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ABSTRACT

This paper describes RICE, an RLC interconnect evaluation tool based upon the moment-matching technique of Asymptotic Waveform Evaluation (AWE). The RLC circuit moments are calculated by a path-tracing algorithm which enables the analysis of large interconnect models several thousand times faster than a circuit simulation while requiring 5 to 10 times less memory. RICE also includes a new approach for determining the circuit dominant time-constants which avoids the inherent instability problems associated with moment matching methods in general.

I. INTRODUCTION

As the feature sizes of integrated circuits continue to shrink and operating speeds increase, the characterization of the parasitic effects associated with on-chip interconnect paths becomes more critical and more difficult. This difficulty is the result of an increase in both the metal resistance per unit length and the switching speeds as line widths and channel lengths decrease. In addition, the close proximity of two metal lines makes the component cross-talk capacitance larger. Even inductance effects, which are certainly evident for boards and multi-chip modules, may be important for modeling the i.c. packaging or chip-to-package interface.

In attempting to capture the interconnect effects on high-frequency digital signals, the "analog" detail of the signal waveforms becomes important. The signal characterization, therefore, must be in terms of a *waveform calculator* as opposed to the more traditional *delay calculator*[1]. Moreover, accurately modeling the RC, or even RLC effects of fast switching signals requires distributed models or an enormous number of lumped RC/RLC segments.

This paper describes a Rapid Interconnect Circuit Evaluator (RICE) based on the moment matching technique of Asymptotic Waveform Evaluation (AWE)[2]. Previously, AWE was demonstrated as an efficient means of approximating the time-domain or frequency-domain response of linear(ized)

RLC circuits. RICE exploits the structure of typical RLC interconnect paths and can provide better than 10^2 x speedup over a more generalized version of AWE (AWEsim)[3] and more than 10^4 x speedup over a circuit simulator[4] for very large interconnect paths. This significant speedup permits interconnect paths modeled in terms of even 100,000 linear segments to be analyzed in a few seconds, in contrast to tens of hours for a circuit simulator analysis.

With circuits that contain more than 10^5 elements, the runtime storage requirements become extremely important. RICE exploits the interconnect structure to reduce memory requirements by over 80% as compared to directly factoring a complete circuit matrix. In addition, by focusing the AWE technique on the analysis of passive, linear, RLC interconnect paths, a more robust algorithm is used for mapping moments to waveform approximations. The nonlinear equation solution which maps the moments to the dominant time constants is constrained to guarantee a stable approximation, thereby circumventing the well-known instability problems associated with moment matching in general[5].

II. BACKGROUND

In the past, MOS delay calculators have been able to effectively characterize the VLSI circuit interconnect in terms of an RC tree circuit model and an Elmore delay analysis[6]. The Elmore delay value, or first moment of the impulse response, can be used as a dominant time constant approximation to permit waveform analysis. For an RC tree model, the Elmore approximation is obtainable in linear time[7]. The accuracy of the waveform is limited, however, and bounding the waveform can, at times, be overly pessimistic or optimistic[8].

Higher order methods were developed to permit improved waveform approximations without much penalty in execution time. In [9], a second-order RC-tree model, still of linear complexity, is shown to handle the effect of dominant zeros, a problem for the first-order Elmore approximation. In [2], Asymptotic Waveform Evaluation (AWE) is described as a general n-th order extension of the Elmore approximation which uses moment matching to solve general RLC circuits. AWE's efficiency was demonstrated in [3] for solving linear interconnect paths and small-signal analog circuit models. For large interconnects, AWEsim can provide 100x CPU-time improvement over a circuit simulation.

AWE permits the analysis of interconnect models other than RC-trees and therefore coupling capacitance, resistor loops, and inductance are handled without loss of generality. Such

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