, a new random value is generated; however, no new value is generated for a derived parameter. Therefore, it is possible to apply independent variations to parameters of different devices, as well as the same variation to parameters of a group of devices. Parameters that describe distributions can be used in expressions, thus it is possible to create combinations of variations (correlations).

These concepts are best explained with circuit examples. In the three following examples, variation is defined on the width of a physical resistor, which has a model. If this device was a polysilicon resistor for example, then the variations describe essentially the effects of photoresist exposure and etching on the width of the poly layer.

- test1.sp has a distribution parameter defined called globw. A parameter called globwidth is assigned the value of globw. The parameter globwidth is assigned a different random value for each Monte Carlo sample. The parameter globwidth is used to define the width of the physical resistors r1, r2, r3, and r4, with model “resistor”. Since parameter globwidth does not have its own distribution defined, but rather gets its value from the parameter globw, the value for globwidth is the same wherever it is used; thus the resistors have the same width for each Monte Carlo sample, and therefore the same resistance. When plotting the simulation results v1, v2, v3, and v4 from the `.meas` file, the waveforms overlay perfectly. This type of setup is typically used to model global variations, which means variations that affect all devices the same way.
- test2.sp has a distribution parameter defined called locwidth. This parameter is used to define the width of the physical resistors r1, r2, r3, and r4, with model “resistor”. Since the parameter has its own distribution defined, its value will be different for each reference, and of course for each Monte Carlo sample. Therefore, the resistors will always have different values, and the voltages will be different. This type of setup is typically used to model local variations, which means variations that affect devices in a different way.
- test3.sp has two kinds of distributions defined: globw/globwidth as in the first example, and locwidth as in the second example. The sum of the two is used to define the width of the resistors. Therefore, the resistors will always have different widths: a common variation due to globwidth and a separate variation due to locwidth. In the example, the distribution for locwidth was chosen as narrower than for globwidth. When overlaying the measurement results, the large common variation can easily be seen; however, all voltages are different.

In summary, each reference to a parameter with a specified distribution causes a new random variable to be generated for each Monte Carlo sample. When referencing the parameter on an instance, the effect of a local variation is created. When referencing the parameter on an expression for a second parameter and using the second parameter on an instance, then the effect of a global variation is created.

Variations Specified in the Context of Subcircuits

The concept explained in the previous section applies also to subcircuits as instances, and instances within subcircuits. Here we again use the example of a physical resistor, with variation of its width.

- test4.sp uses a subcircuit for each resistor instead of the top-level resistors in test3.sp. On each subcircuit, a parameter “width” is assigned a value by an expression, which is the same for all of them. This value is then passed into the subcircuit and the resistor width gets this value. Because the expression is the same for all subcircuits, the value of parameter “width” will be the same for all subcircuits, thus it expresses a global variation. Therefore all resistors have the same width, and the terminal voltages are the same.
- In test5.sp, if a different “width” is used for the subcircuits, then the expressions are treated separately, get local variation assigned, and different values are passed into the subcircuit. In test5.sp, the differences inside of the expressions are kept numerically very small, thus the differences from the different values of “locwidth” are dominant and the results look almost identical to the ones from test3.sp.
- In test6.sp, the resistor width is assigned inside of the subcircuit. The variations get picked up from the top level. Because each subcircuit is a separate entity, the parameter “w” is treated as a separate reference, thus each resistor will have its own value, partly defined through the common value of “globwidth” and partly through the separate value of “locwidth”.
- test7.sp has two resistors in the subcircuit. Each device in each subcircuit has a separate reference to the variation, therefore each device gets its own value.
- In test8.sp, the variation definition for “locwidth” has been moved from the top level into the subcircuit. Each resistor has a common global variation and its own local variation.
- test9.sp assigns the top level variation to a local parameter, which in turn is applied to the width definition of the resistor. This happens independently within each subcircuit, thus we end up with the same values for the resistor pair in each subcircuit, but different values for the different pairs. This technique can be applied to long resistors when a middle terminal is required for connecting capacitance to the substrate. The resulting two resistor pieces will have the same resistance, but it will be different from other resistor pairs.

In summary, each subcircuit has its own parameter space, therefore it is possible to put groups of identical components into a subcircuit, and within each group all devices have the same parameter values, but between the groups, parameters are different. When specifying variations on these parameters, the effects of local variations between the groups are created.

Variations on a Model Parameter Using a Local Model in Subcircuit

If a model is specified within a subcircuit, then the specified parameter values apply only to the devices in the same subcircuit. Therefore, it is possible to calculate the value of a model parameter within the subcircuit; for example, as a function of geometry information.

When specifying variations on these parameters, the effects of local variations between subcircuits are created. If this method is used at the extreme with one device per subcircuit, then each device has its own model. This approach leads to a substantial overhead in the simulator and is therefore not recommended.

Indirect Variations on a Model Parameter

In sections Variations Specified on Geometrical Instance Parameters and Variations Specified in the Context of Subcircuits, variations on geometrical parameters were presented. If we want to specify variations on a model parameter; for example, the threshold of a MOS device, then the approach explained in the previous section with one model per device in a subcircuit could be used. However, this is impractical because the netlist needs to be created to call each device as a subcircuit, and because of the overhead. Since variations are of interest only on a few model parameters, an indirect method of varying model parameters can be used. Some special instance parameters are available for this purpose. For example, for MOS devices, the parameter delvt0 defines a shift in threshold.

Referencing a parameter with a distribution as value for `delvt0` creates the effect of local threshold variations. A significant number of parameters of this type are available in HSPICE RF for BSIM3 and BSIM4 models. The variations can be tailored for each device depending on its size for example. A disadvantage of this method is that the netlist needs to be parameterized properly to get the correct variations. The process of preparing a basic netlist for Monte Carlo simulations with this approach is tedious and error prone, therefore it is best handled with scripts.

Bsim3 supports the following instance parameters:

L, w, ad, as, pd, ps, nrd, nrs, rdc, rsc, off, ic, dtemp, delvto, geo, sa, sb, sd, nf, stimod, sa1, sa2, sa3, sa4, sa5, sa6, sa7, sa8, sa9, sa10, sb1, sb2, sb3, sb4, sb5, sb6, sb7, sb8, sb9, sb10, sw1, sw2, sw3, sw4, sw5, sw6, sw7, sw8, sw9, sw10, mulu0, mulua, mulub, tnodeout, rth0, cth0, deltox, delk1, delnfct, and acnqsmod.

Bsim4 supports the following instance parameters:

L, w, ad, as, pd, ps, nrd, nrs, rdc, rsc, off, ic, dtemp, delvto, geo, rbsb, rbdb, rbpb, rbps, rbpd, trnqsmod, acnqsmod, rbodymod, rgatemod, geomod, rgeomod, nf, min, mulu0, delk1, delnfct, deltox, sa, sb, sd, stimod, sa1, sa2, sa3, sa4, sa5, sa6, sa7, sa8, sa9, sa10, sb1, sb2, sb3, sb4, sb5, sb6, sb7, sb8, sb9, sb10, sw1, sw2, sw3, sw4, sw5, sw6, sw7, sw8, sw9, sw10, xgw, ngcon, sca, scb, scc, sc, delk2, delxj, mulngate, delrsh, delrshg, dellpe0, deldvt0, and mulvsat.

Variations Specified on Model Parameters

In this section, we investigate the method of specifying distributions on parameters and using these parameters to define values of model parameters. With this approach, the netlist does not have to be parameterized. The `modmonte` option can be used to distinguish between global variations (all devices of a particular model have the same parameter set) or local variations (every device has a unique random value for the specified parameters).

- test10.sp shows a simple case where the model parameter for sheet resistivity is assigned a distribution defined on the parameter `rsheet`. The results show that all resistors have the same value for each Monte Carlo sample, but a different one for different samples. This setup is useful for studying global variations.
- test11.sp has `.option modmonte=1` added. Now every resistor has a different value.

Note that `.option modmonte` has no effect on any other approach presented here.

In summary, assigning parameters with specified distributions to model parameters allows for investigating the effects of global or local variations, but not both. The possibility of selecting one or the other with a simple option is misleading in the sense that the underlying definitions for global and local variations are not the same for a realistic semiconductor technology.

Variations Specified Using DEV and LOT

The two limitations of the approach described in section Variations Specified on Model Parameters are resolved in this method by specifying global and local variations directly on a model parameter with the syntax:

```
parameterName=parameterValue LOT/distribution LotDist
+ DEV/distribution DevDist
```

Where,

`LOT` keyword for global distribution
`DEV` keyword for local distribution
distribution is as explained in section Variations Specified on Geometrical Instance Parameters
`LotDist`, `DevDist` characteristic number for the distribution. 3-sigma value for Gaussian distributions.

- test12.sp has large global and small local variation, similar to the setup in the file test3.sp The result shows four different curves, with a large common part and small separate parts. The amount of variation defined in the two files is the same. The curves look different from the test3.sp results, because different random sequences are used. However the statistical results (sigma) converge for a large number of samples.

There is no option available to select only local or only global variations. This can be an obstacle if the file is read-only or encrypted.

Combinations of Variation Specifications

Specifying distributions on parameters and applying them to model parameters can be used on some models and the `DEV`/`LOT` approach on others in the same simulation.

- test13.sp has `DEV`/`LOT` specified for model res1, and the parameter “width” for model res2. The values for the resistors with model res1 are different, and the values for resistors with model res2 are the same.
- test14.sp is similar to test7.sp and has `modmonte=1` specified. All four resistors have different values. However, note that in reality, the sigma for width would be different when simulating local or global variations.
- test15.sp has instance parameter variations specified on two resistors and `DEV`/`LOT` on two others. From the waveforms, v3 and v4 form a first pair, and v1 and v2 a second pair.

It is also possible to mix variations on instance parameters and model parameters in the same setup.

- test16.sp has small instance parameter variations specified on width and relatively large model parameter variations on the sheet resistivity, `rsh`. The results show four different waveforms, with a common behavior.
- test17.sp shows instance and model parameter variations as in the previous test case, but `.option modmonte` is set to 1, thus the model variations affect every device in a different way. The results show completely independent behavior of all four resistors.

If an instance parameter or instance parameter variations and model parameter variations are specified on the same parameter, then the instance parameter always overrides the model parameter. Because only few parameters can be used in both domains, this case is rather seldom, but it needs to be considered to avoid unexpected results.

- test18.sp has model variation specified on width with a parameter. Two resistors have width also defined on instance. The resistors with instance parameter do not vary at all. The other two resistors vary independently, as expected because `.option modmonte` is set to 1.
- test19.sp is similar to test18.sp with `.option modmonte` set to 0. The two resistors that do not have width defined on the instance line vary together.
- test20.sp has `DEV`/`LOT` specified. Instance parameters override variations on selected resistors.

Variation on Model Parameters as a Function of Device Geometry

For local variations (see DC Mismatch Analysis), it is a common requirement to specify variation on a model parameter as a function of device geometry. For example, the MOS device threshold was observed to vary with the total device area.

The approach explained in the section Indirect Variations on a Model Parameter can be used. While this allows for specifying local variations on each device, it does not include the capability of using expressions based on element parameters. Thus, variation cannot be described with an expression that includes the device’s geometry. Conceptually, a netlist processor could be written that inserts the appropriate values for the parameters as a function of device size. (Synopsys does not make such a tool available).

The `DEV/LOT` approach has no mechanism to describe variation as a function of an element parameter.

16

Advanced Features

Describes how to invoke HSPICE RF and how to perform advanced tasks, including redirecting input and output.

HSPICE RF accepts a netlist file from stdin and delivers the ASCII text simulation results to an HTML file or to stdout. Error and warning messages are forwarded to standard error output.

This chapter describes how to do this as well as how to invoke HSPICE RF and redirect input and output.

Creating a Configuration File

You can create a configuration file, called *.hspicerf*, to customize your HSPICE RF simulation. HSPICE RF first searches for *.hspicerf* in your current working directory, then in your home directory as defined by `$HOME`. The configuration options listed in Table 27 are available for your use.

Table 27 Configuration File Options

Keyword	Description	Example
flush_waveform	Flushes a waveform. If you do not specify a percentage, then the default value is 20%.	`flush_waveform percent%`
ground_floating_ node	Uses .IC statements to set floating nodes in a circuit to ground. You can select three options for grounding floating nodes: ▪ If set to `1,` grounds only floating nodes (gates, bulk, control nodes, non-rail bulk) that are included in the .IC set. ▪ If set to 2, adds unconnected terminals to this set. ▪ If set to 3, uses .IC statements to ground all floating nodes, including dangling terminals.	`ground_floating_ node 1`
hier_delimiter	Changes the delimiter for subcircuit hierarchies from "." to the specified symbol.	`hier_delimiter /`
html	Stores all HSPICE RF output in HTML format.	`htmlhspicerf test` This example creates a file named test.html in the current directory.
integer_node	Removes leading zeros from node names. For example, HSPICE RF considers 0002 and 2 to be the same node. Without this keyword, 0002 and 2 are two separate nodes.	`integer_node`
max_waveform_size	Automatically limits the waveform file size. ▪ If the number is less than 5000, HSPICE RF resets it to 2G. ▪ If you do not set the number, HSPICE RF uses the default, 2G. ▪ If you do not set the line, the file size has no limit.	`max_waveform_ size 2000000000`

Table 27 Configuration File Options (Continued)

Keyword	Description	Example
negative_td	Allows negative time delay input in `pwl` (piecewise linear with repeat), `pl` (piecewise linear), `exp` (exponential, rising time delay only), `sin` (damped sinusoidal), `pulse` (trapezoidal pulse), and `am` (amplitude modulation) formats.	If you do not set `negative_td`, a negative time delay defaults to zero.
port_element_ voltage_ matchload	Allows the alternate Port element definition. A Port element consists of a voltage source in series with a resistor. For the explanation that follows, let the user-specified DC, AC, or transient value of the Port element be V, and let the voltage across the overall port element be Vp. By default, HSPICE RF will set the internal voltage source value to V. The value of Vp will be lower than V, depending on the internal impedance and the network's input impedance. With the alternate definition, the internal voltage source value is adjusted to 2*V, so that Vp=V when the Port element's impedance is matched with the network input impedance. The actual value of Vp will still depend on the port and network impedances.	`port_element_ voltage_ matchload`
rcxt_divider	Defines the hierarchy delimiter in the active nodes file in RCXT format.	`rcxt_divider /`
skip_nrd_nrs	Directs HSPICE RF to consider transistors with matching geometries (except for NRD and NRS) as identical for pre-characterization purposes.	`skip_nrd_nrs`
unit_atto	Activates detection of the “atto.” unit. Otherwise, HSPICE RF assumes that “a” represents “amperes.”	`unit_atto`
v_supply	Changes the default voltage supply range for characterization.	`v_supply 3`
wildcard_left_range	Begins range expression.	`wildcard_left_ range [`

Table 27 Configuration File Options (Continued)

Keyword	Description	Example
wildcard_match_all	Matches any group of characters.	`wildcard_match_ all *`
wildcard_match_one	Matches any single character.	`wildcard_match_ one ?`
wildcard_right_range	Ends range expression.	`wildcard_right_ range ]`

Note:

For more information about wildcards, see Using Wildcards in HSPICE RF on page 369.

Inserting Comments in a .hspice File

To insert comments into your .hspicerf file, include a number sign character (#) as the first character in a line. For example, this configuration file shows how to use comments in a *.hspicerf* file:

```
# sample configuration file
# the next line of code changes the delimiter
# for subcircuit hierarchies from "," to "^"
hier_delimiter ^
# the next line of code matches any groups of "*" characters
wildcard_match_all *
# the next line of code matches one "?" character
wildcard_match_one ?
# the next line of code begins the range expression with
# the "[" character
wildcard_left_range [
# the next line of code ends the range expression with
# the "]" character
wildcard_right_range ]
```

Using Wildcards in HSPICE RF

You can use wildcards to match node names. HSPICE RF uses wildcards somewhat differently than standard HSPICE.

Before using wildcards, you must define the wildcard configuration in a .hspicerf file. For example, you can define the following wildcards in a .hspicerf file:

```
file .hspicerf
wildcard_match_one     ?
wildcard_match_all     *
wildcard_left_range    [
wildcard_right_range   ]
```

The `.PRINT`, `.PROBE`, `.LPRINT`, and `.CHECK` statements support wildcards in HSPICE RF.

For more information about using wildcards in an HSPICE configuration file, see Using Wildcards in PRINT, PROBE, PLOT, and GRAPH Statements in the *HSPICE Simulation and Analysis User Guide*.

Limiting Output Data Size

For multi-million transistor simulations, an unrestricted waveform file can grow to several gigabytes in size. The file becomes unreadable in some waveform viewers, and requires excessive space on the hard drive.

This section describes options that limit the number of nodes output to the waveform file to reduce the file size. HSPICE RF supports the following options to control the output:

- SIM_POSTTOP Option
- SIM_POSTSKIP Option
- SIM_POSTAT Option
- SIM_POSTDOWN Option
- SIM_POSTSCOPE Option

SIM_POSTTOP Option

You use the `SIM_POSTTOP` option to limit the data written to your waveform file to data from only the top *n* level nodes. This option outputs instances up to *n* levels deep. For example,

```
.OPTION SIM_POSTTOP=<n>
```

Note:

To enable the waveform display interface, you also need the `POST` option.

For additional information, see .OPTION SIM_POSTTOP in the *HSPICE and HSPICE RF Command Reference*.

SIM_POSTSKIP Option

You use the `SIM_POSTSKIP` to have the `SIM_POSTTOP` option skip any instances and their children that the subckt_definition defines. For example,

```
.OPTION SIM_POSTSKIP=<subckt_definition>
```

For additional information, see .OPTION SIM_POSTSKIP in the *HSPICE and HSPICE RF Command Reference*.

SIM_POSTAT Option

You use the SIM_POSTAT

option to limit the waveform output to only the nodes in the specified subcircuit

instance. For example,

```
.OPTION SIM_POSTAT=<instance>
```

This option can be used in conjunction with the `SIM_POSTTOP` option and when present, has precedence over the `SIM_POSTSKIP` option.

For additional information, see .OPTION SIM_POSTAT in the *HSPICE and HSPICE RF Command Reference*.

SIM_POSTDOWN Option

You use the `SIM_POSTDOWN` option to include an instance and all children of that instance in the output. For example,

```
.OPTION SIM_POSTDOWN=<instance>
```

It can be used in conjunction with the `SIM_POSTTOP` option and when present, has precedence over the `SIM_POSTSKIP` option.

For additional information, see .OPTION SIM_POSTDOWN in the HSPICE and HSPICE RF Command Reference.

SIM_POSTSCOPE Option

You use the `SIM_POSTSCOPE` option to specify the signal types to probe from within a scope. For example,

```
.OPTION SIM_POSTSCOPE=net|port|all
```

For additional information, see .OPTION SIM_POSTSCOPE in the *HSPICE and HSPICE RF Command Reference*.

Probing Subcircuit Currents

To provide subcircuit power probing utilities, HSPICE RF uses the X() and X0() extended output variables. You can use these X variables in `.PROBE`, `.PRINT`, or `.MEASURE` statements.

The following syntax is for the output variable X():

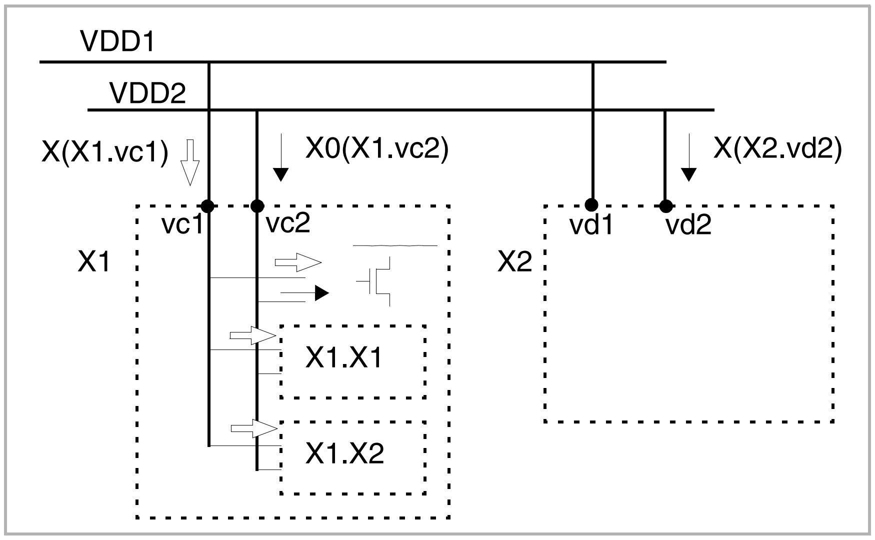
```
X (subcircuit_node_path)
X0 (subcircuit_node_path)
```

subcircuit_node_path specifies the subcircuit path and the subcircuit node name definition. The node must be either an *external* node in a subcircuit definition or a global node.

X() returns the total current flowing into a subcircuit branch, including all lower subcircuit hierarchies. X0() returns only current flowing into a subcircuit branch, minus any current flowing into lower subcircuit hierarchies. Figure 45 on page 372 illustrates the difference between the X() and X0 () variables.

The dotted line boxes represent subcircuits, and the black circles are the external nodes. The X(X1.vc1) path returns the current of the X1subcircuit, through the *vc1* node, including the current to the X1.X1 and X1.X2 subcircuits as represented by the white (black outlined) arrows. In contrast, X0(X1.vc2) returns only the current flowing through vc2 to the top level of the X1 subcircuit as shown by the black arrows.

Figure 45 Probing Subcircuit Currents



Example 1

In this example, the first five lines constitute the definition of the `sb1` subcircuit with external nodes named `node1`, `node2`, and `clr`. The line beginning with `X1` is an instance of `sb1` with nodes named;

- `11` (references `node1`)
- `12` (references `node2`)
- `0` (references `clr`)

```
.subckt sb1 node1 node2 clr
* subckt elements
R1 node1 node2 1K
C1 clr node1 1U
.ends
* subcircuit instance
X1 11 12 0 sb1
.PRINT X(X1.node1) 'X(X1.clr) + I(X1.R1)'
```

To find the current flowing into node `11` of the `X1` subcircuit instance, this example uses the `X()` variable. HSPICE RF maps node `11` to the `node1` external node as shown in the first part of the `.PRINT` statement.

The latter half of the `.PRINT` statement illustrates that you can combine the `X()` variable with `I()` variables.

Example 2

In this example, the `X()` variable finds the current through the *in* node of the `S1` subcircuit.

```
.subckt S1 in out
R1 in inp 1K
C1 inp 0 1u
R2 in out 1K
.PROBE X(in)
.ends
```

Generating Measurement Output Files

You can make all of the same measurements with the `.MEASURE` statement in HSPICE RF as you can in HSPICE.

The results of the `.MEASURE` statements appear in a file with one of the following filename extensions:

- .mt# for measurements in transient analysis
- .ms# for measurements in DC analysis
- .ma# for measurements in AC analysis
- .mb# for measurements in HB analysis
- .mp# for measurements in HBNOISE analysis

For more information about `.MEASURE` statements, see the *HSPICE and HSPICE RF Command Reference*.

Optimization

Like HSPICE, HSPICE RF employs an incremental optimization technique. This technique solves the DC parameters first, then the AC parameters, and finally the transient parameters.

To perform optimization, create an input netlist file that specifies:

- Optimization parameters with upper and lower boundary values along with an initial guess.
- An AC, DC, TRAN, HB, or HBOSC optimization statement.

- An optimization model statement.
- Optimization measurement statements for optimization parameters.

If you provide the input netlist file, optimization specifications, limits, and initial guess, then the optimizer reiterates the simulation until it finds an optimized solution.

Usage Notes and Examples

- Optimization works for TRAN, AC, DC, HB, HBOSC, and HBAC analyses.
- You can add the `GOAL` options in every meaningful `.MEASURE` statement, like `FIND-WHEN`, `FIND-AT`, and so forth.
- A data sweep is not required to be defined in the `.HB` statement for HB optimization to use the measured result from `.MEASURE HBNOISE`, `PHASENOISE`, or `HBTRAN` statements. Therefore, parameter sweep is not supported for this type of optimization.
- Optimize multiple parameters with multiple goals by selecting `.MODEL OPT LEVEL=0` (modified Lavenberg-Marquardt method).
- Optimize single parameters in single measurement situations by selecting `.MODEL OPT LEVEL=1` (bisection method).
- Examples
  - Setting optimization parameters

    ```
    .param W=opt1(231u, 100u, 800u)
    .param Rs=opt1(10,8,20)
    ```

  - Optimization analysis statement

    ```
    .HB tones=2.25g 2.5g nharms=6,3
     + sweep Pin:dbm -30 0 2
     + sweep optimize = opt1
     + results = gain $measure result to tune the parameters
     + model= optmod1
    ```

  - Selecting an optimization model

    ```
    .model optmod1 opt level=1 $Bisection method
     + itropt=40 relin=1e-4 relout=1e-6 $ accuracy settings
    ```

  - Measurement statements to tune the optimization parameters

    ```
    .measure HB vif find vdb(if+)[-1,1] at 10e-6
    .measure HB vrf find vdb(rf+)[0,1] at 10e-6
    .measure HB gain=param('vif-vrf') goal=-2
    ```

- Measurement statement to find the fundamental frequency from HB analysis

  ```
  .measure HB frequency_max FIND 'HERTZ[1]' at=0
  ```

Optimizing AC, DC. and TRAN Analyses

The HSPICE syntax is followed for optimizing AC, DC. and TRAN analyses. The required statements are:

- Optimization `.PARAM` statement

  ```
  .PARAM <ParamName>=OPTxxx(<Init>,<LoLim>,<HiLim>)
  ```

- Optimizing `.TRAN` statement

  ```
  .TRAN tincr1 tstop1 <tincr2 tstop2 ... tincrN tstopN>
  + SWEEP OPTIMIZE=OPTxxx RESTULTS=measname MODEL=optmod
  ```

- Optimizing `.MODEL` statement

  ```
  .MODEL mname OPT LEVEL=[0|1]
  ```

  Where:

  - 0 specifies the Modified Levenberg-Marquardt method. You would use this setting with multiple optimization parameters and goals.
  - 1 specifies the Bisection method. You would use this setting with one optimization parameter.

Optimizing HB Analysis

There are two types of optimizations with HB analyses:

- Optimization with only HB measurements
- Optimization with HBNOISE, PHASENOISE, or HBTRAN measurements

Optimization With HB Measurements

The required statements are:

- Analysis statement

```
.HB TONES=<f1>[<f2> ... <fn>] <NHARMS=<h1>,<h2> ... <hn>>
+ SWEEP parameter_sweep OPTIMIZE=OPTxxx RESULT=measname
+ MODEL=mname
```

- Measure statement

```
.MEASURE HB measname FIND out_var1 AT=val GOAL=val
```

Optimization With HBNOISE, PHASENOISE, or HBTRAN Measurements

The required statements are:

- Analysis statement

```
.HB TONES=<f1>[<f2> ... <fn>] <NHARMS=<h1>,<h2> ... <hn>>
+ SWEEP OPTIMIZE=OPTxxx RESULT=measname MODEL=mname
```

For example,

```
.HBOSC tones=1g nharms = 5 optimize = opt1
+ result = y1, y2 model = m1
    .model m1 opt level=0
    .PHASENOISE dec 1 1k 1g
    .meas phasenoise y1 find phnoise at 10k goal = -150dbc
    .meas phasenoise y2 RMSJITTER phnoise units = sec goal =
1.0e-12
```

- Measure statement

```
.MEASURE HBNOISE measname FIND out_var1 AT=val GOAL=val
.MEASURE PHASENOISE measname FIND out_var1 AT=val
+ GOAL=val
.MEASURE HBTRAN measname FIND out_var1 AT=val GOAL=val
```

Optimizing HBOSC Analysis

There are two types of optimizations with .HBOSC analyses:

- Optimization with only HB measurements
- Optimization with HBNOISE, PHASENOISE, or HBTRAN measurements

Optimization With HB Measurements

The required statements are:

- Analysis statement

  ```
  .HBOSC TONES=<f1>[<f2> ... <fn>] <NHARMS=<h1>,<h2> ... <hn>>
  + SWEEP parameter_sweep OPTIMIZE=OPTxxx RESULT=measname
  + MODEL=mname
  ```

- Measure statement

  ```
  .MEASURE HB measname FIND out_var1 AT=val GOAL=val
  ```

Optimization With HBNOISE, PHASENOISE, or HBTRAN Measurements

The required statements are:

- Analysis statement

  ```
  .HBOSC TONES=<f1>[<f2> ... <fn>] <NHARMS=<h1>,<h2> ... <hn>>
  + SWEEP OPTIMIZE=OPTxxx RESULT=measname MODEL=mname
  ```

  For example,

  ```
  .HBOSC tones=1g nharms = 5 sweep x 1 5 1 optimize = opt1
  + result = y1, y2 model = m1
     .model m1 opt level=0
     .PHASENOISE dec 1 1k 1g
     .meas phasenoise y1 find phnoise at 10k goal = -150dbc
     .meas phasenoise y2 RMSJITTER phnoise units = sec goal =
  1.0e-12
  Measure statement—
  .MEASURE HBNOISE measname FIND out_var1 AT=val GOAL=val
  .MEASURE PHASENOISE measname FIND out_var1 AT=val
  + GOAL=val
  .MEASURE HBTRAN measname FIND out_var1 AT=val GOAL=val
  ```

Optimization with HBNOISE, PHASENOISE or HBTRAN measurements must not be used in combination with HB measurement optimization as shown in Optimization With HB Measurements.

Using CHECK Statements

The CHECK statements in HSPICE RF offer the following instrumentation:

- Setting Global Hi/Lo Levels
- Slew, Rise, and Fall Conditions
- Edge Timing Verification
- Setup and Hold Verification
- IR Drop Detection

The results of these statements appear in a file with an .err extension. To prevent creating unwieldy files, HSPICE RF reports only the first 10 violations for a particular check in the .err file.

Setting Global Hi/Lo Levels

You use the `.CHECK GLOBAL_LEVEL` statement to globally set the desired high and low definitions for all CHECK statements. For example,

```
.CHECK GLOBAL_LEVEL (hi lo hi_th lo_th)
```

Values for hi, lo, and the thresholds are defined by using this statement.

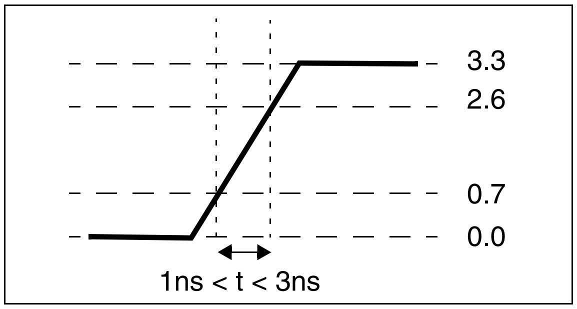
For syntax and description of this statement, see .CHECK GLOBAL_LEVEL in the *HSPICE and HSPICE RF Command Reference*.

Slew, Rise, and Fall Conditions

You use the `.CHECK SLEW` statement to verify that a slew rate occurs within the specified window of time. For example,

```
.CHECK SLEW (min max) node1 <node2 ...> <(hi lo hi_th lo_th)
```

Figure 46   SLEW Example

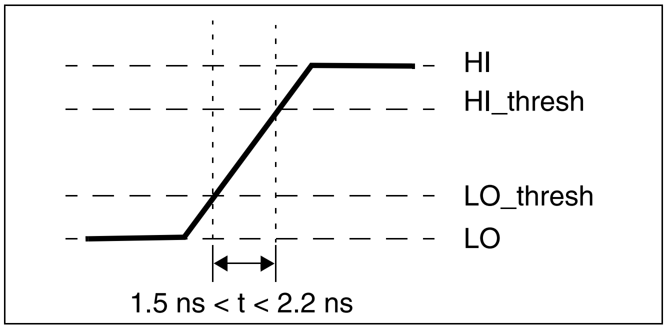


For syntax and description of this statement, see .CHECK SLEW in the *HSPICE and HSPICE RF Command Reference*.

You use the `.CHECK RISE` statement to verify that a rise time occurs within the specified window of time. For example,

```
.CHECK RISE (min max) node1 <node2 ...> <(hi lo hi_th lo_th)>
```

Figure 47 RISE Time Example



For syntax and description of this statement, see .CHECK RISE in the *HSPICE and HSPICE RF Command Reference*.

You use the `.CHECK FALL` statement to verify that a fall time occurs within the specified window of time. For example,

```
.CHECK FALL (min max) node1 <node2 ...> <(hi lo hi_th lo_th)>
```

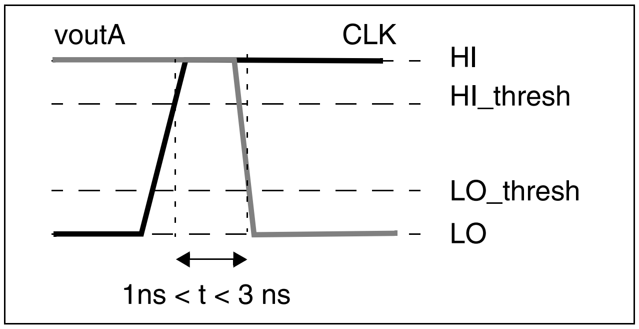
For syntax and description of this statement, see .CHECK FALL in the *HSPICE and HSPICE RF Command Reference*.

Edge Timing Verification

The edge condition verifies that a triggering event provokes an appropriate RISE or FALL action, within the specified time window. You use the `.CHECK EDGE` statement to verify this condition. For example,

```
.CHECK EDGE (ref RISE|FALL min max RISE|FALL)
+ node1 < node2 . . . > < (hi lo hi_th low_th) >
```

Figure 48   EDGE Example



For syntax and description of this statement, see .CHECK EDGE in the *HSPICE and HSPICE RF Command Reference*.

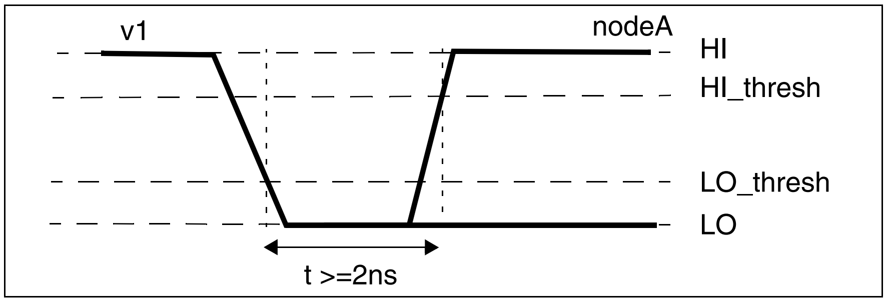
Setup and Hold Verification

You use the `.CHECK SETUP` and `.CHECK HOLD` statements to ensure that specified signals do not switch for a specified period of time. For example,

```
.CHECK SETUP (ref RISE|FALL duration RISE|FALL) node1
+< node2 . . . > < (hi lo hi_th low_th) >
.CHECK HOLD (ref RISE|FALL duration RISE|FALL) node1
+< node2 . . . > < (hi lo hi_th low_th) >
```

- For a SETUP condition, this is the minimum time before the triggering event, during which the specified nodes cannot rise or fall.

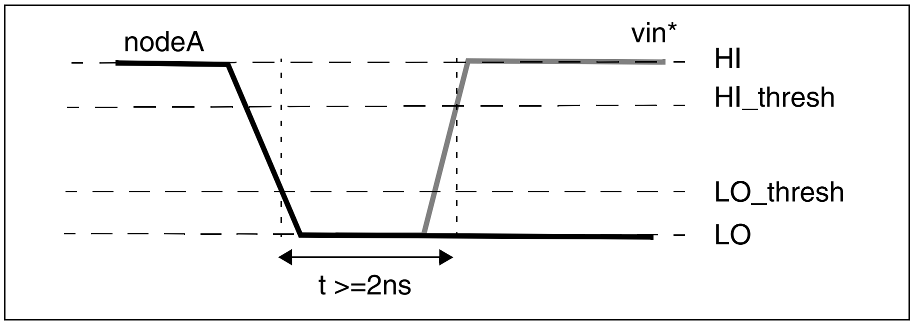
Figure 49   SETUP Example



For syntax and description of this statement, see .CHECK SETUP in the *HSPICE and HSPICE RF Command Reference*.

- For a HOLD condition, this is minimum time required after the triggering event, before the specified nodes can rise or fall.

Figure 50 HOLD Example



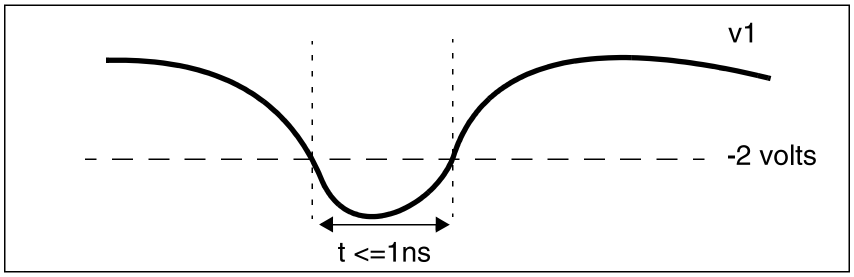
For syntax and description of this statement, see .CHECK HOLD in the *HSPICE and HSPICE RF Command Reference*.

IR Drop Detection

You use the `.CHECK IRDROP` statement to verify that the IR drop does not exceed, or does not fall below, a specified value for a specified duration. For example,

```
.CHECK IRDROP ( volt_val time ) node1 < node2 . . . >
+ < ( hi lo hi_th low_th ) >
```

Figure 51 IR Drop Example



For syntax and description of this statement, see .CHECK IRDROP in the *HSPICE and HSPICE RF Command Reference*.

POWER DC Analysis

You use the `.POWERDC` (standby current) statement to calculate the DC leakage current of a design hierarchy. For example,

```
.POWERDC <keyword> <subckt_name1...>
```

This statement creates a table that lists the measurements of the AVG, MAX, and MIN values for the current of every instance in the subcircuit. This table also lists the sum of the power of each port in the subcircuit.

You use the `SIM_POWERDC_HSPICE` option to increase the accuracy of operating point (OP) calculations.

Or for even higher accuracy in operating point calculations, you use the `SIM_POWERDC_ACCURACY` option.

For syntax and description of this statement and options, see .POWERDC, .OPTION SIM_POWERDC_ACCURACY or .OPTION SIM_POWERDC_HSPICE in the *HSPICE and HSPICE RF Command Reference*.

Power DC Analysis Output Format

```
*** Leakage Current Result ***
Subckt Name=XXX
Instance Name       Port   Max(A)   Min(A)   Avg(A)
.....
Total Power          Max(W)   Min(W)   Avg(W)
NOTE:    Power=Sum{Ii * Vi}
Subckt Name=XXX
Instance Name       Port   Max(A)   Min(A)   Avg(A)
.....
Total Power          Max(W)   Min(W)   Avg(W)
```

Example

```
.global vdd vss
.powerdc all
x1 in1 mid1 inv
x2 mid1 out1 inv
.subckt inv in out
mn out in vss vss nch
mp vdd in out vdd pch
.ends
.end
```

(Output)

```
*** Leakage Current Result ***
Subckt Name=Top Level
Instance Name      Port   Max(A)   Min(A)   Avg(A)
   x1   in      .......
   x1   out      .......
   x2   in      .......
   x2   out      .......
   Total Power         .......
Subckt Name=inv
Instance Name      Port   Max(A)   Min(A)   Avg(A)
   mn   d      .......
   mn   g      .......
   mn   s      .......
   mn   b      .......
   mp   d      .......
   mp   g      .......
   mp   s      .......
   mp   b      .......
   Total Power         .......
```

POWER Analysis

The `.POWER` statement in HSPICE RF creates a table, which by default contains the measurements for AVG, RMS, MAX, and MIN for every signal specified. For example,

```
.POWER <signals> <REF=vname FROM=start_time TO=end_time>
```

By default, the scope of these measurements are set from 0 to the maximum timepoint specified in the `.TRAN` statement.

For syntax and description of `.POWER` statement, see .POWER in the *HSPICE and HSPICE RF Command Reference*.

Example 1

In this example, no simulation start and stop time is specified for the x1.in signal, so the simulation scope for this signal runs from the start (0ps) to the last .tran time (100ps).

```
.power x1.in
.tran 4ps 100ps
```

Example 2

You can use the FROM and TO times to specify a separate measurement start and stop time for each signal. In this example:

- The scope for simulating the x2.in signal is from 20ps to 80ps.
- The scope for simulating the x0.in signal is from 30ps to 70ps.

```
.param myendtime=80ps
.power x2.in REF=a123 from=20ps to=80ps
.power x0.in REF=abc from=30ps to='myendtime - 10ps'
```

Setting Default Start and Stop Times

In addition to using `FROM` and `TO` times in a `.POWER` statement, you can also use the `SIM_POWERSTART` and `SIM_POWERSTOP` options with `.POWER` statements to specify default start and stop times for measuring signals during simulation. These times apply to all signals that do not have their own defined `FROM` and `TO` measurement times. For example,

```
.OPTION SIM_POWERSTART=<time>
.OPTION SIM_POWERSTOP=<time>
```

These options control the power measurement scope; the default is for the entire run.

For syntax and description of these options, see .OPTION SIM_POWERSTART or .OPTION SIM_POWERSTOP in the *HSPICE and HSPICE RF Command Reference*.

Controlling Power Analysis Waveform Dumps

You use the `SIM_POWERPOST` option to control power analysis waveform dumping. For example,

```
.OPTION SIM_POWERPOST=ON|OFF
```

Considering the potentially enormous number of signals, there is no waveform dumping by default for the signals in the `.POWER` statement. Setting `SIM_POWERPOST=ON` turns on power analysis waveform dumping.

Controlling Hierarchy Levels

By default, HSPICE RF performs power analysis on the top three levels of hierarchy. You use the `SIM_POWER_TOP` option to control the number of hierarchy levels for power analysis. For example,

```
.OPTION SIM_POWER_TOP=<value>
```

By default, power analysis is performed on the top levels of hierarchy.

SIM_POWER_ANALYSIS Option

You use the `SIM_POWER_ANALYSIS` option to print a list of signals that match tolerance and timepoint settings. For example,

```
.OPTION SIM_POWER_ANALYSIS="< time point > < tol >"
```

-or-

```
.OPTION SIM_POWER_ANALYSIS="bottom < time point > < tol >"
```

These two options do not give you tabulated data, but they do provide a list of signals that match the tolerance setting. HSPICE RF traverses down all hierarchies and prints node(s) specified in the `.POWER` statement with larger port current than the threshold current.

- The first `SIM_POWER_ANALYSIS` option produces a list of signals that consume more current than `tol` at `time point`.
- The second `SIM_POWER_ANALYSIS` option produces the list of lowest-level signals, known as leaf subcircuits, that consume more than `tol` at `time point`.

For syntax and description of these options, statement, see .OPTION SIM_POWER_ANALYSIS in the *HSPICE and HSPICE RF Command Reference*.

Power Analysis Output Format

Power analysis, using the `.POWER` statement, creates a table that can be read by any spreadsheet to post-process the data.

Signal #	Port_Current_ Name	Definition_ Name	Parent	Dep-Up	Dep-Dn	Max(A)	Min(A)	Avg(A)	RMS(A)

Column	Description
Signal #	Index number assigned to the Port_Current_Name. You can use this value to find the parent for the port.
Port_Current_Name	Name of the port.
Definition_Name	Definition name of the subcircuit containing this port.
Parent	Identifies the parents of the Port_Current_Name.
Dep-Up	Depth count of Port_Current_Name, from top of hierarchy.

Column	Description
Dep_Dn	Depth count of Port_Current_Name, from bottom of hierarchy.
Max(A)	Maximum current flowing through the Port. You can specify more than one local maximum current value.
Min(A)	Minimum current flowing through the Port. You can specify more than one local minimum current value.
Avg(A)	Average current flowing through the Port.
RMS(A)	Root Mean Square (RMS) current flowing through the Port.

Tabulated data increases your analysis capability; based on the data generated in this format, you can analyze:

- Sub-circuits that consume a maximum amount of power.
- Leaf-nodes that consume a maximum amount of power.
- Parent's power.

Example

```
REF = NEW FROM = 0.000e+00 TO = 5.000e-7
```

Signal #	Port_Current_ Name	Definition_ Name	Parent	Dep-Up	Dep-Dn	Max(A)	Min(A)	Avg(A)	RMS(A)
14	XINV.OUT	STAGE_100	1	2	3	1.580 e-09	-1.615 e-09	1.155e -14	1.569 e-11
21	XINV.XI1.OUT	STAGE_10	17	3	2	1.667 e-03	-1.524 e-03	-1.946 e-08	2.825 e-05
28	XINV.XI1.XRI N1.OUT	INVERTER	24	4	1	7.981 e-04	-8.409 e-04	1.730 e-08	2.008 e-05
43	XINV.XI1.XRI N2.OUT	INVERTER	25	4	1	1.426 e-03	-1.314 e-03	-1.110 e-08	2.584 e-05
58	XINV.XI1.XRI N3.OUT	INVERTER	26	4	1	1.670 e-03	-1.500 e-03	1.257 e-08	2.780 e-05

Signal #	Port_Current_ Name	Definition_ Name	Parent	Dep-Up	Dep-Dn	Max(A)	Min(A)	Avg(A)	RMS(A)
73	XINV.XI1.XRI N4.OUT	INVERTER	21	4	1	1.667 e-03	-1.524 e-03	-1.946 e-08	2.825 e-05
88	XINV.XI2.OUT	STAGE_10	18	3	2	1.697 e-03	-1.424 e-03	5.399 e-08	2.840 e-05
95	XINV.XI2.XRI N1.OUT	INVERTER	91	4	1	1.702 e-03	-1.526 e-03	-1.915 e-08	2.807 e-05
110	XINV.XI2.XRI N2.OUT	INVERTER	92	4	1	1.724 e-03	-1.459 e-03	2.989 e-08	2.844 e-05
125	XINV.XI2.XRI N3.OUT	INVERTER	93	4	1	1.677 e-03	-1.514 e-03	-1.321 e-09	2.823 e-05
140	XINV.X12.XRI N4.OUT	INVERTER	88	4	1	1.697 e-03	-1.424 e-03	5.399 e-08	2.840 e-05
155	XINV.XI3.OUT	STAGE_10	19	3	2	1.738 e-03	-1.442 e-03	3.126 e-08	2.842 e-05
162	XINV.XI3.XRI N1.OUT	INVERTER	158	4	1	1.700 e-03	-1.514 e-03	-2.076 e-08	2.824 e-05
177	XINV.XI3.XRI N2.OUT	INVERTER	159	4	1	1.651 e-03	-1.433 e-03	-1.307 e-08	2.872 e-05
192	XINV.XI3.XRI N3.OUT	INVERTER	160	4	1	1.842 e-03	-1.498 e-03	1.608 e-08	2.845 e-05
207	XINV.XI3.XRI N4.OUT	INVERTER	155	4	1	1.738 e-03	-1.442 e-03	3.126 e-08	2.842 e-05
222	XINV.XI4.OUT	STAGE_10	14	3	2	1.580 e-09	-1.615 e-09	1.155 e-14	1.569 e-11
229	XINV.XI4.XRI N1.OUT	INVERTER	225	4	1	1.686 e-03	-1.457 e-03	4.245 e-09	2.845 e-05
244	XINV.XI4.XRI N2.OUT	INVERTER	226	4	1	1.700 e-03	-1.521 e-03	-3.056 e-08	2.827 e-05

Signal #	**Port_Current_ Name**	**Definition_ Name**	**Parent**	**Dep-Up**	**Dep-Dn**	**Max(A)**	**Min(A)**	**Avg(A)**	**RMS(A)**
259	XINV.XI4.XRIN3.OUT	INVERTER	227	4	1	1.754 e-03	-1.494 e-03	-3.101 e-09	3.007 e-05
274	XINV.XI4.XRIN4.OUT	INVERTER	222	4	1	1.580 e-09	-1.615 e-09	1.155 e-14	1.569 e-11

Detecting and Reporting Surge Currents

The `.SURGE` statement in HSPICE RF automatically detects and reports a current surge that exceeds the specified surge tolerance. For example,

```
.SURGE surge_threshold surge_width node1 < node2 .... noden >
```

This statement reports any current surge that is greater than *surge_threshold* for a duration of more than *surge_width*.

For additional information, see .SURGE in the *HSPICE and HSPICE RF Command Reference*.

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