A COMPLETE CALIBRATION PROCEDURE FOR TIME DOMAIN NETWORK ANALYZERS

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ABSTRACT

This paper deals with a complete calibration procedure of a TDR-TDT system which yields to the Time Domain Network Analyzer (TDNA). All measurements are achieved in the Time Domain ; the errors are corrected in the Frequency Domain, after Fourier Transform. The bandwidth of the system extends from DC to 20 GHz. A comparison of the results obtained by this method with those obtained by frequency measurements using a LRL correction is made.

I . INTRODUCTION

Microwave measurements can be performed in the two reciprocal domains : frequency and time.

At present time, frequency-domain (FD) measurements are widely spreaded because of the fast development of accurate measurement tools. Nevertheless, Time-Domain (TD) systems bring many advantages, as low cost, large bandwidth, intrinsic impedance reference, windowing capability and real physical domain for electronic engineering [1]. They have been used since more than twenty years in electrical applications [2,3] and also for TD spectroscopy to study the permittivity of liquids and various biological materials [4]. The accuracy of FD measurement systems is partly due to the improvements on hardware and to the implementation of efficient calibration techniques as OSTL or autocalibration procedures [5].

In the TD, the measurements are done by fast sampling oscilloscopy on fast signals extending to the microwave region. As FD measurements, TD provides measurement errors; some of them are systematic and others are not. To our knowledge, complete calibration methods are not yet available [6,7] and the time domain reflected or transmitted signals (TDR or TDT) are generally exploited in a qualitative manner. Some equipment supplyers have implemented normalization process on their oscilloscopes [8,9], but this procedure is not stricly speaking a calibration; it can be compared to the simplified "OPEN-SHORT" normalization used on a scalar network analyzer.

TD Systems giving the scatering matrix of a device under test in the FD have been built by several groups [10,11,12], but for giving accurate results for Sij parameter mesurements, these systems, referred as TDANA [13], must be used in a very well matched set up. When this condition can not be respected, a more sophisticated calibration procedure becomes necessary.

In this paper a complete calibration of a TDR-TDT system is presented. In this calibration procedure, all measurements are

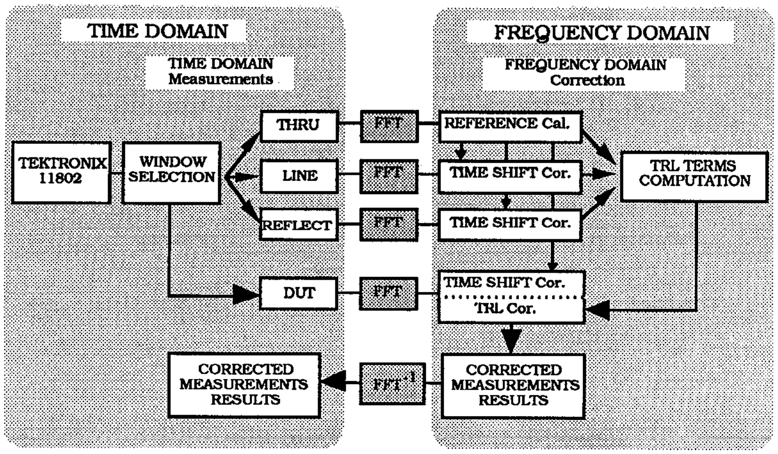

Figure 1. Logical diagram of the calibration procedure.

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achieved in TD (see figure 1). Systematic errors are corrected in the FD after Fast Fourier Transform (FFT) by using a TRL procedure [5]. The error due to the non-stationnarity of the TD source (time shift) is also corrected in the FD (this choice providing a better sensitivity to time shift and then a better accuracy). The corrected measurements are expressed either in the FD or in the TD (convenient precautions must be taken for avoiding aliasing errors).

As an application of the system, measurements are done on microstrip lines in thick film technology. In order to show the efficiency of TD calibration, rough and corrected measurement results, expressed in the FD, are compared. Corrected TD system measurements have also been compared to FD measurements using a vector network analyzer (Wiltron 360 VNA) and an LRL procedure.

II . ERRORS ANALYSIS

Figure 2a shows the schematic diagram of the TD system. A Tektronix 11802 sampling oscilloscope is used with two pulse generators and feed-through sampling heads (SD24) and two precision coaxial air lines. The overall rise time of this TDR-TDT system is about 25 ps. In this context the usefull bandwidth ranges from DC to 20 GHz.

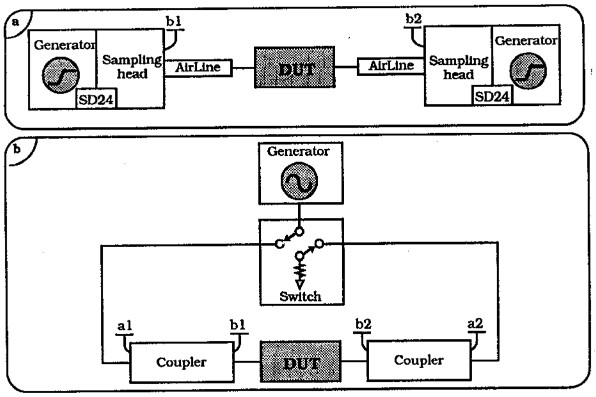

Figure 2. Simplified schematic diagrams of both TD (a) and FD (b) systems.

For comparison, figure 2b shows the simplified schematic diagram of a FD system. In both cases (TD and FD), the signals transmitted and reflected by the DUT are measured. In the first one, the excitation signal is a step-like pulse, in the second one it is a swept frequency signal.

Table 1 shows a comparison between system errors encountered in FD and those in TD.

The basic difference between the two approaches is that in the time domain the system works in transient state whereas in the frequency domain it works in steady state. As a consequence, reflected and transmitted signals are "naturally" time-separated in the TD. So the directivity error is intrinsically zero.

SYSTEM ERRORS	FREQUENCY DOMAIN	TIME DOMAIN	ERROR TYPE
Source Mismatch	Sweeper and Test Set	Sampling and Pulse generator	Systematic error
load Mismatch	Detector	Sampling head	Systematic error
Tracking	Source	source	Systematic error
Directivity	Bridge, Coupler	No error Time-separated signals	Systematic error
Switch dissymetry	VNA Switchs		Systematic error
Phase Noise **Jitter**	Source	Trigger	Non Systematic error
Phase shift **Time shift**	Thermal effects ...	Thermal effects ...	Non Systematic error

Table 1. FD and TD systems errors comparison.

The errors due to source mismatch, load mismatch and tracking are encountered in the two reciprocal domains.

The FD phase noise error can be associated to the jitter in the TD. This statement is however to be taken with precaution. Effectively, when expressed in the FD, jitter has effect on both phase and magnitude of the measured signals.

Finally, time shift, mainly due to thermal drift, can be associated to phase shift in FD.

At this point, it has to be mentioned that time shift is not a systematic error. But in a TD system the incident pulse can be seen and then be taken as an intrinsic time reference. So if the time base is stationnary (which is a realistic hypothesis), time shift of the generator can be corrected as a systematic error.

III . TD SYSTEM CALIBRATION PROCEDURE

A logical diagram for the procedure in shown in figure 1.

The first step is the choice of the TD window. For reflection measurement, the incident signal must be included in the window for the correction of the time shift.

After that, the measurement of the calibration standards for the TRL is achieved.

Then the FFT of each measurement is computed. The time shift is corrected on each standard measurement. The time shift is translated to a phase rotation in FD. For a better accuracy this rotation is then corrected in FD ; the incident TDR signal of the "THRU" standard is choosen as the reference signal (see figure 1). Thus the residual phase error is below 2° at 18 GHz (i.e a residual time shift error of 300 fs). Figure 3 shows a typical phase rotation between two measurements taken in a 10 seconds interval.

The computation of the error terms obtained by a TRL procedure is the next step.

After these terms have been recorded, one can measure the DUT. Time shift is corrected in the same manner (Reference from the "THRU" incident signal) and the corrected S parameters are derived from a classical TRL calibration.

A post-treatment allows to convert these results back in the TD.

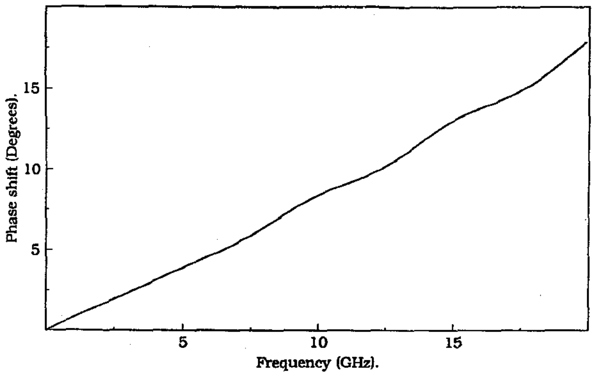

Figure 3. Typical phase rotation due to the generator time shift.

IV . MEASUREMENTS RESULTS AND VALIDATION

The experimental test set-up is presented in figure 4. The DUT is a microstrip line of about 25 Ω characteristic impedance inserted between microstrip acces lines of about 50 Ω characteristic impedance. This kind of DUT has been used because it has not a low pass behaviour in the usefull range (this is a strong constraint for TDNA). The reference planes are P1 and P2 and the DUT acts like a planar resonator.

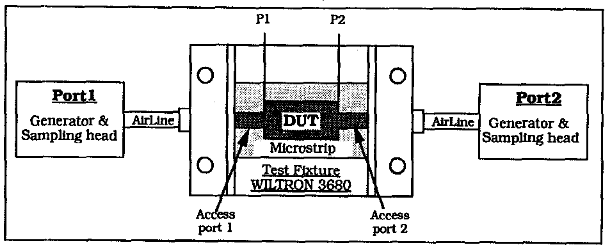

Figure 4. Experimental test set-up with the reference planes P1 and P2.

Corrected and normalized measurements on the magnitude of S11 are shown in figure 5. Normalized measurements correspond to a division (normalization) between the signal transmitted through the DUT and the "THRU" standard (in FD).
In order to validate and to show the performances of this complete calibration, the measurement of the mismatched line in TD have been compared to FD measurement on a WILTRON 360 VNA with standard LRL calibration method. Results of the comparizon on the magnitude of S11 and the phase of S21, which are sensitive parameters, are given in figure 6. A very good agreement between the two approaches can be noted.

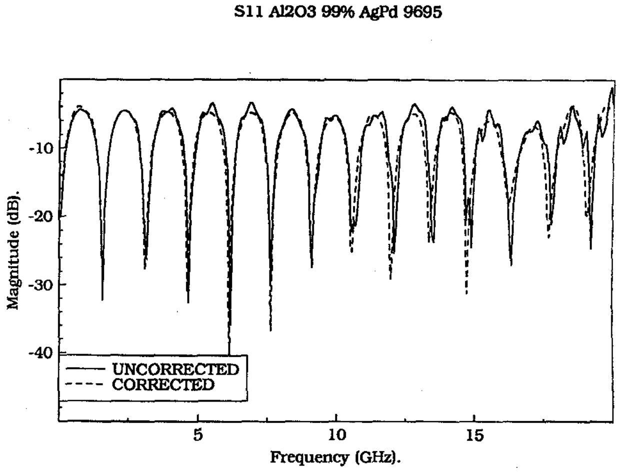

Figure 5. Comparison of corrected and uncorrected measurements. Magnitude of S11.

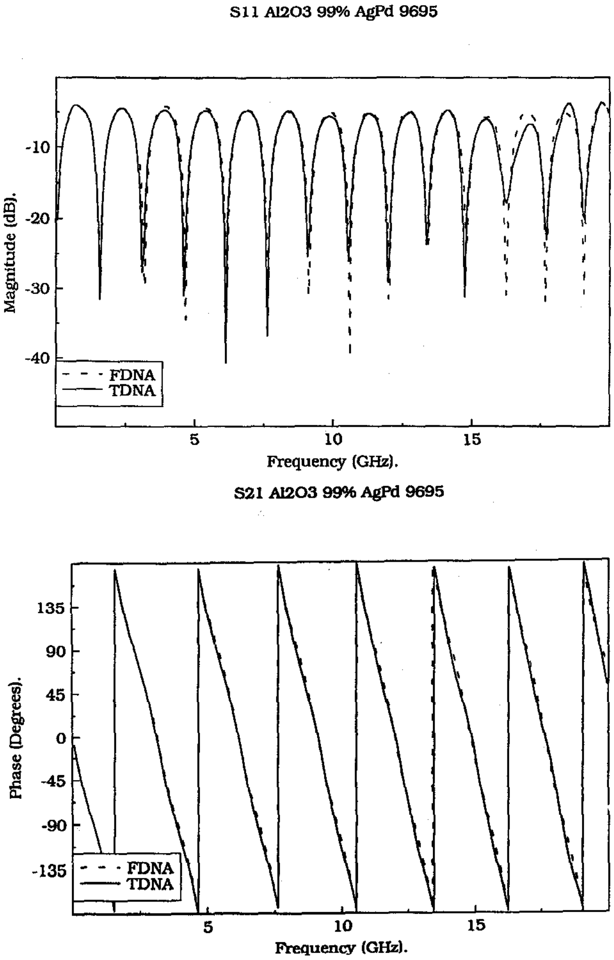

Figure 6. Comparison between time and frequency measurements. Magnitude of S11 and phase of S21.

V . CONCLUSION

A complete calibration procedure for fast sampling oscilloscope has been developped. This calibration allows to use TDR-TDT systems at a quantitative level as a TDNA system. The data acquisition and calibration programs are implemented on a Personal Computer. A whole calibration is achieved in a time comparable to LRL calibration on a classical network analyzer. The corrected results can be expressed either in the frequency or time domain.

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