UNCERTAINTY ANALYSIS FOR NOISE-PARAMETER MEASUREMENTS*

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Abstract

A brief summary is presented for the uncertainty analysis for measurements of noise parameters of amplifiers and transistors, in both connectorized (coaxial) and on-wafer environments. We treat both the *X*-parameters, which are based on the wave representation of the noise correlation matrix, and the traditional IEEE noise parameters.

Introduction

Some time ago, the U.S. National Institute of Standards and Technology (NIST) developed the capability to measure noise parameters of amplifiers [1,2]. The present analysis of such measurements is based on a wave representation of the amplifier's noise correlation matrix, and the uncertainty analysis in this form was first presented in [3]. Recently, the methods and analysis have been extended to permit the measurement of noise parameters of poorly matched transistors in on-wafer environments [4]. This paper summarizes the procedures now used to estimate the standard uncertainties [5] in the measured noise parameters of both amplifiers and transistors, in both connectorized (coaxial) and on-wafer environments. Full details will be given elsewhere.

The next section outlines the measurement method for noise parameters at NIST. It is followed by a section describing the uncertainty analysis, concentrating on features that have been added recently. The paper concludes with a summary.

Measurement Method

The measurement method for either off-wafer (connectorized) amplifiers or on-wafer transistors (or amplifiers) consists of connecting a series of different known terminations to one of the ports of the device under test (DUT) and measuring the resulting noise temperature at the other port. Most or all of the measurements are performed in the forward configuration of Fig. 1(a), in which the known termination ($\Gamma_{G,i}$, $T_{G,i}$) is connected to the input port, and the noise temperature ($T_{2,i}$) is measured at the output port. In the case of poorly matched devices, typically transistors on a wafer, it is advantageous to also perform at least one reverse measurement, as in Fig. 1(b). The termination used for the reverse measurement is typically an ambient-temperature matched load. The noise parameters are then computed by performing a weighted least-squares fit using the equations for the output noise temperatures in terms of the known input termination and the noise parameters.

The set of input terminations typically comprises eight to twelve ambient-temperature terminations and one well matched nonambient noise source (usually hot). The input states are discrete, reflective or matched loads; we do not use a tuner. In the past, the terminations have been connected manually, but we have recently developed an automated "variable termination unit" for this task [6]. The ambient-temperature terminations include one matched load and several reflective terminations chosen to provide adequate coverage of the complex-Γ unit circle. Although we have made no great effort to optimize the choice of input reflection coefficients, simulations have shown that we would gain little by using an optimized set, such as is used by some commercial systems. The reflection coefficients of the input terminations and the S-parameters of the device under test are measured on a VNA. The quantity $G_0 \equiv |S_{21}|^2$ is treated as a free parameter in the fit; the fitted value usually agrees very well with the value obtained from the VNA measurements.

Uncertainties

The noise parameters are computed by a least-squares fit to an over determined system of equations obtained by measuring the output noise temperature for each of a number of different input terminations connected to the amplifier or transistor under test. The type-A uncertainties are computed from the covariance matrix calculated by the fitting program, but the type-B uncertainties require more effort. The

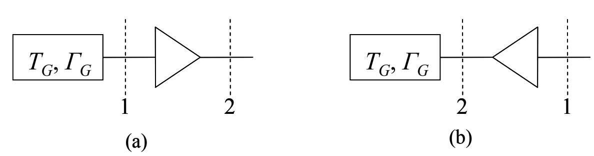

Fig. 1 Forward (a) and reverse (b) measurement configurations.

uncertainties in the underlying or input quantities, such as reflection coefficients, measured noise temperatures, etc., are known or can be estimated; but the problem of propagating these underlying uncertainties to compute uncertainties in the output noise parameters does not admit a simple analytical solution. Therefore, a Monte Carlo (MC) approach is used for the type-B uncertainties.

The MC program now used for the type-B uncertainties is an extension of the earlier program developed for measurements on well matched, connectorized amplifiers [3]. The program performs repeated simulations of noise-parameter measurements and computes the type B uncertainties from the standard deviations of the distributions of the different variables. For each simulated measurement set, the noise parameters are computed for both the noise-correlation-matrix representation and for the IEEE-parameter representation, so that the distributions, and therefore the uncertainties, are computed for both representations.

The MC program will be described in detail elsewhere, but some features that merit mentioning are that the measurements of all S-parameters, reflection coefficients, and noise temperatures (input, output, and ambient) are simulated separately, and correlations among the various measurements are included. The set of input terminations is chosen by the user, and the set of simulated output noise-temperature measurements is analyzed in the same way as are real measurements, to yield a set of noise parameters. The number of simulated measurement sets is chosen to be large enough to ensure that the deviation of any uncertainty from its asymptotic value is less than 10 %, and in most cases it is 3 % or less. Usually 10,000 measurement sets suffice, but sometimes more are needed. The uncertainties in the underlying measurements (the reflection coefficients, S-parameters, noise temperatures), as well as the correlations among them, are read into the program.

In order to extend the amplifier program to the on-wafer transistor case, several modifications were necessary. Because the measurement planes of interest are on the wafer, we must characterize and correct for the effects of the probes, which introduces additional uncertainty. Also, the uncertainties in VNA and noise measurements are different on a wafer from what they are in coaxial lines, and therefore the input uncertainties are different for the on-wafer case. The third complication is that the transistor may be very poorly matched, leading to relatively large values of the reflection coefficient at its output. This requires that we refine our estimate of the uncertainty in measuring the output noise temperature. It also requires us to adopt a prescription for handling unphysical results in the simulations. In addition to these modifications, the treatment of correlations in the measured noise temperatures was improved, and a cut was introduced to eliminate simulated measurement sets for which a good fit was not obtained (as would be done with a set of real measurements.) Space constraints preclude a discussion of these modifications here; more details will be presented in a full journal paper.

Summary

The uncertainty analysis for noise-parameter measurements at NIST was summarized, and the extensions for poorly matched transistors in an on-wafer environment were noted. This analysis has been used for measurements of both coaxial amplifiers [7] and on-wafer transistors and amplifiers [4].

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