Adaptive Time-Domain Macromodeling Algorithm for Fast Termination of FDTD Simulations

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Abstract

In this paper, a novel adaptive stopping criterion for FDTD simulations of microwave components is applied to a package example. The new stopping criterion relies on the Vector Fitting algorithm to successively build an updated macromodel for the frequency response of the device under study based on increasing time-limited transient responses. In this way, it aims at minimizing the number of timesteps and, hence, the overall simulation time to capture the device's frequency response within a given frequency band up to a predefined accuracy level.

1 Introduction

Over the last decades, the finite difference time domain (FDTD) technique has gained more and more importance for the broadband design and optimization of complex microwave systems. Besides its flexibility with respect to the meshing of complex 3D structures, an important reason for the success of FDTD is its ability to capture the broadband frequency response of a system in one single simulation by applying a Fourier transform to the system's time domain response to a broadband pulse excitation. However, care has to be taken that that the FDTD simulation is not terminated before the system's transient response has decayed sufficiently in order to avoid inaccuracies in the frequency domain due to simple zero-padding in the time-domain. On the other hand, a significant amount of computational resources may be wasted if the FDTD simulation is too long [1, 2]. An extra difficulty is that the optimal number of time-steps also depends on the frequency range of interest and on the desired accuracy. A question that arises naturally is if there exists a criterion that allows to stop the FDTD simulation after the minimal number of time steps required to capture the frequency behavior within a given frequency band up to a predefined accuracy level. Existing methods often try to achieve this by extrapolating the time-domain response based on autoregression [3], generalized-pencil-of-functions [4], neural networks models [5], Prony's method [6], pole tracking [7].

2 Overview of Algorithm

This paper applies a new adaptive stopping criterion [8] that directly considers the (premature) frequency domain response for which it successively builds a rational macromodel by means of the Vector Fitting algorithm [9]. This concept is inspired by an adaptive frequency sampling algorithm [10]. All details about the procedure are found in [8], a short outline of the procedure is given below for convenience of the reader :

- The FDTD solver simulates the structure over a short time interval and transforms the transient response to the frequency domain using the discrete Fourier transform.
- Based on the calculated frequency samples a rational macromodel in the frequency band of interest is computed.
- In successive iterations, the time interval is extended by a fixed amount and subsequent macromodels are compared.
- If the deviation between these successive models is smaller then a predefined accuracy threshold, then the frequency content of the extended transient response is assumed to be negligible and the algorithm terminates.

3 Example : QFN package

The effectiveness of the adaptive stopping criterion is illustrated by applying it to a two-port Quad Flat No leads (QFN) package. Modern IC design is not finished until it is packaged. QFN packages are popular low cost packages for RFIC, MMIC and RF SiP applications. Therefore, it is very important for IC designers to get an insight in the electromagnetic performance of the package in the early stages of the design process.

Figure 1 shows the top-view of the overall system consisting of : a chip (in this case a thin film circuit), four bond wires, a QFN package, and input and output microstrip lines all mounted on a PCB. The transmission from the input to the output is studied from DC up to 25 GHz to verify the performance of the double bonding over this broad frequency range. Studying the performance using FDTD simulations is challenging because of the small cell sizes that are required in the FDTD grid to accurately capture the dynamic behavior of the bond wires. Due to the stability criterion, small cell sizes inevitably result in a small time step, making it essential to minimize the number of time steps needed to characterize the broadband behavior.

Initially, the FDTD simulator calculates the currents $i(t)$ and voltages $v(t)$ for 10.000 time steps at the two ports of the structure. Their frequency domain counterparts $I(\omega_k)$ and $V(\omega_k)$ are obtained by the discrete Fourier transform and constitute the S-parameter response $\{S(\omega_k)\}$ of the system.

A subset of the S-parameter data samples $\{\bar{S}(\bar{\omega}_k)\}$ is subjected to the selective rational macromodeling procedure, and the time interval is extended by 1000 time steps in successive

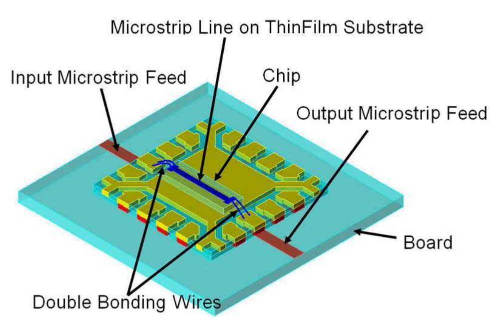

Figure 1: Top-view of QFN package.

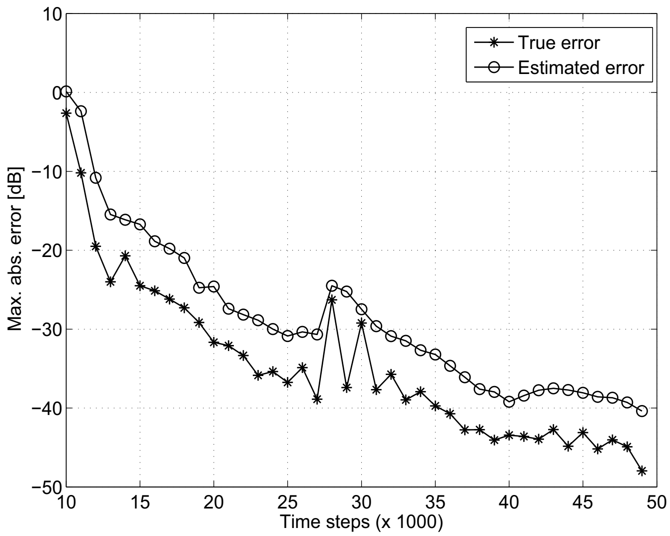

Figure 2: Maximum absolute error vs. number of time steps.

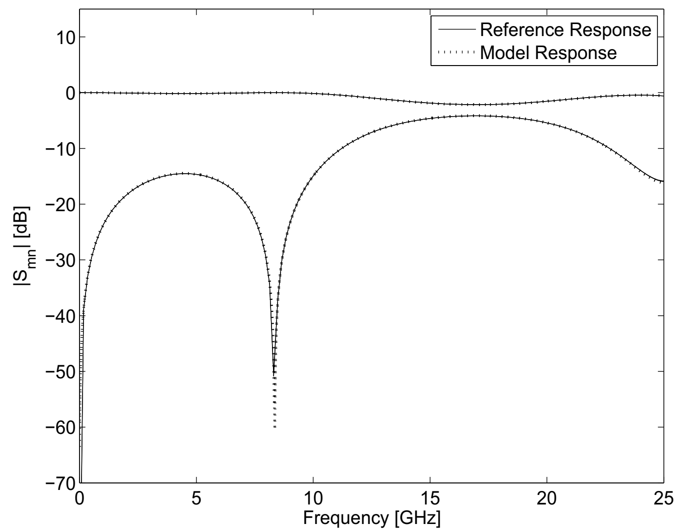

Figure 3: Freq. response of model based on 49.000 timesteps.

iterations until the frequency domain macromodels converge to a common solution. The evolution of the maximum absolute error between consecutive macromodels in the frequency domain (i.e. estimated error) is shown in Figure 2. It is found that at least 49.000 time steps are needed to obtain the desired accuracy of $\delta =$ -40 dB. This leads to a significant reduction when compared to classical energy-based stopping criteria [11] that require at least 70.000 time steps.

The reference frequency response is computed for validation purposes and the true error is shown in Figure 2. Clearly, both error curves are closely correlated and follow a similar trend. Figure 3 shows the magnitude of the converged macromodel and the reference data and a good agreement is observed.

4 Conclusion

A novel stopping criterion is introduced to reliably minimize the number of time steps that are needed in FDTD simulations to capture the broadband behavior of microwave components up to a given accuracy level. A QFN package example indicates that the proposed method significantly reduces the computational cost of the time domain characterization, especially if the pulse excitation of the system is slowly decaying.

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References

[1] P. Kozakowski and M. Mrozowski, "Low-Order Models from FD-TD Time Samples", *IEEE Microwave and Wireless Components Letters*, vol. 12, no. 11, pp. 438–440, November 2002.

[2] G. Selli, J. Drewniak and D. Pommerenke, "An Extrapolation Procedure to Shorten Time Domain Simulations", *International Symposium on Electromagnetic Compatibility - EMC 2004*, vol. 1, no. 9-13, pp. 113-117, August 2004.

[3] V. Jandhyala, E. Michielssen, R. Mittra, "FDTD Signal Extrapolation using the Forward-Backward Autoregressive (AR) Model", *IEEE Microwave and Guided Wave Letters*, vol. 4, no. 6, pp. 163-165, June 1994.

[4] Y. Hua and T. K. Sarkar, "Generalized pencil-of-function method for extracting poles of an EM system from its transient response", *IEEE Transactions on Antennas and Propagation*, vol. 37, pp. 229-234, February 1989.

[5] C. Wu, E. A. Navarro, J. Navasquillo and J. Litva, "FDTD Signal Extrapolation using a Finite Impulse Response Neural Network Model", *Microwave and Optical Technology Letters*, vol. 21, no. 5, pp. 325-330, April 1999.

[6] W. L. Ko and R. Mittra, "A combination of FDTD and Prony's Method for Analyzing Microwave Integrated Circuits", *IEEE Transactions on Microwave Theory and Techniques*, vol. 39, pp. 2176-2181, December 1991.

[7] Y. Kuznetsov, A. Baev, P. Lorenz, P. Russer, "Network Oriented Modeling of Passive Microwave Structures", *International Conference on Computer as a Tool*, pp. 10-14, September 2007.

[8] D. Deschrijver, D. Pissoort and T. Dhaene, "Adaptive Stopping Criterion for Fast Time Domain Characterization of Microwave Components", *IEEE Microwave and Wireless Components Letters*, vol. 19, no. 12, December 2009.

[9] B. Gustavsen and A. Semlyen, "Rational Approximation of Frequency Domain Responses by Vector Fitting", *IEEE Transactions on Power Delivery*, vol. 14, no. 3, pp. 1052–1061, July 1999.

[10] T. Dhaene, J. Ureel. N. Fache and D. De Zutter, "Adaptive Frequency Sampling Algorithm for Fast and Accurate S-Parameter Modeling of General Planar Structures", *IEEE International Microwave Symposium - MTT-S Digest*, vol. 3, pp. 1427-1430, May 1995.

[11] Agilent EEsof COMMS EDA, Electromagnetic Professional (EMPro) Software, Agilent Technologies Inc, Santa Rosa, CA (USA).