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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 Controller” on page 1-9 provides details on the tabs and fields in the LSSP simulation controller.

**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.
Large-Signal S-Parameter Simulation

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.

**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.

- 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.

- Add the LSSP control element to the schematic. Double-click to edit it. Fill in the fields under the Freq and Ports tabs:
  - 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.

- The Krylov option can be enabled for circuits that contain a large number of nonlinear devices or harmonics. Refer to the topic “Selecting a Solver” in the chapter “Harmonic Balance Basics” in the Harmonic Balance Simulation documentation for instructions on how to use this option.

- You can use previous simulation solutions to speed up the simulation process. For more information, refer to 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.

Note   This design, LSSP_test.dsn, is in the Examples directory under Tutorial/LSSP_test_prj. The results are in LSSP_test.dds.

Figure 1-1. Large-Signal S-parameter Simulation Example in ADS
Large-Signal S-Parameter Simulation

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.

   **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.

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 HB1. Click **OK**.

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

\[ A_j = \frac{V_j + Z_{0j} I_j}{2\sqrt{R_{0j}}} \quad B_i = \frac{V_i - Z_{0i}^* I_i}{2\sqrt{R_{0i}}} \]

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 Controller

The parameters for the LSSP Simulation component are identical to those for HB, with two exceptions:

- In Advanced Design System, the simulation component has a Ports tab (see “Ports in ADS” on page 1-9). In RF Design Environment, the LSSP options card has a Port Frequencies table (see “Port Frequencies in RF Design Environment” on page 1-10).

- The options for Small-signal mode, Nonlinear noise, and Oscillator are not available.

Refer to the topic “HB Simulation Controller” 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. Simulator parameter names, as they appear in netlists and ADS schematics, are in parentheses.

<table>
<thead>
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<th>Table 1-1. LSSP Simulation Ports Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ports</strong></td>
</tr>
<tr>
<td><strong>Edit</strong></td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td><strong>Select</strong></td>
</tr>
</tbody>
</table>
Large-Signal S-Parameter Simulation

**Port Frequencies in RF Design Environment**

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.

**Port Frequencies**

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.

**Frequency (field)**

- Use the **Add** button to add a new port frequency.
- Use the **Delete** button to delete a highlighted entry.
- Use the **Update** button to update the information of a highlighted entry.
- Use the **Clear** button to clear the entry field.
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