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Using S-parameter Data Effectively

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Using S-parameter data effectively

S-parameters are increasingly important part of the designer's EDA/CAD toolbox, as RF becomes part of more designs

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One of the basic tools in the RF design process is the use of S-parameter measurements. These measurements can be used in today's computer-aided design (CAD) tools as part of the circuit-simulation process. S-parameters describe a component as a black box and are used to emulate behavior of electronic components over a range of frequencies.

There are many uses for S-parameters in active and passive component circuit design and analysis. The focus of this article is to show how to incorporate S-parameters in the design process using a CAD approach.

The use of S-parameters for circuit simulation has been around almost since these parameters were first introduced. Synthesis and analysis tools that target RF and microwave applications almost always include capabilities to simulate with them. In many simulators we find S-parameter blocks for which one specifies the value of each S-parameter individually. Let us look at an example to further illustrate how to use S-parameters for the design of a low-noise amplifier (LNA).

S-parameters provide the necessary values to do analyses such as Stability and Gain Circles. However, for an LNA design, the small-signal noise parameters (such as N_{fmin} , S_{opt} , and R_n) will also be required, so that the noise circles needed to design for a certain noise figure can be constructed in the simulator. A set of S-parameters and noise parameters measured at 1 GHz are given on **Table 1**.

continued ...

S11	S12	S21	S22
0.728 ∠ -71.556	0.08 ∠ 50.066	9.837 ∠ 129.906	0.772 ∠ -48.669
NFmin	Rn	Sopt	
0.66 dB	8.669 Ω	0.407 ∠ 20.816	

Table 1. S-Parameter and Small Signal Noise Parameters

In this article we will use Advanced Design System (ADS) from Agilent Technologies for all the simulations. The schematic with the S-parameters and noise parameters included is shown in **Figure 1**.

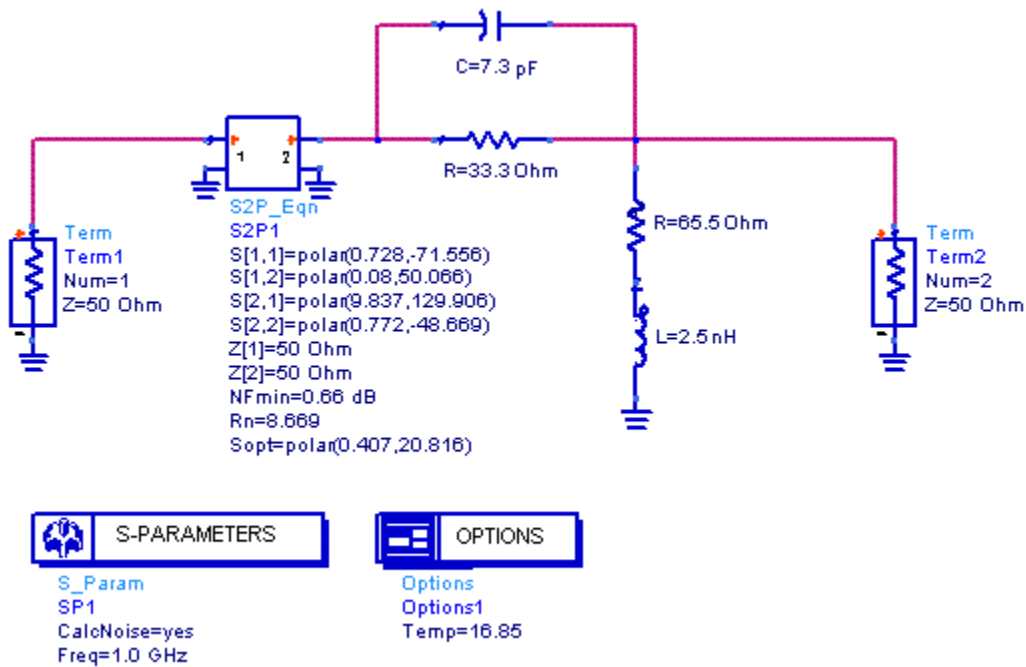


Figure 1 – S-Parameter simulation including noise analysis setup

After executing the simulation the data can be post-processed to obtain the needed information for the design of the LNA as shown in **Figure 2**.

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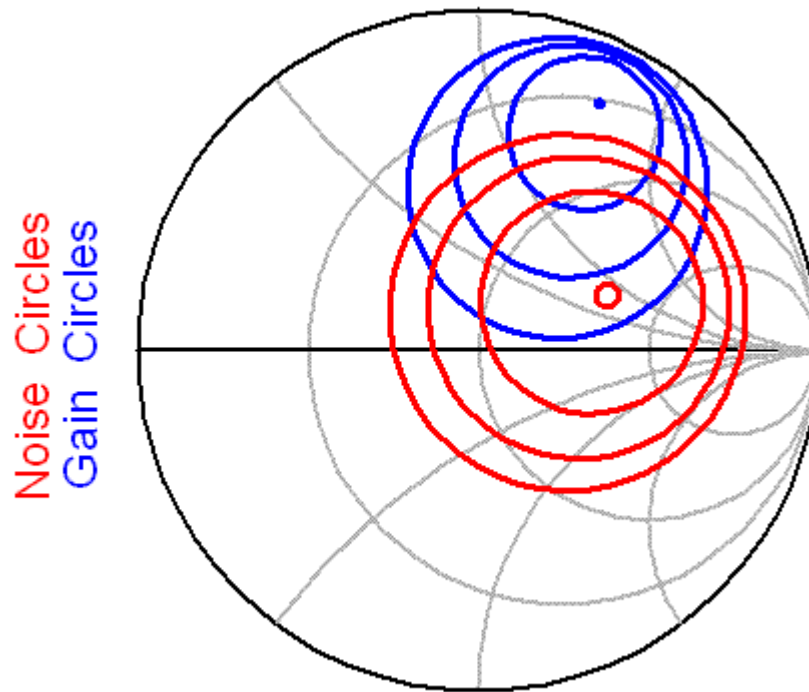


Figure 2 - Noise and Available Gain Circles

This analysis shows the power and versatility of using S-parameters. The process is very useful in the actual design flow because S-parameters can be measured using a vector network analyzer (VNA), and then used in a simulation. To extend this basic capability, you can save the measured S-parameters over frequency into a file format that the simulator can use. There are two file formats-*-citifile* and *touchstone* (see **Reference 1**)--that can be created by a VNA to be used with ADS.

This approach provides more flexibility than do the single-point S-parameters. In practice, designers have data that comes either from the part vendor or from lab measurements for the different devices, when an existing SPICE or compact model is not available. In this article, we will focus on the touchstone file format since this is by far the more popular of the two formats.

Designers can find a variety of S-parameter measurements from vendors on the Internet, or might even have their own company-archived measured data. In general, this is a good starting point. However, measurements of the device are often performed in an environment different from that of the final application. This can introduce some significant errors in the simulation.

A capacitor, for example, can exhibit a different resonant frequency when mounted on different PCB types, due to the influence of the mounting pads and the PCB material characteristics (for example, thickness, dielectric constant). Similar issues are also encountered with solid-state devices (such as a transistor

for LNA applications). To avoid these issues, use lab measurements with the devices mounted on the same PCB as the one with which you will be manufacturing your product.

Another area of concern with touchstone files is what happens when we, accidentally or not, simulate at frequencies that are outside those included in the data file. The software can provide either a mechanism to extrapolate the data, or to stop the simulation because it has no valid data in part or all of the frequency range. For extrapolation there are two popular techniques: either use the closest known data point or constant extrapolation, or use the two closest known data points and do a linear extrapolation.

These extrapolation techniques are both an approximation that can, if chosen incorrectly, cause severe errors and even simulation convergence issues. Refer to the two examples shown in **Figure 3**.

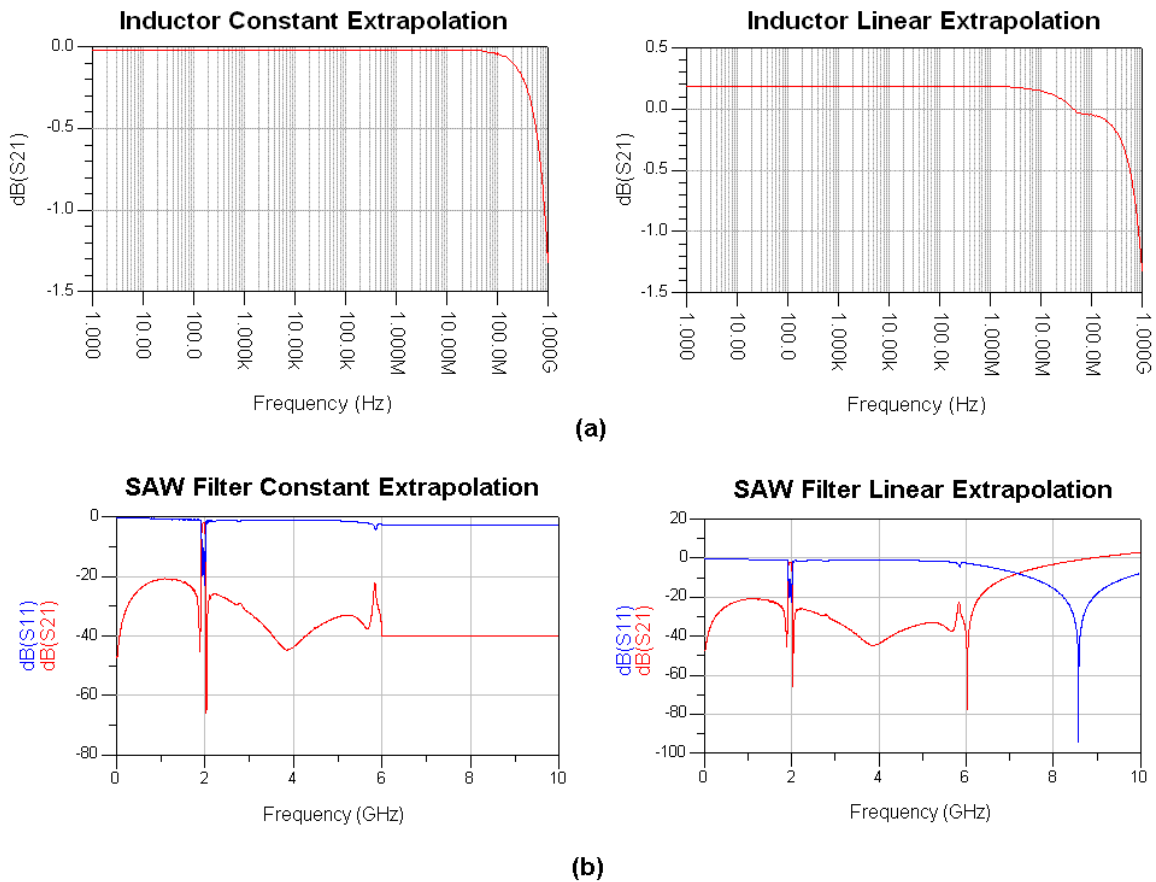


Figure 3 - (a) Inductor S-Parameter Results (b) SAW Filter S-Parameter Results

Both data files in the example in Figure 3 have data from 50 MHz to 6 GHz. On the inductor results, notice how the linear extrapolation produces an inflexion

point at 50 MHz, which we know is incorrect from the expected inductor behavior. The SAW filter shows “gain” above 8.5 GHz when the linear extrapolator is used, which is impossible for a passive device. The user needs to be aware of the useful frequency range in the touchstone file and select the appropriate extrapolator.

Another way around this issue is to manually add either the DC point or high-frequency value manually into the touchstone file. The risk of improper extrapolation is eliminated with this approach.

One very important aspect of S-parameter data files is that the simulator should have the capability to interpolate inside the range of the data as well. However, there may be cases in which there is a certain region of the response that requires more closely spaced data samples; otherwise, important aspects of the response (for example, high-Q circuit resonance) might get missed entirely.

In this case, the designer can measure a wide band, then focus into the narrow band of interest to make a second measurement with a finer frequency resolution, and manually combine these files. The files are ASCII data files and are editable with any text editor.

Large-Signal S-Parameters

Our discussion so far implies that S-parameters are linear by definition. What this means for the CAD user is that the device being represented is either passive or is assumed to be operating in the linear region of the response by the simulator. Therefore, for an S-parameter analysis, even when measured under a large-signal excitation, the output will not produce harmonics.

How effective are these “large-signal” S-parameters in the design process? When no other model is available, S-parameters provide a black-box representation, even for large-signal analysis.

Part of the benefit of using S-parameters for large-signal analysis is to have a data file that includes the measured S-parameter as a function of power and frequency (also known as Large-Signal S-parameters). Inside the ADS simulator this is done via the P2D file. The P2D file is invoked by a special simulation component called AmplifierP2D. It is preferable to use a P2D file rather than just a large-signal touchstone file because, by definition, the touchstone file is for a single, small-signal power level, while the P2D will accommodate S-parameters over frequency and power. The creation of the measured P2D file is facilitated by the software. In other words, the software has the capability to control instrumentation and create the P2D file. The P2D file also can be created from simulation results as well.

Let's look at a few examples to illustrate the usefulness of a P2D data model. First, we will analyze the output power versus input power of a power amplifier (PA) at a fixed input frequency, **Figure 4a**. The P2D file can also be used to simulate the output power versus frequency, **Figure 4b** (fixed input power).

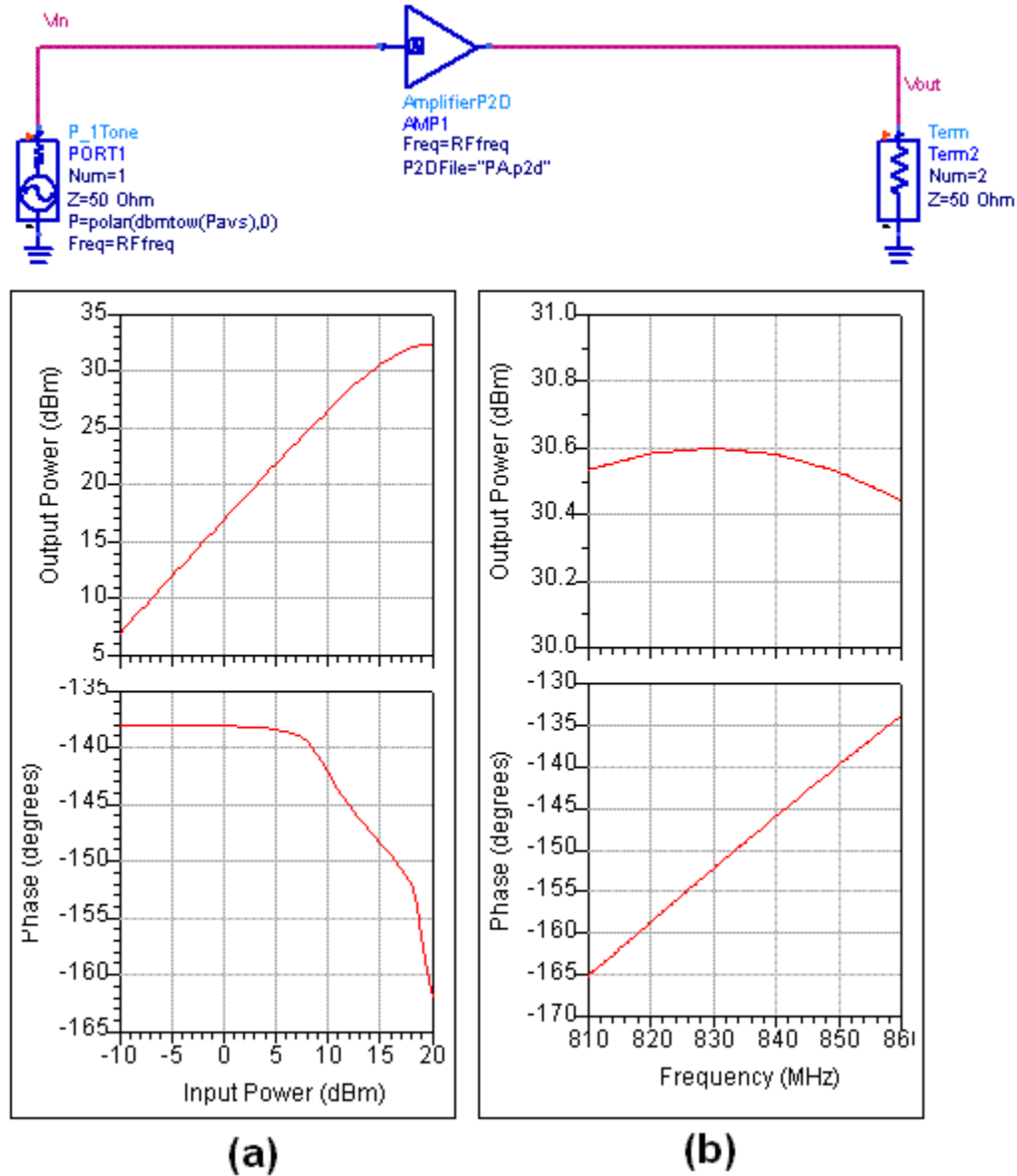


Figure 4 – AmplifierP2D (a) Power Sweep Results (b) Large Signal Frequency Sweep Results

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Another powerful use of P2D and touchstone files is system-level analyses. For example, what happens to the output after connecting the PA above with a diplexer (which is represented by a touchstone file)? The circuit and the analysis results are shown in **Figure 5**.

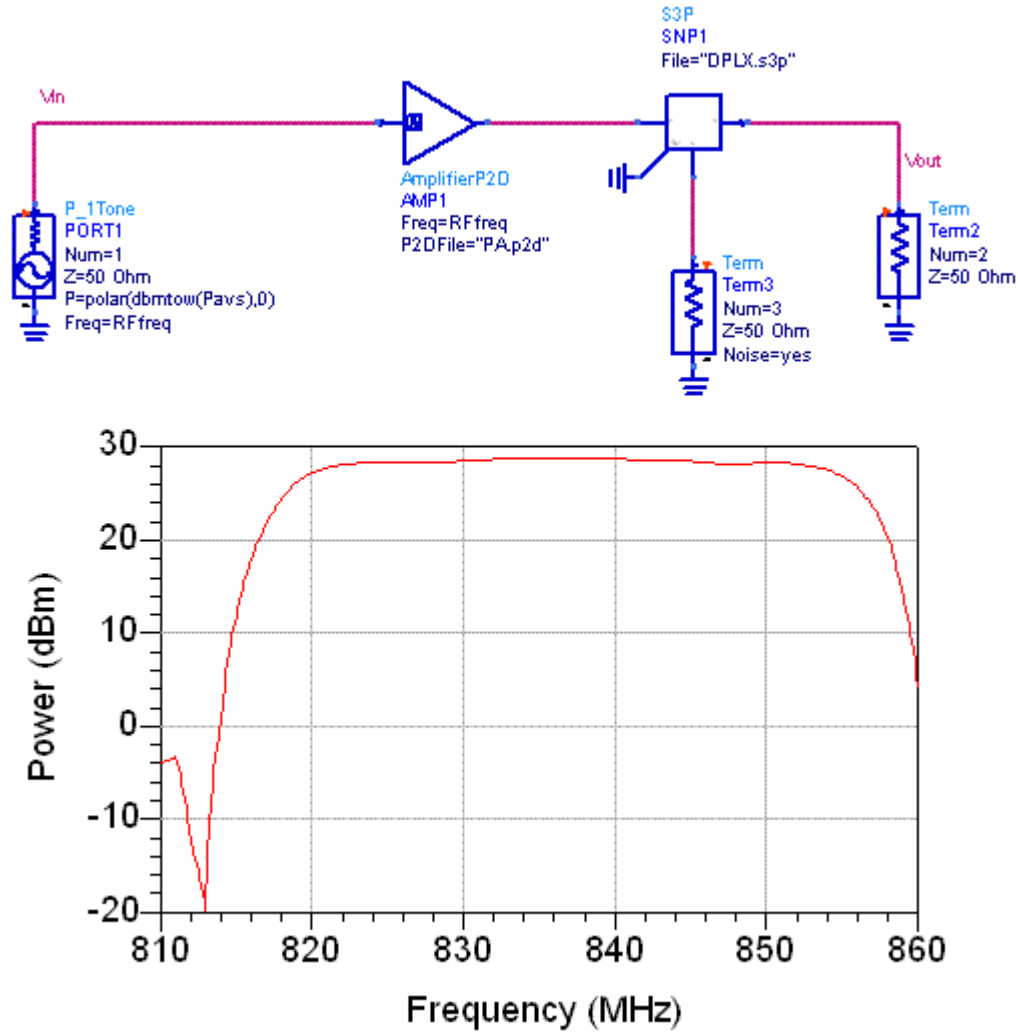


Figure 5 – (a) PA and Diplexer Circuit (b) Simulation Results

These data files also can be used with modulated sources in a Circuit Envelope simulation. The P2D file is a “snapshot” of the performance of the device under test (DUT) under single-tone excitation, and is therefore considered a tuned model.

This means that when using the AmplifierP2D component in ADS, you only get the S-parameters at the frequency specified on the component (remember, no harmonics at the output either). Therefore, a very wide modulation bandwidth can

produce some significant errors, especially if the adjacent channel measurements are of interest.

For example, the plot in **Figure 6** shows the output of a modulated carrier that is fed to both a P2D model and to the discrete circuit model. Notice that inside the modulation bandwidth, the two signals look almost identical; as the signal gets farther away from the carrier frequency, the two signal spectral densities differ.

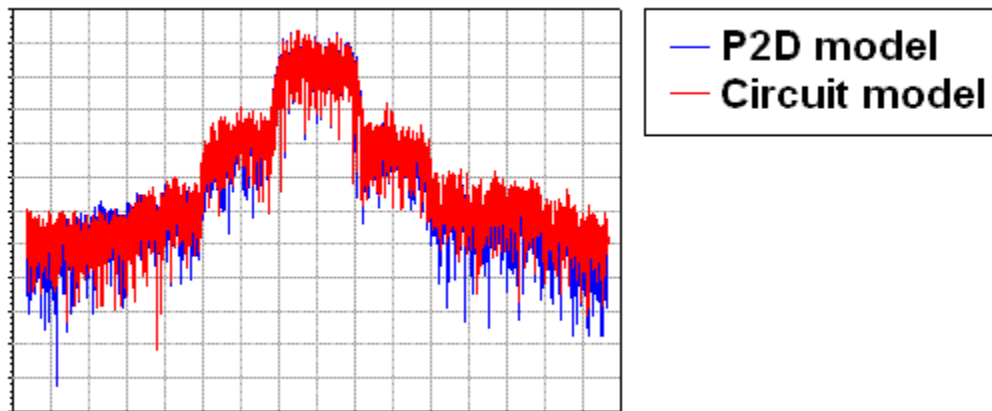


Figure 6 – P2D file simulation with a Modulated Signal

Another very important use for touchstone and P2D files is early access to design performance. In the early stages of a project, the system engineer may have a need to assess the link-budget margin and may need to get information on the performance of the PA. The typical process is to use datasheet type parameters (for example, gain, 1-dB compression point IP3.). This process has been a mainstream one for a very long time, but what if, with one file, we could get the actual measured performance to incorporate in the analysis? This situation is a very good example of where a P2D file can provide a higher level of accuracy than what is available from a datasheet.

Another use may involve intellectual property protection. The P2D and touchstone files can be produced directly from the simulator. Hence, during the design cycle, a vendor or design team can provide design data which allows the system design team or customer to determine if the proposed design is in line with the overall system requirements, without actual hardware being built yet.

The accuracy of the data model files is crucial to the success of the endeavor. The measurement based files are as accurate as the measurement accuracy and should emulate the actual system design conditions (e.g. bias, temperature, etc.) as closely as possible. It is important to note that if you have a time-varying circuit, as in a power-control loop, or strong memory effects, these are not captured or included in the P2D model.

Understanding how to use touchstone and P2D files is very useful in the design cycle of RF circuits. Also, P2D files provide an added bonus in terms of simulation speed. For very complex design simulations, using a P2D model can be several orders of magnitude faster than the discrete design, due to the P2D lookup table.

References

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- [2] Abrie, Pieter L. D., *RF and Microwave Amplifiers and Oscillators*, Artech House (1999)
- [3] Gonzalez, G., *Microwave Transistor Amplifiers Analysis and Design*, Prentice Hall (1997)
- [4] ADS2005A manual - <http://eesof.tm.agilent.com/>
- [5] Agilent Technologies Application Note 154 "S-Parameter Design"

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