SIMULATOR FOR AMPLIFIER AND TRANSISTOR NOISE-PARAMETER MEASUREMENTS*

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Abstract

This paper describes a simulation program that was developed to compare the uncertainties that would be expected with different measurement strategies for the noise parameters of connectorized amplifiers and of amplifiers or transistors on wafers. Both type A and type B uncertainties are included. An illustrative example is given.

Introduction

The recent uncertainty analysis [1] for noise-parameter measurements on and off wafer provides a good basis for developing a simulation tool for such measurements. The uncertainty analysis uses a Monte Carlo evaluation of the type B uncertainties in the noise parameters, and this program has been modified and extended into a simulator for noise-parameter measurements. The program computes the type B uncertainties, as well as the average type A uncertainties, from a large sample of simulated measurement results. The simulation program can be used to compare the uncertainties achievable with a variety of different measurement strategies. It already has been used to demonstrate the application of certain verification methods for noise-parameter measurements [2]. In this paper, we outline the structure of the simulator and demonstrate its use with a practical application.

Simulation Program

The simulation program is based on the Monte Carlo program used in the NIST uncertainty analysis for noise-parameter measurements [1]. Full details of this Monte Carlo program are given in [3]. The user inputs the nominal “true” values for the noise parameters and *S*-parameters of the amplifier or transistor, the reflection coefficients and noise temperatures of all the input terminations, and the “input uncertainties,” i.e., the standard uncertainties (including correlation effects) in the basic measurements such as the *S*-parameters, reflection coefficients, input noise temperatures, and output noise temperatures. Regarding the measurement of the output noise temperature, the program could be easily adapted to measurement of output powers rather than noise temperatures. If the measurements are on a wafer or through adapters or an attenuator, the nominal characteristics of the probes, adapters, or attenuator are also input. The gain is also determined from the noise measurements, and so in the rest of this paper, “noise parameters” will include both the four actual noise parameters and the gain.

Using the input true values and uncertainties, the program generates a set of simulated measurements of all the quantities that would be measured in a real set of measurements: the noise temperatures and reflection coefficients of all the input terminations, the *S*-parameters of the amplifier or transistor and its output reflection coefficient (optional) for each input termination, the output noise temperature of the amplifier for each of the input terminations, and the characteristics of any adapter, probes, or attenuators that may be present. Each set of measurements is analyzed in the same way that a set of real measurements would be analyzed, with a least-squares fit to the set of equations for the output noise temperature in terms of the noise parameters (and the measured quantities). The fit results in values for each noise parameter and the gain, as well as a type A uncertainty for each of these quantities, which is obtained from the statistics of the fit. This process is repeated a large number of times N_S, yielding N_S values of each of the noise parameters and a corresponding set of N_S values for the type A uncertainty in each noise parameter. The type B uncertainty in each noise parameter is computed in the usual way [1, 3] from the distribution of the N_S “measured” values, and the typical value for the type A uncertainty is taken to be the root mean square value of the N_S values for the type A uncertainty in that noise parameter. The value chosen for N_S depends on the DUT. N_S = 10,000 is usually sufficient, but for a poorly matched transistor, N_S = 50,000 or more may be necessary. The program typically takes roughly 10 seconds to run for a single frequency. Results are given both for the parameter representation used by NIST [1,3] and for the more common IEEE form of the noise parameters.

Each set of simulated measurement results is subjected to some tests as a quality check, just as would be done for real measurements, and measurement sets that fail these tests are discarded before the uncertainties are computed. These tests are described in [3].

Sample Application

In [2] the simulator was used to investigate a particular verification method for amplifier noise-parameter measurements. Here we present a more basic application, using the simulator to guide the

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choice of a set of input states for noise-parameter measurements. Noise-parameter measurements generally consist of measuring the output of the device under test (DUT) for a series of different input terminations and fitting to the equation for the output in terms of the noise parameters. For a given DUT and frequency, the achievable uncertainty depends on the uncertainties in the various measurements, but also on the choice of the set of input states.

As an illustrative example, we consider the set of possible input terminations represented in Fig. 1, and we compute the standard uncertainties and the fraction of bad measurements (those that violate a physical bound or have a poor fit) for different subsets of input terminations. The amplifier considered has $T_{min} = 59.71$ K, $R_n = 6.55\ \Omega$, and $|\Gamma_{\mathrm{opt}}| = 0.199$. The minimal "base" set will be input states 1 – 5. The input uncertainties are those of [1,3]. The results are given in Table 1, where we tabulate the standard uncertainty in three of the noise parameters for different choices of input states. We also give the percentage of time (% Bad) that a result is obtained that violates a physical bound or does not admit a good fit (χ^2 per degree of freedom greater than one). The results demonstrate the effectiveness of additional measurements and also show that inclusion of a matched ambient state (#6) is more effective than an additional reflective state.

Discussion and Summary

The example given above is just one of a wide range of noise-parameter measurement strategies or variations that the simulator can easily test (compared to actually performing the measurements). In a forthcoming full journal paper we plan to consider inclusion of a cold (i.e., well below ambient) input noise source in place of or in addition to the hot source, multiple hot input terminations with different reflection coefficients, inclusion of one or more measurements of the "reverse" configuration (i.e., direct measurement of noise emanating from the input of the amplifier), dependence of the output uncertainties on the input uncertainties, and other issues of interest.

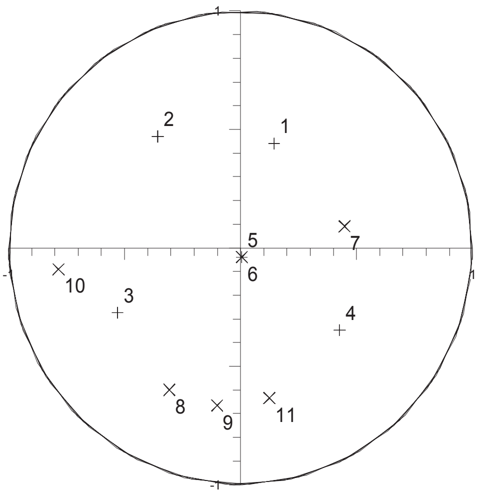

Fig. 1 Constellation of input complex reflection coefficients relative to the unit circle. State 5 is a hot noise source; all others are ambient temperature.

Table 1. Simulation results for different sets of input terminations, with "B" referring to the base set. The base-set results do not include any type-A uncertainties or contributions to bad results.

Input	$u(T_{min})$ (K)	$u(\lvert\Gamma_{opt}\rvert)$	$u(R_n)$ (Ω)	% Bad
Base	6.44	0.0054	0.38	0.01
B+6	3.97	0.0031	0.19	3.98
B+7	7.52	0.0066	0.44	3.89
B+9	6.73	0.0054	0.34	4.18
B+7+9	6.45	0.0054	0.33	1.37
B+6+7+9	4.00	0.0030	0.17	0.48
All	3.90	0.0029	0.12	0.01

References

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