J-4

STATISTICAL ANALYSIS OF SIMULATED AUTOMATIC NETWORK ANALYZER MEASUREMENTS

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ABSTRACT

In this paper, the simulation model of a dual four-port ANA (DFANA) has been used to generate a set of data incorporating the measurement errors of such an instrument. These errors have been assumed to be primarily due to the different sources of noise and uncertainties normally existing in a DFANA measurement system. Measurement statistical analysis has been presented.

INTRODUCTION

The simulation model developed previously (1) for a dual four-port ANA (DFANA) is used in this paper, to calculate a hypothetical set of measurements . This type of simulated data can be used in evaluating a given ANA architecture as well as determining its optimum operational status.

A Mathematical model is applied to perturb the real and imaginary parts of the calculated signals to find the simulated measured signals. The error sources are considered to be primarily the noise and uncertainties existing in the measurement system. Each error source, for example an amplifier, is modeled by its noise and gain terms which are treated as random variables with given probability distributions.

Statistical distributions of measured DUT S parameters are analyzed and properties of these simulated parameters are investigated both in terms of real/imaginary and amplitude/phase.

SIMULATION MODEL

The block diagram of the simulation model used here is shown in Figure 1. This model consists of several tasks (shown by the circles) and input-outputs (shown by the rectangles). Each task is a piece of computer program, with its own inputs and outputs, implementing the corresponding mathematical operations to be used in the simulation process. Each task is performed on each and every point over the measured frequency range.

The signal flow diagram of a DFANA is shown in Figure 2. Ports "0" and "3" correspond to the measurement ports, and "1" and "2" are the device ports. This diagram is used in the synthesis and error correction tasks.

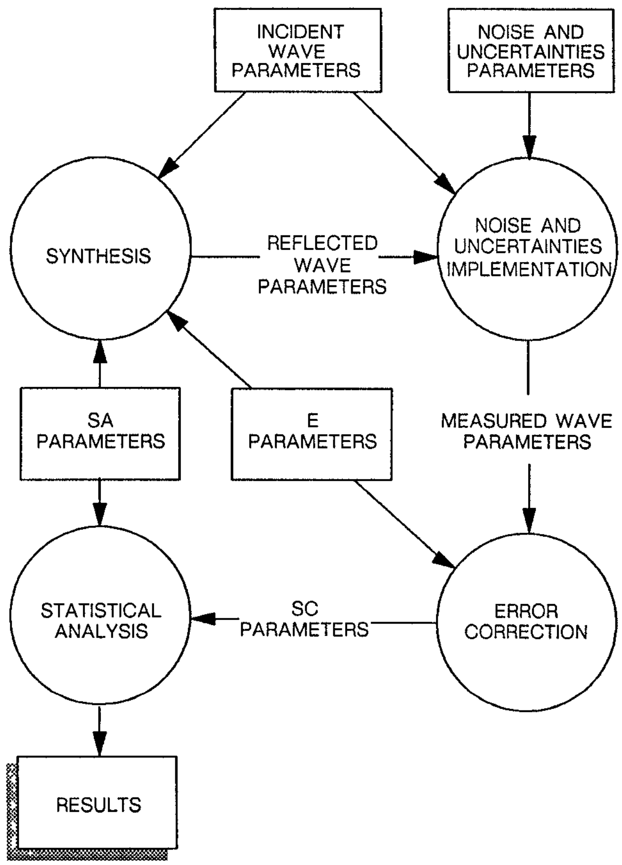

Figure 1.
Simulation Model

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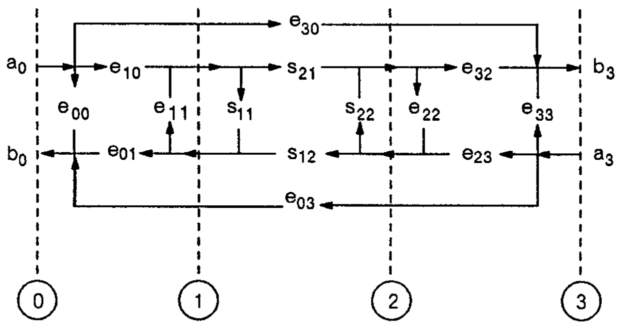


Figure 2.
DFANA Signal Flow Diagram

SYNTHESIS

The synthesis task is an embedding operation, based on the block diagram of Figure 2. This task combines the E parameters of the measurement heads with the DUT S parameters (represented by SA parameters) to obtain the combined S parameters at the measurement planes "0" and "3". The matrix equations corresponding to the embedding operation have been presented in (1). Finally, the reflected wave parameters at the measurement ports are calculated from the incident wave parameters.

NOISE AND UNCERTAINTIES IMPLEMENTATION

The noise and uncertainties implementation task uses a prescribed mathematical model, with a given set of parameters, to perturb the real and imaginary parts of the measured incident and reflected waves. In the DFANA considered here, signals picked by the directional couplers are passed through several components including a mixer, a series of IF amplifiers, an IF detector, an A-D preamplifier and an A-D. Each of these components is modeled in the block diagram of Figure 3, by a gain (G) term and a noise (N) term. K corresponds to the total number of such components.

Both the gain and the noise terms are treated as random variables with known probability distributions which are specified by the input parameters. The noise of different components are modeled by different probability distributions.

For example, thermal noise of an amplifier is modeled as a scaled, zero-mean Gaussian white noise with a standard deviation of one. The corresponding scaling factor is found for each component from its noise figure. It should be noted that although the noise figure of the overall cascaded system can be found from the noise figures of the individual components, to maintain a realistic degrees-of-freedom in the simulation process independent noise sources should be modeled for every component.

The quantization error of an A/D is represented by a zero-mean uniform distribution between +/- one half of the A/D resolution. Both the Gaussian and the uniform distributions are realized by the library routines of the computer linked to the main simulation program.

In Figure 3, E[x] implies "the expected value of x". The appropriate probability distributions of all the G and N terms characterize the sources of noise and uncertainties in the system. A Monte Carlo type of simulation is implemented to draw numerical values for the random variables which are used in the simulation process.

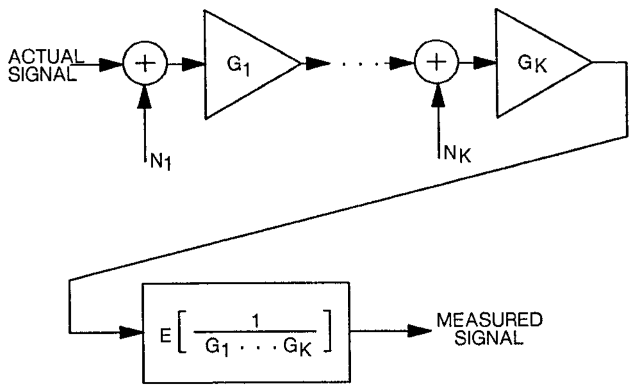


Figure 3.
Noise and uncertainties Implementation

ERROR CORRECTION

In the deembedding operation or the error correction task the followings are implemented. First, from the simulated measured wave parameters the corresponding S parameters are calculated. Next, the corrected SC parameters are found using the procedure described in (1). Statistical distributions of the corrected S parameters both in terms of real/imaginary and amplitude/phase are calculated in the next step.

STATISTICAL ANALYSIS

This task consists of plotting and analyzing the distribution of a corrected S parameter. Statistical figures such as mean, standard deviation and coefficient of variation are calculated for the real part, imaginary part, amplitude and phase of the selected S parameter. Finally, a comparison amongst the statistical figures reveals the nature of measured S parameter sensitivity to the noise and uncertainties of the system.

SIMULATION OF A DFANA

In the DFANA considered here, signals generated by the synthesis task are passed through eight cascaded stages in the measurement process. The gains of all the components are considered to be fixed and known. Gains and noise characteristics of these components are given in Table 1.

Table 1.

type	gain	scale	distribution
mixer	0.056	1587.	Normal
amp.	3.98	126.	Normal
amp.	3.98	126.	Normal
amp.	1.0	126.	Normal
amp.	1.0	126.	Normal
detector	0.316	126.	Normal
amp.	10.	400.	Normal
A/D	1.0	152590.	Uniform

The simulation is performed at a fixed frequency, for 220 times. The selected incident wave, E parameters and SA parameters are as follows.

a11 = (3.5e+06 , 3.5e+06) nV
a21 = (4.0e+02 , 4.0e+02) nV

a12 = (4.0e+02 , 4.0e+02) nV
a22 = (3.5e+06 , 3.5e+06) nV

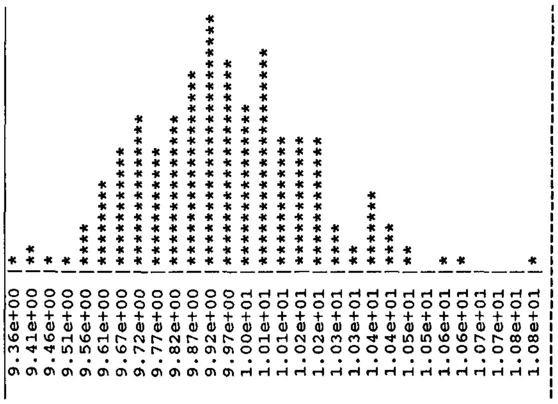
e00 = e33 = (0.1778 , 0.)
e11 = e22 = (0.1995 , 0.)
e03 = e30 = (0.0003 , 0.)
e01e10 = e23e32 = (1.0 , 0.)
e01e23 = e10e32 = (1.0 , 0.)

S11 = (1.0e-01 , 0.0e+00)
S21 = (10.0e+00 , 0.0e+00)
S12 = (1.0e-01 , 0.0e+00)
S22 = (1.0e-01 , 0.0e+00)

RESULTS

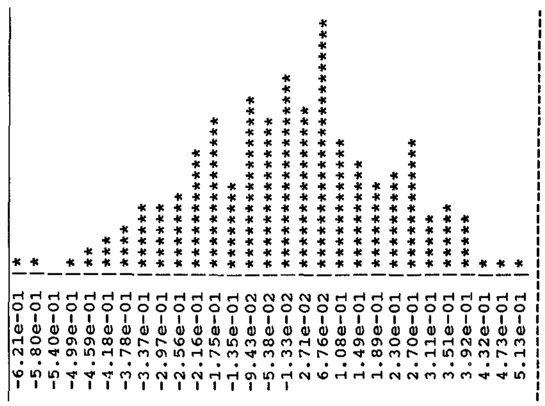
Statistical distributions of the corrected S parameters are shown in Figure 4. It can be seen that the mean values are close to the actual ones which indicates that simple averaging is an effective way of estimating the actual values from the noisy measurements for the case studied here.

REAL PART OF S21



mean.real = 9.991411e+00
stdv.real = 2.387215e-01
coef. of var. = 2.389267e-02

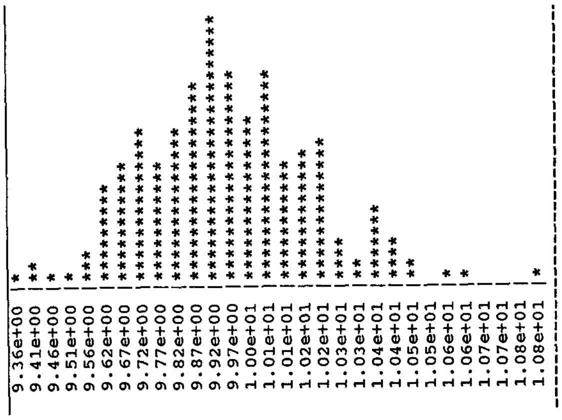
IMAGINARY PART OF S21



mean.imag = 1.707468e-02
stdv.imag = 2.160314e-01
coef. of var. = 1.265215e+01

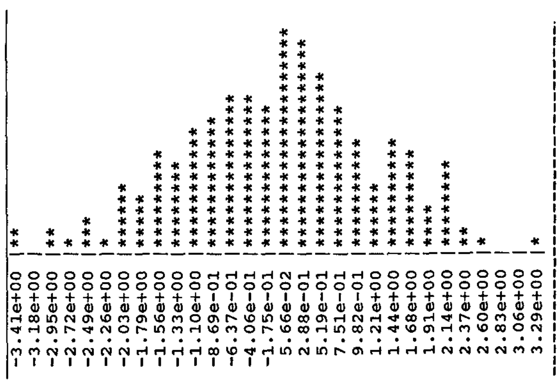
Figure 4.a
Real & Imaginary Parts of Simulated S21

AMPLITUDE OF S21



mean.amp = 9.993758e+00
stdv.amp = 2.388170e-01
coef. of var. = 2.389662e-02

PHASE OF S21



mean.phase = 9.861562e-02 deg.
stdv.phase = 1.237714e+00 deg.
coef. of var. = 1.255089e+01

Figure 4.b
Amplitude & Phase of Simulated S21

To investigate the sensitivity of S21 to the measurement noise, the amplitudes of the incident waves, a11 and a22, are reduced by a factor of 12 and a new set of four statistical distributions are found for S21. In this case, as expected, reduction of the signal-to-noise ratios in the system results in larger and more spread differences between the measured and actual values. It is also observed that "phase" is the most sensitive parameter of S21 to the measurement noise. This can be seen by comparing the coefficients of variations between the imaginary part and the phase of S21. Statistical figures obtained from the second simulation are shown below.

REAL PART OF S21

mean.real = 1.016362e+01
stdv.real = 3.850230e+00
coef. of var. = 3.788247e-01

IMAGINARY PART OF S21

mean.imag = -2.944279e-01
stdv.imag = 3.815856e+00
coef. of var. = -1.296024e+01

AMPLITUDE OF S21

mean.amp = 1.069802e+01
stdv.amp = 4.280571e+00
coef. of var. = 4.001275e-01

PHASE OF S21

mean.phase = -5.376157e-01 deg.
stdv.phase = 1.676982e+01 deg.
coef. of var. = -3.119295e+01

SUMMARY

The simulation model of a DFANA is used in this paper to calculate a set of simulated S parameters. A statistical analysis is performed on the simulated S21 in terms of real/imaginary and amplitude/phase.

REFERENCES

(1) Sotoudeh, V., Roos, M., "Measurement Environment Simulation of a Microwave Automatic Network Analyzer", presented in ARFTG 28th conference, December 1986.