Improved Time-Domain Characterization of High-Speed Interconnection Structures

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1. Introduction

Impedance controlled interconnection systems are usually characterized using Time Domain Reflectometry (TDR). Time-domain characterization and representation of digital high-speed interconnection structures has some advantages over frequency-domain methods. The reflection and transmission picture gives important insight in the properties of such systems. The behaviour of discontinuities such as transitions through connectors, the position of cable faults and the impedance variation through general interconnection structures are easily detected. However, time-domain data are often obtained without precision calibration techniques, which limits their utility. In this study, two improved time-domain characterization methods are presented. The first one is based on time-domain measurements (with a time-domain reflectometer), and the second one on frequency domain measurements (with a vector network analyzer).

2. Improved Time-Domain Characterization

We will illustrate and compare the two improved time-domain characterization methods by applying them to a simple example: a double step-in-width microstrip line (figure 1).

2.1 Time-domain reflectometry method

The first method is based on very accurate time-domain measurements obtained with the HP54120 time-domain reflectometer and with a self-developed highly innovative high-frequency board probing system [1]. On figure 1, the probe tip, which is essentially a broad-band transition from the coaxial cable from the network analyzer to the planar structure, is shown.

We briefly describe a new calibration and normalization algorithm. Using this algorithm, the reference plane can be placed just in front of the device under test (DUT) and the imperfections in the measurement set-up before the DUT are compensated. The algorithm needs two reference standards to be measured in the time domain i.e. a 50 Ω impedance and a short circuit. In figure 2, the TDR pictures of both reference standards are shown. The disturbances caused by the probe transition can be seen. Based on these reference measurements, a digital filter is created.

The "raw" time-domain measurement of the test structure is shown in figure 3. Using the measured information of the reference standards, the data are first corrected and then transformed to the frequency domain. Next, the data are filtered and normalized to the desired

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rise time. Finally, the data are transformed back to the time-domain. The calibrated and normalized (to a rise time of 100 ps) TDR pictures are shown in figure 4.

2.2 S-parameter approach

The performance of a device under test is uniquely specified by its scattering parameters. Using the HP8510B network analyzer and the same probing system as above [1], the S-parameter data of the device under test can be measured very accurately. A new method has been developed for the simulation of transients in networks consisting of interconnection structures characterized by their S-parameters and terminated with arbitrary linear or non-linear loads [2]. Based on this algorithm, a computer program has been written to accurately convert the measured S-parameter data to TDR-pictures. Note that this simulation algorithm is not limited to linear loading networks!

We now briefly describe the algorithm. First, the S-parameters are measured with the calibrated vector network analyzer HP8510B. As an example, the S_{11}-parameter of the structure under test is shown in figure 5 (reference impedance = 50 Ω). Then, the frequency domain data are transformed into the time domain impulse response of the structure under test. Finally, the transient simulation algorithm is solved in a time-stepping fashion: at each point in time, all ports of the interconnection structure are modelled as a Thevenin (or Norton) equivalent circuit, consisting of a resistance and a voltage (or current) source which amplitude is computed by convolution of the impulse response with previous voltage (or current) waves. This equivalent circuit representation is implemented in a SPICE-like transient simulator. The new simulation algorithm can be seen as a generalization and an extension of the simulation method for uniform lines proposed in [3].

In figure 6, the calculated TDR picture for the structure under test is shown. The rise time of the voltage source (step of 0.4 V) is chosen to be 100 ps, and the interconnection structure is terminated in a 50 Ω load. Due to the high-quality frequency-domain measurements, this time-domain representation is very accurate. The simulated TDR picture (figure 6) is in good agreement with the calibrated and normalized TDR picture (figure 4).

References

[1] P. Degraeuwe, L. Martens and D. De Zutter, "Measurement Set-up for High-Frequency Characterization of Planar Contact Devices," submitted to the 1992 IEEE MTT-Symposium.

[2] T. Dhaene and D. De Zutter, "Extended Thevenin Models for Transient Analysis of Nonuniform Dispersive Lossy Multiconductor Transmission Lines," IEEE International Symp. on Circuits and Systems, San Diego, May 1992.

[3] T. Dhaene and D. De Zutter, "Extended Scattering Matrix Approach for Transient Analysis of Coupled Dispersive Lossy Transmission Lines with Arbitrary Loads", Electromagnetics, 1992 (accepted for publication).

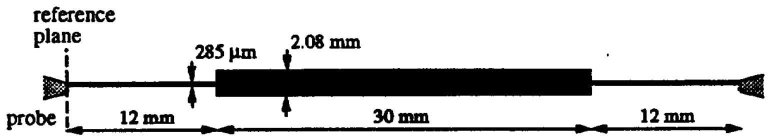

Fig. 1 : Structure under test: double step-in-width microstrip line.

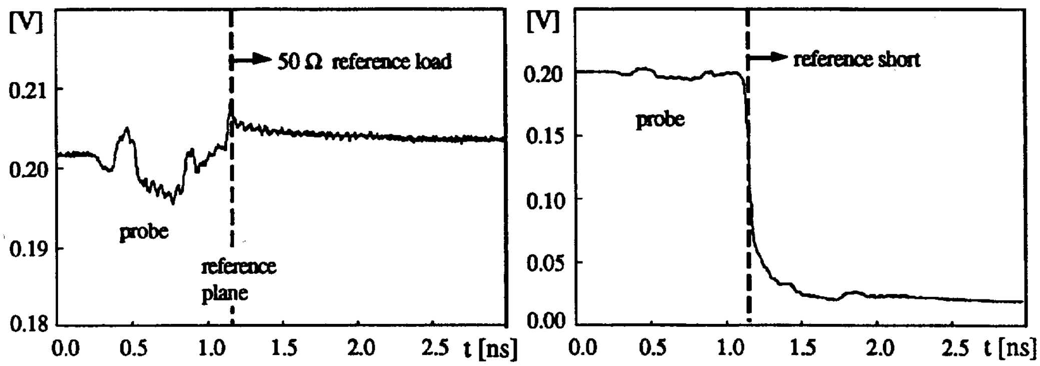

Fig. 2 : TDR picture of calibration standards: 50 Ω reference load and short.

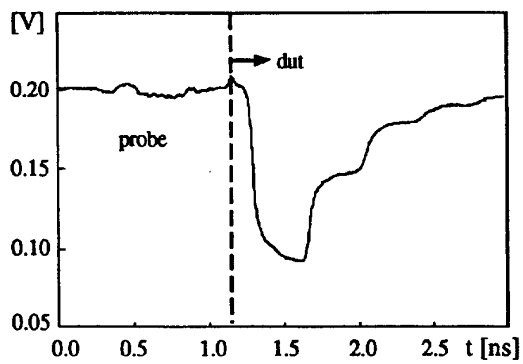

Fig. 3 : "Raw" TDR measurement.

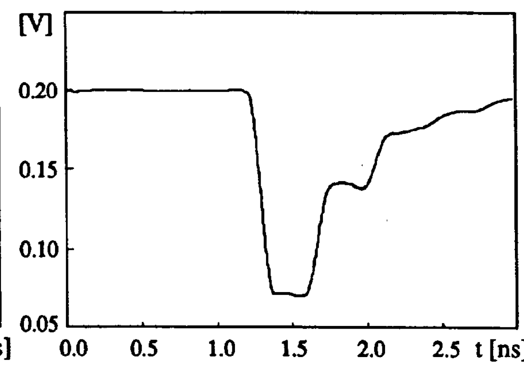

Fig. 4 : Calibrated and normalized (t_r = 100 ps) TDR picture.

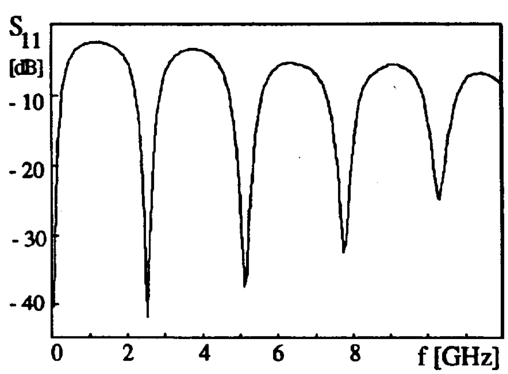

Fig. 5 : S_{11} (reference impedance = 50 Ω).

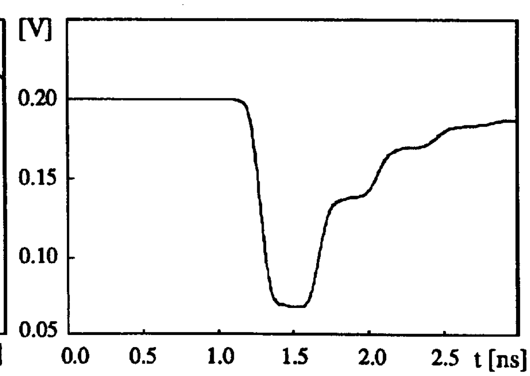

Fig. 6 : Simulated TDR picture (t_r = 100 ps).