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Guidelines for Robust S-Parameter Model Development Application Note

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Guidelines for Robust S-Parameter Model Development Application Note

Purpose

The purpose of this document is to provide guidelines for the production of S-parameter models for use by Cadence's Allegro PCB SI 630 product in time domain simulations.

You obtain the S-parameter models in:

- Allegro PCB SI 630
- EDA modeling tools
- Lab measurements

Overview

This document provides general guidelines that improve the robustness of S-parameter models for time domain simulation.

The problem is that Allegro PCB SI 630 users receive S-parameter models which are not robust and fail in time domain simulation usage. This causes the following issues:

- Inability to perform simulations, causing delayed design cycles.
- Inaccurate blame of the simulation tools, causing user dissatisfaction and increasing Cadence support costs.
- Inaccurate blame of model suppliers, causing user dissatisfaction and increasing support costs.

Assumptions and Constraints

Relevant assumptions and constraints related to this document:

- All S-parameter models are in standard Touchstone format.
- VNA equipment today generally can only measure down to 10MHz.

- Documentation supplied by model supplier to indicate how ports should be hooked up in the simulation circuit

Definition of Terms and Acronyms

- EDA – electronic design automation
- VNA – vector network analyzer
- DC – direct current, in this context referring to a frequency of 0Hz

Reference Materials

- Allegro PCB SI data sheet:

  http://www.cadence.com/products/si_pk_bd/pcb_si/index.aspx

- Cadence S parameter webinar

  http://www.cadence.com/webinars/webinars.aspx?xml=sparam

S-Parameter Modeling Guidelines

The guidelines fall into the following categories:

- Start frequency
- End frequency
- Number of frequency points

Start Frequency

The start frequency refers to the lower end of the frequency range covered by the S-parameter model. Time domain circuit simulators must determine steady state and transient solutions for the given circuit. Failure to provide a low enough start frequency can result in simulation convergence errors and inaccurate results.

The ideal start frequency for an S-parameter model used in time domain circuit simulation is `0Hz`, or `DC`. If the S-parameters generate from topologies in the Allegro PCB SI 630 SigXplorer environment, a start frequency of `0` is possible (default).

Automatically going down to DC is often not feasible from other EDA tools or from VNA measurements. For example, you can take VNA measurements down to a low limit of `10MHz`. If lower frequencies are not available in your model generation or from measurement, add these matrices into the model. Sometimes these matrices can be borrowed from similar models or from mathematical S-Parameter generation for similar structures. You can successfully cut and paste lower frequency matrices from other sources. Whenever possible, provide values from sources that have insight into the structure.

Allegro PCB SI 630 automatically uses linear extrapolation to determine the low frequency points as needed, when you do not have data down to DC. You can use S-parameter models that contain data down to `10MHz` for most cases. Using start frequencies higher than `10MHz` increases the risks of non-convergence during time domain simulation.

Start frequency guidelines include:

- Provide data down to DC, if possible.
- If this is not possible, provide data to frequencies as low as possible. Use a maximum start frequency of `10MHz`.
- If data is available to cover low frequencies from alternate sources, incorporate this data and augment S-parameter models that initially have a start frequency greater than `10MHz`.

End Frequency

End frequency is the upper limit of the S-parameter model. End frequency needs to cover the bulk of the harmonic energy seen from the driving signal and is a function of the rise time of the driver. An insufficient end frequency results in a loss of accuracy when using the model.

The minimum end frequency to use for S-parameter modeling is:

End Freq = `2/t_rise`

where `t_rise` is the 20% - 80% rise time of the driving signal. For example, if your rise time is approximately `40 picoseconds`, use end frequency:

```
2/40p = 50 GHz
```

To provide optimum accuracy, you must examine the driving signal in more detail and determine the required simulation time step. To estimate the full 0% - 100% rise time value, start with the 20% - 80% rise time value:

```
t_rise_0_100 = (t_rise_20_80) / 0.6
```

To estimate the typical time domain simulation time step, use:

```
time_step = (t_rise_0_100)/10 = dt
```

For the most accurate results, use:

```
BW = 1/(2*dt) = end frequency
```

Models with BW less than this require interpolation and may result in some loss of accuracy.

Table 1-1 Recommendations for end frequency for different rise times

Rise Time (20% - 80%)	Minimum End Frequency	Optimum End Frequency
200 ps	10 GHz	15 GHz
100 ps	20 GHz	30 GHz
70 ps	30 GHz	45 GHz
50 ps	40 GHz	60 GHz
40 ps	50 GHz	75 GHz

For S-parameter models that are linear and well-behaved, you can reduce the end frequency, resulting in smaller data files, better usability, and improved simulation performance. Ensure that you capture the relevant frequency content of the transmitted signals.

To verify that a reduction in end frequency is acceptable:

- Perform time domain simulation on a model with the recommended end frequency.
- Perform time domain simulation on a model with a reduced end frequency.
- Compare the 2 results.

If both models produce nearly identical results, you can use a reduced end frequency.

Number of Frequency Points

To support the small time steps required for MGH time domain simulation, the S-parameters must be of sufficient granularity to enable accurate numeric processing. Insufficient resolution in the frequency domain results in a loss of accuracy for time domain simulation. For time domain simulation purposes, use **linear** frequency sweeping (not logarithmic), such that the steps between frequency points are consistent.

The recommended frequency step is `10MHz`. A number of frequency points, that are a power of 2, aids numerical processing. For an end frequency of `20GHz`, use 2048 frequency points. Table 1-2 provides recommendations for the number of frequency points, given different end frequencies.

Table 1-2 Recommendations for the number of frequency points for different end frequencies

End Frequency	Recommended Number of Freq Points
10 GHz	1024
20 GHz	2048
30 GHz	4096
40 GHz	4096
50 GHz	4096

For S-parameter models that are linear and well-behaved, you can reduce the number of frequency points, resulting in smaller data files, better usability, and improved simulation performance. Ensure that you capture the non-linear portions of the S-parameter curves with sufficient resolution. To verify that a reduction in the number of frequency points is acceptable:

- Perform time domain simulation on a model with the recommended number of frequency points.
- Perform time domain simulation on a model with a reduced number of frequency points.
- Compare the 2 results.

If both models produce nearly identical results, you can use fewer frequency points.

Quality Checks

Once you create S-parameter models, check for quality, based on the following criteria :

- Passivity.
- Reciprocity.
- Time domain simulation.

If you develop S-parameter models using the guidelines described in this document and pass the quality checks described in this section, you can successfully use the models in time domain simulation with Allegro PCB SI 630.

Passivity

S-parameters generated from passive interconnect structures should be passive. Lab measurements and EDA modeling tools sometimes generate non-passive models for these structures, which provide erroneous time domain simulation results. For example, non-passive S-parameter models for lossy interconnect produce results showing erroneous signal gain, instead of loss.

Initially review the S-parameter data graphically. For example, use the SigWave application in Cadence's Model Integrity environment. Check to ensure that the magnitude is <=`1` for all data points. This step is optional, as the next step checks this in more detail.

Check for passivity in Cadence's Model Integrity environment or directly from the command line using *ts2dml*. For example, to check the passivity of a Touchstone file named `test.s4p`, type the following at the command line:

ts2dml –passivity=0.000001 test.s4p > pass_chk.log

This examines the complex numbers in the S-parameter file, inspects the eigenvalues of the resulting Hermit matrices for negativity, and writes the output of the checking to a text file called *pass_chk.log*. Flags appear for any non-passive frequency points found in the model. Use a passivity tolerance of at least `0.001`, with a preferred tolerance of `0.000001`. If the model passes this criteria, the time domain simulation will be robust.

Note: If there are only a few points found to violate this criteria, delete the offending points and re-run the check.

Reciprocity

For passive interconnects built from linear, reciprocal materials, S-parameters should exhibit reciprocity. For example, in a reciprocal 2-port symmetric structure, insertion loss should be identical from either direction or that S21 = S12.

For most cases, the interconnect structure is asymmetric, in that reflections (ex. S11 and S22) are not equivalent for ports on opposite sides of the network. However, the insertion loss (or transmission) through the structure should still exhibit reciprocity.

For example, taking the 4-port case of a differential pair through a mated connector, where physical signal connections are made from Port 1 > Port 2, and Port 3 > Port 4, the following relationships exist:

S21 = S12

S43 = S34

Model developers and users can overlay these plots directly in Cadence's Model Integrity environment to verify that these conditions exist where applicable.

Time Domain Simulation

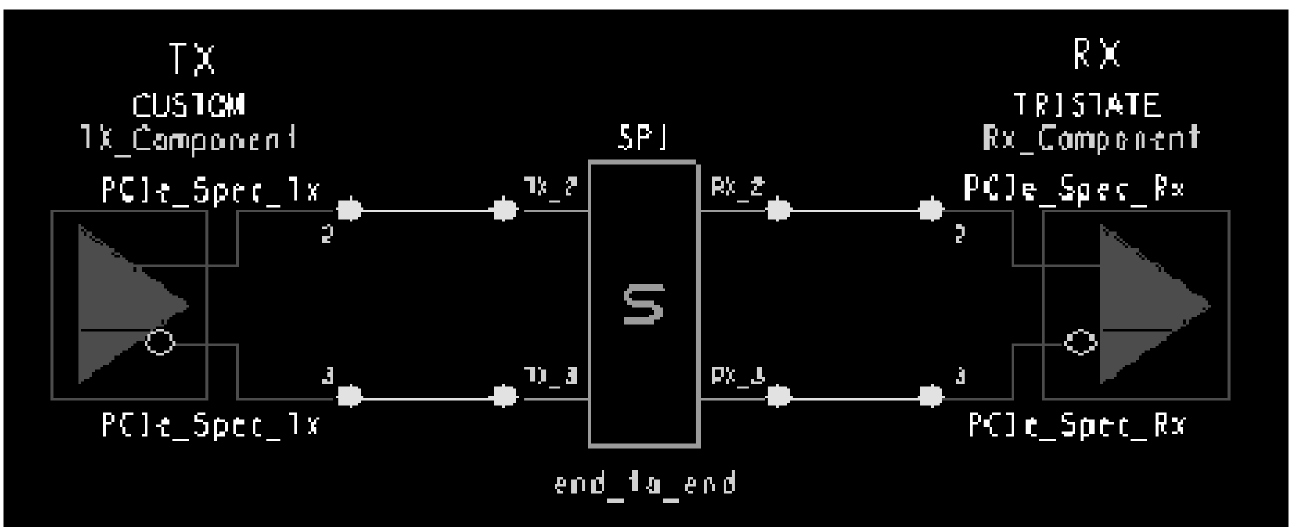
As a final quality check, exercise the S-parameter model in a test topology within the SigXplorer environment of Allegro PCB SI 630. Inspect the resulting waveforms to verify the expected voltage swings, and that you have reasonable results. If measured data or other golden simulation data is available, compare these and judge for accuracy.

Exercising the S-parameter model within SigXplorer shows any effect file size may have on library loading and performance. This is an important item to check for S-parameter models containing many ports.

Figure 1-1 is a uniform and symmetric differential pair (where S21 equals S43).

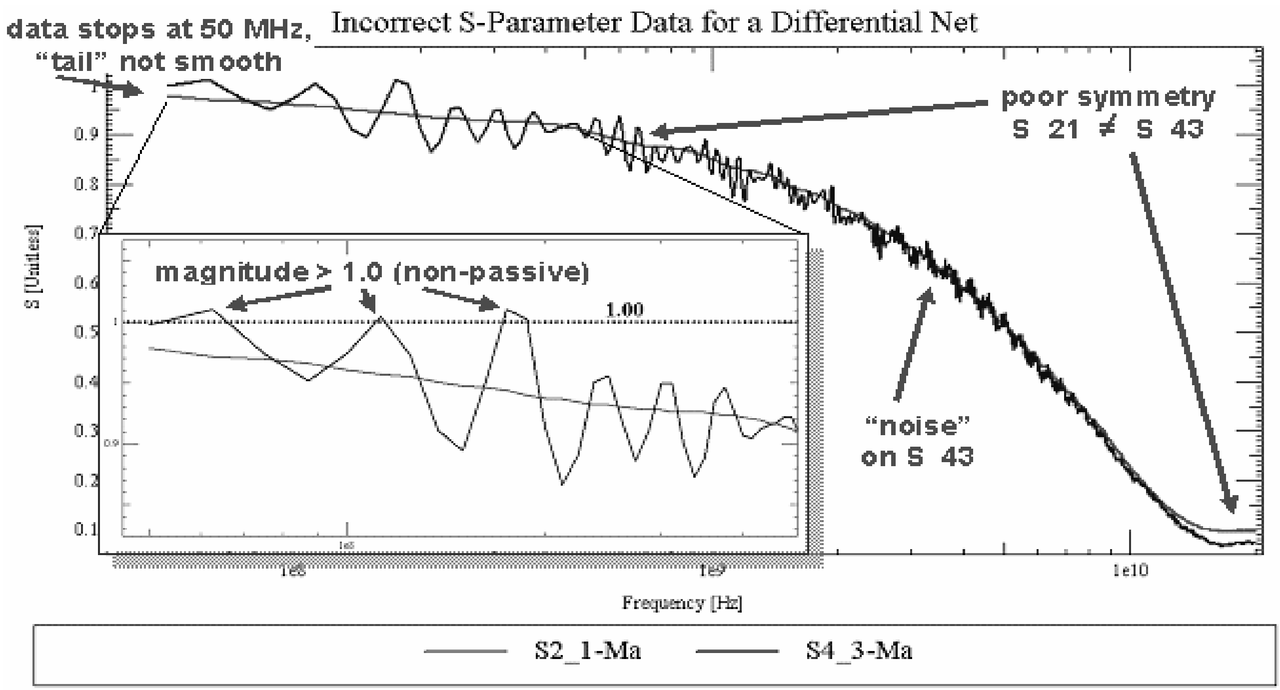
Figure 1-1 Example of a Problematic S-Parameter Case

.



This particular case initially exhibited a number of fairly common S-parameter issues. The associated plots appear in Figure 1-2.

Figure 1-2 Problematic S-Parameter Model Example



As model developers and users are more familiar with S-parameters, they will recognize common qualitative issues, such as those shown above, and the quality and usability of S-parameter models for time domain simulation will improve.