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# Large-Signal S-Parameter Simulation

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# Chapter 1: Large-Signal S-Parameter Simulation

The LSSP Simulation component in the Simulation-LSSP palette (ADS), or LSSP Analysis (RFDE), computes S-parameters for nonlinear circuits such as those that employ power amplifiers and mixers. In the latter case, S-parameters can be computed *across frequencies*, that is, from the RF input to the IF output. LSSP simulation is based on the harmonic balance simulation and uses harmonic balance techniques.

Refer to the following topics for details on large-signal S-parameter simulation:

- [“Performing a Large Signal S-Parameter Simulation” on page 1-2](#) shows the minimum setup requirements for a large-signal S-parameter simulation.
- [“Example \(ADS Only\)” on page 1-3](#) is a detailed setup for calculating large-signal S-parameters, using a BJT as the example.

For an example of an LSSP analysis of a mixer circuit, refer to the design *LSSP2.dsn*, and its associated dataset, *LSSP2.dds*. It is in the same project folder as the BJT example. This example illustrates how to use a term at the output port, and uses a voltage source at the LO.

- [“LSSP Simulation Description” on page 1-7](#) is a brief explanation of the LSSP simulator and how it compares to the S-parameter simulator.
- [“LSSP Simulation Parameters” on page 1-9](#) provides details on the tabs and fields in the LSSP simulation controller.

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**Note** You must have the LSSP simulator license to run the simulation. You can build the examples in this chapter without the license, but you will not be able to simulate them.

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# Performing a Large Signal S-Parameter Simulation

Start by creating your design, then add current probes and identify the nodes from which you want to collect data. For a successful analysis:

- Apply ports to all inputs and outputs. Use a P\_1Tone or P\_nTone power source to drive a port. Terminate other ports using port-impedance terminations (Term). Verify impedance.

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**Note** The power level at a passive port (Term) will be calculated by turning on power sources and measuring the power at the port; this value will be used to drive the port.

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- Check the *Num* field for each port. The S-parameter port numbers are derived from these fields. For a 2-port circuit, you want the input labeled as Num = 1 and the output as Num = 2.
- In circuits with mixers, use a voltage source for the LO, not a power source. This prevents the LO input from being recognized as a port and consequently having the S-parameters calculated with respect to it.
- In ADS, add the LSSP control element to the schematic, then double-click to edit its parameters in the fields under the Freq and Ports tabs. In RFDE, select LSSP in the Choosing Analyses dialog, then edit the fields that appear:
  - For Freq, set the fundamental frequency and order.
  - For Ports, set the port frequency for each port. S-parameters will be measured at this frequency. Port frequency can be the input frequency or a harmonic.
  - For choosing a matrix solver, the *Auto Select* mode is the default and recommended choice. For instructions about using this option, see the topic “Selecting a Solver” in the section “HB Simulation Parameters” located in the “Harmonic Balance Basics” chapter of the *Harmonic Balance Simulation* documentation.
- You can use previous simulation solutions to speed up the simulation process. For more information, see the topic “Reusing Simulation Solutions” in the chapter “Harmonic Balance Basics” in the *Harmonic Balance Simulation* documentation.

For details about each field, click *Help* from the dialog box.

## Example (ADS Only)

Figure 1-1 illustrates the setup for a large-signal S-parameter (LSSP) simulation of a BJT. Power sources drive all ports in this example.

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**Note** This design, *LSSP\_test.dsn*, is in the *Examples* directory under *Tutorial/LSSP\_test\_prj*. The results are in *LSSP\_test.dds*.

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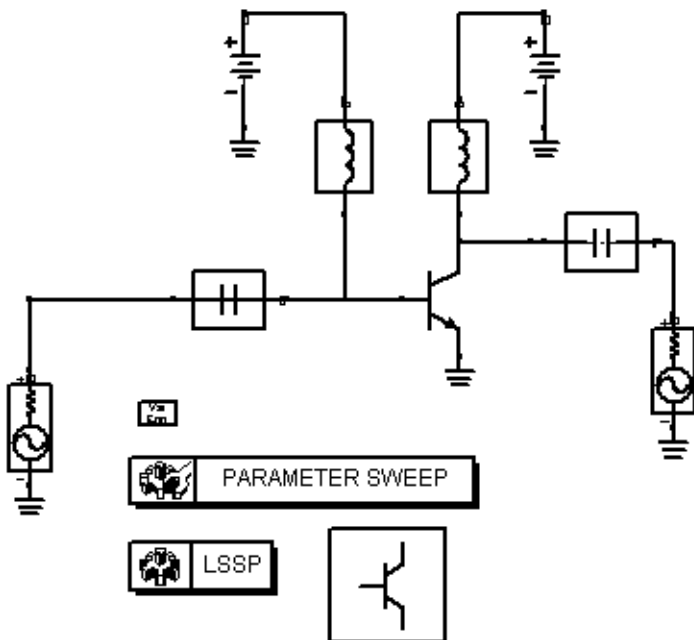


Figure 1-1. Large-signal S-parameter simulation example in ADS

1. From the **Simulation-LSSP** palette, select a **P\_1Tone** component and place it at the input of the circuit. Edit the component and set the following values:
  - Num=1
  - $P=dbmtow((10),0)$
  - Freq=LSSP\_freq
2. Select another **P\_1Tone** power source and place it at the output of the circuit. The values are the same as for the input source, except here Num = 2.

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**Note** The values in the Num parameter on the sources and terminations should reflect the placement of the ports in the circuit, so that the S-parameter data is meaningful. The number of the input (source) should be set to Num=1, and that of the output (load) to Num=2.

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3. Select and place an **LSSP** simulation component on the schematic, edit it, and select the **Freq** tab to set the following parameters:

- Frequency= LSSP\_freq
- Order[1]= 3

Click **Add**. Make sure that *1 LSSP\_freq 3* is the only line that appears in the list of fundamental frequencies. (If *LSSP\_freq* appears as the second fundamental in the frequency list, select the line above it and click *Cut*.)

4. Select the **Sweep** tab. Ensure that **Start/Stop** is selected and *Sweep Type* is **Linear**, then set the following values:

- Start = 0
- Stop = 100
- Step =1

5. Select the **Ports** tab. In the *Frequency* field, at the right of the dialog box, enter LSSP\_freq and click **Add**. This establishes the frequency at port 1, where the large-signal S-parameter will be measured. It does not have to be the same value as the fundamental frequency, it can be a harmonic.

For example, a port may have harmonics present at 0 Hz, 1 MHz, 99 MHz, 100 MHz, and 101 MHz. You can then specify your interest in the 99 MHz component by entering 99 MHz here. On the schematic, this appears as LSSP\_FreqAtPort[n]. In this example, it would appear as LSSP\_FreqAtPort[2]=99 MHz.

6. To set the frequency for port 2, click **Add** again. You should see two entries in the Port Frequency list box, each set to LSSP\_freq.

7. Click **OK** to accept changes and close the dialog box.

8. From the **Data Items** palette, select **VarEqn**. Place and edit the component to define the variable LSSP\_freq and set its value. Select the default equation ( $X=1.0$ ). In the *Variable Value* field at the right, enter 1.0 GHz.

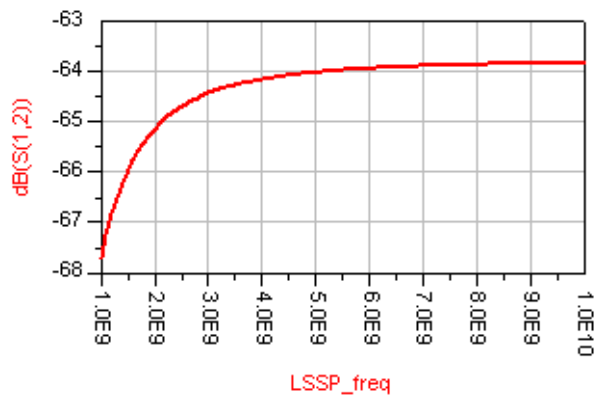
9. Click **OK** to accept changes and close the dialog box.

10. Since the fundamental is set to a single frequency, you can use a ParamSweep component to sweep a frequency range. Return to Simulation-LSSP, select and place a ParamSweep component, and edit it. Select the **Sweep** tab and set the following values:

- Parameter to sweep = LSSP\_freq
- Sweep Type = Linear
- Enable Start/Stop
- Start = 1 GHz
- Stop = 10 GHz
- Step-size = 0.1 GHz

11. Click **Simulations** and set Simulation 1 to *HBI*. Click **OK**.

12. Launch the simulation, and when it is finished, display the results. LSSP data items may be identified with an HB prefix. The following plot displays S(1,2).



# LSSP Simulation Description

Unlike small-signal S-parameters, which are based on a small-signal simulation of a linearized circuit, large-signal S-parameters are based on a harmonic balance simulation of the full nonlinear circuit. Because harmonic balance is a large-signal simulation technique, its solution includes nonlinear effects such as compression. This means that the large-signal S-parameters can change as power levels are varied. For this reason, large-signal S-parameters are also called power-dependent S-parameters.

Like small-signal S-parameters, large-signal S-parameters are defined as the ratio of reflected and incident waves:

$$S_{ij} = \frac{B_i}{A_j}$$

The incident and reflected waves are defined as:

$$A_j = \frac{\mathbf{V}_j + Z_{0j}\mathbf{I}_j}{2\sqrt{R_{0j}}}, \quad B_i = \frac{\mathbf{V}_i - Z_{0i}^*\mathbf{I}_i}{2\sqrt{R_{0i}}}$$

where

$V_i$  and  $V_j$  are the Fourier coefficients, at the fundamental frequency, of the voltages at ports  $i$  and  $j$ ,

$I_i$  and  $I_j$  are the Fourier coefficients, at the fundamental frequency, of the currents at ports  $i$  and  $j$ ,

$Z_{0i}$  and  $Z_{0j}$  are the reference impedances at ports  $i$  and  $j$ , and

$R_{0i}$  and  $R_{0j}$  are the real parts of  $Z_{0i}$  and  $Z_{0j}$ .

This definition is a generalization of the small-signal S-parameter definition in that  $V$  and  $I$  are Fourier coefficients rather than phasors. For a linear circuit, this definition simplifies to the small-signal definition.

## LSSP Simulation Process

The simulator performs the following operations to calculate the large-signal S-parameters for a two-port:

- Terminates port 2 with the complex conjugate of its reference impedance. Applies a signal with the user-specified power level  $P_1$  at port 1, using a source whose impedance equals the complex conjugate of that port's reference impedance. Using harmonic balance, calculates the currents and voltages at ports 1 and 2. Uses this information to calculate  $S_{11}$  and  $S_{21}$ .
- Terminates port 1 with the complex conjugate of its reference impedance. Applies a signal of power  $P_2 = |S_{21}|^2 P_1$  at port 2 using a source whose impedance equals the complex conjugate of the reference impedance of port 2. Using harmonic balance, calculates the currents and voltages at ports 1 and 2. Uses this information to calculate  $S_{12}$  and  $S_{22}$ .

## Comparing LSSP and S-Parameter Simulations

S-parameter simulations are performed on linear circuits. LSSP simulations can be performed on nonlinear circuits and thus include nonlinear effects such as gain compression and variations in power levels.

Both LSSP and S-parameter simulations generate PortZ[] and S[] fields in the associated dataset. LSSP generates the additional field PortPower[], which contains the power, in dBm, seen at each port for the respective LSSP port frequencies.

To compare LSSP and S-parameter simulations, refer to *LSSP1.dsn* and *SP1.dsn*. They are in the ADS *examples* directory under *Tutorial/SimModel\_prj*. The data displays are *LSSP1.dds* and *SP1.dds*.

For a review of the S-parameter simulator, refer to the topic “S-Parameter Simulation Description” in the *S-Parameter Simulation* documentation.

# LSSP Simulation Parameters

The parameters for LSSP Simulation are identical to those for Harmonic Balance, with these exceptions:

- In ADS, the simulation component has a *Ports* tab (see [“Ports in ADS” on page 1-9](#)).
- In RFDE, the LSSP options form has a *Port Frequencies* table (see [“Port Frequencies in RF Design Environment” on page 1-10](#)).
- In ADS, the Params tab contains additional parameters (see [“Defining Simulation Parameters in ADS” on page 1-11](#)).
- The options for *Small-signal mode*, *Nonlinear noise*, and *Oscillator* are not available.

For details about the parameters not described here, see the section “HB Simulation Parameters” in the chapter “Harmonic Balance Basics” in the *Harmonic Balance Simulation* documentation.

## Ports in ADS

Set up the ports portion of the simulation as shown in [Table 1-1](#). In the following table, names used in netlists and schematics appear under *Parameter Name*.

Table 1-1. ADS LSSP Simulation Ports Options

Setup Dialog Name	Parameter Name	Description
Port Frequency	LSSP_FreqAtPort[n]	Ports must be placed and defined. Set the port number of the input source to 1, and the port number of the output Term (termination) component to 2.
Select		Contains the list of fundamental frequencies. Use the Edit field to add fundamental frequencies to this window. <ul style="list-style-type: none"><li>- Add enables you to add an item.</li><li>- Cut enables you to delete an item.</li><li>- Paste enables you to take an item that has been cut and place it in a different order.</li></ul>
Edit		Edit the Frequency field, then use the buttons to Add the frequency to the list displayed under Select.
Frequency		The frequency of the fundamental(s). Change by typing over the entry in the field. Select the units (None, Hz, kHz, MHz, GHz) from the drop-down list.

## Port Frequencies in RF Design Environment

Set up the ports portion of the simulation as shown in [Table 1-2](#). In the following table, names used in netlists appear under *Parameter Name*.

**Table 1-2. RFDE LSSP Simulation Ports Options**

Setup Dialog Name	Parameter Name	Description
Port Frequencies		Ports must be placed and defined. Set the port number of the input source to 1, and the port number of the output Term (termination) component to 2.
Frequency	LSSP_FreqAtPort[n]	<p>Each port frequency will have a number assigned in the # field when you add a new frequency. For example, entry number 1 would correlate to port number 1 (input source) on the schematic and entry number 2 would correlate to port number 2 (output terminal) on the schematic.</p> <p>Use the edit field to add port frequencies.</p> <ul style="list-style-type: none"> <li>- Add enables you to add a new port frequency.</li> <li>- Delete enables you to delete a highlighted entry.</li> <li>- Update enables you to update the information of a highlighted entry.</li> <li>- Clear enables you to clear the entry field.</li> </ul>

## Defining Simulation Parameters in ADS

Defining the simulation parameters in ADS consists of these basic parts:

- Specifying the amount of device operating-point information to save
- Setting FFT oversampling ratio
- Setting the Initial Guess parameters

In the following table, names used in netlists and ADS schematics appear under *Parameter Name*.

Table 1-3. LSSP Simulation Parameter Options

Setup Dialog Name	Parameter Name	Description
Device operating point level	DevOpPtLevel	Enables you to save all the device operating-point information to the dataset. Default setting is None.
None	None	No information is saved.
Brief	Brief	Saves device currents, power, and some linearized device parameters.
Detailed	Detailed	Saves the operating point values which include the device's currents, power, voltages, and linearized device parameters.
FFT		
Fundamental Oversample	FundOversample	Sets the FFT oversampling ratio. Higher levels increase the accuracy of the solution by reducing the FFT aliasing error and improving convergence. Memory and speed are affected less when the direct harmonic balance method is used than when the Krylov option is used.
More...	Oversample[n]	Displays a small dialog box. To increase simulation accuracy, enter in the field an integer representing a ratio by which the simulator will oversample each fundamental.

**Table 1-3. LSSP Simulation Parameter Options (continued)**

Setup Dialog Name	Parameter Name	Description
Initial Guess		
Use Initial Guess	UseInFile	<p>Check this box to enter a file name for a solution to be used as initial guesses. This file is typically generated from a previous simulation by enabling <i>Write Final Solution</i>. If no initial guess file name is supplied, a default name (using DC solution) is generated internally, using the design name and appending the suffix <i>.hbs</i>. A suffix is neither required nor added to any user-supplied file name. For example, if you have saved the Harmonic Balance solution from a previous simulation, you can later do a nonlinear noise simulation and use this saved solution as the initial guess, removing the time required to recompute the nonlinear Harmonic Balance solution. Or you could quickly get to the initial Harmonic Balance solution, then sweep a parameter to see the changes. In this latter case, you will probably either want to disable the <i>Write Final Solution</i> option or use a different file name for the final solution to avoid overwriting the initial guess solution. (See <a href="#">“Write Final Solution” on page 1-13.</a>)</p> <p>The Annotate value specified in the DC Solutions tab in the Options block is also used to control the amount of annotation generated when there are topology changes detected during the reading of the initial guess file. Since HB simulations also utilize the DC solution, to get optimum speed-up, both the DC solution and the HB solution should be saved and re-used as initial guesses. See <i>DC Simulation</i>.</p> <p>The initial guess file does not need to contain all the HB frequencies. For example, one could do a one-tone simulation with just a very nonlinear LO, save that solution away and then use it as an initial guess in a two tone simulation. The exact frequencies do not have to match between the present analysis and the initial guess solution. However, the fundamental indexes should match. For example, a solution saved from a two tone analysis with Freq[1] = 1GHz and Freq[2] = 1kHz would not be a good match for a simulation with Freq[1] = 1kHz and Freq[2] = 1 GHz.</p> <p>If the simulator cannot converge with the supplied initial guess, it then attempts a global node-setting by connecting every node through a small resistor to an equivalent source. It then attempts to sweep this resistor value to a very large value and eventually tries to remove it.</p>
File	InFile	Specify a filename to save results.
Regenerate Initial Guess for ParamSweep (Restart)		

**Table 1-3. LSSP Simulation Parameter Options (continued)**

Setup Dialog Name	Parameter Name	Description
Final Solution		
Write Final Solution	UseOutFile	<p>Check this box to save your final HB solution to the output file. If a filename is not supplied, a file name is internally generate using the design name, followed by an <i>.hbs</i> suffix. If a file name is supplied, the suffix is neither appended nor required. If this box is checked, then the last HB solution is put out to the specified file. If this is the same file as that used for the Initial Guess, this file is updated with the latest solution.</p> <p>Transient simulations can also be programmed to generate a harmonic balance solution that can then be used as an initial guess for an HB simulation. Refer to <i>Harmonic Balance Simulation</i>.</p>
File	OutFile	Specify a filename to save results.
Harmonic Balance Assisted Harmonic Balance	HBAHB_Enable	Set the HBAHB mode to <i>Auto</i> , <i>On</i> , or <i>Off</i> . Default is <i>Auto</i> and is recommended.



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