Fast Sequential FDTD Diakoptics Method Using the System Identification Technique

Tian-Wei Huang, Bijan Houshmand, and Tatsuo Itoh, *Fellow, IEEE*

Abstract—**The sequential finite-difference time-domain (FDTD) Diakoptics method is accelerated by the system identification technique. The time-domain convolution in Diakoptics is replaced by a difference equation with a small number of coefficients. Hence, the memory size is also reduced. The validity of this method is confirmed by comparison with simulated results from Microwave SPICE. The accuracy of this fast algorithm is also demonstrated by the analysis of cascaded circuit modules.**

I. Introduction

One way to simulate a large circuit is to divide this circuit into several small modules, simulated individually. According to this application, the time-domain Diakoptics method has been developed in TLM [1], [2], and in FDTD [3], [4]. The time-domain Diakoptics can include all the mutual interactions among modules through a convolution interface, so it is a full-wave analysis. Applying Diakoptics in the device optimization problems, the repetitive computation of fixed large structures is avoided. The time-domain Diakoptics is also one candidate method for the implementation of parallel computation in time-domain simulations.

The time-domain Diakoptics uses time-domain convolution for connecting modules. This convolution requires the knowledge of the entire signal history, especially for a module with an infinitely-long impulse response. Instead of using convolution approach, a linear discrete-time system can be characterized by its constant-coefficient difference equation, generated by the system identification (SI) technique [5], [6]. This difference equation depends only on a small number of past inputs and outputs. In [7], a single module is analyzed by the SI technique. This letter extended this fast algorithm to cascaded modules. The memory reduction and computational efficiency are also demonstrated.

II. Theory

There are two different approaches to characterize a discrete-time system. The first one is convolution approach that uses impulse response $h(k)$ to represent a system, like a finite-duration impulse response (FIR) filter. The second one is system identification approach that replaces a system by its difference equation with coefficients a_k, b_k, and time-delay

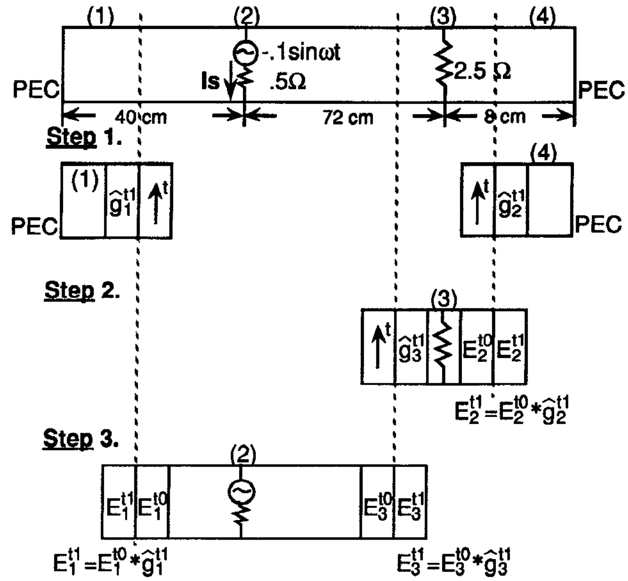
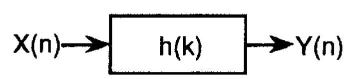


Fig. 1. A shorted parallel plate waveguide is analyzed by the sequential FDTD Diakoptics method.

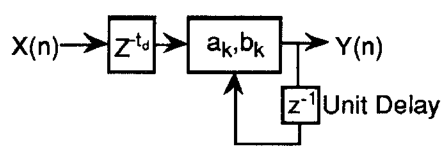
t_d. Because the SI approach has feedback, it is an infinite-duration impulse response (IIR) filters. A detailed description of SI technique is available in [8].

1) Convolution Approach (Nonrecursive):



$$Y(n) = \sum_{k=0}^{n} h(k)X(n-k). \quad (1)$$

2) System Identification Approach (Recursive):



$$Y(n) = -\sum_{k=1}^{N} a_k Y(n-k) + \sum_{k=0}^{M} b_k X(n-k-t_d). \quad (2)$$

Where, $X(n)$ and $Y(n)$ are the input and output of this system. For FDTD Diakoptics, $X(n)$ and $Y(n)$ are the total

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The authors are with the Department of Electrical Engineering, University of California at Los Angeles, 405 Hilgard Avenue, Los Angeles, CA 90024–1594.

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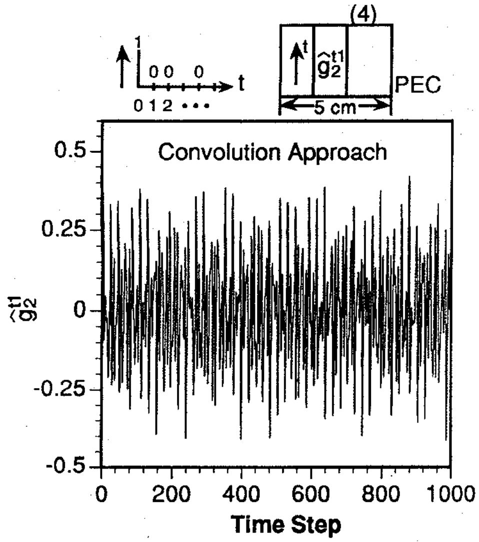

Fig. 2. Impulse response of module (4) in Fig. 1, which can be replaced by a difference equation with 80 coefficients obtained from SI approach using 90 time steps. This difference equation can generate the indistinguishable impulse response to the above.

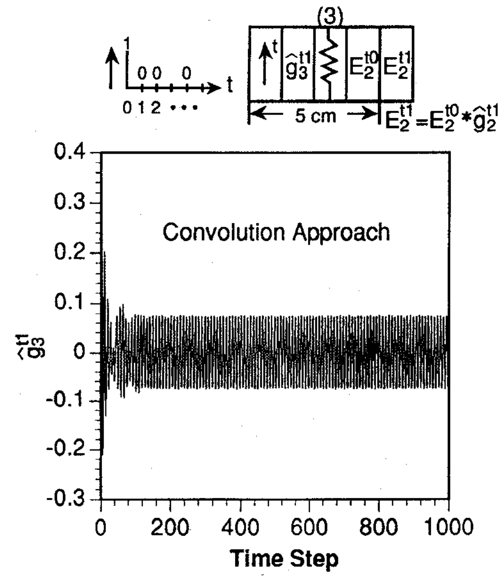

Fig. 3. Impulse response of cascaded module (3) and (4) in Fig. 1, which can be replaced by a difference equation with 80 coefficients obtained from SI approach using 90 time steps. This difference equation can generate the indistinguishable impulse response to the above.

tangential E-field, defined in [3]. Since the TLM and FDTD discretize both time and space, there is a stop-band for high frequencies. For a low-pass system, an IIR filter can provide a smaller order realization than a FIR filter. Hence it is more efficient to use SI approach in Diakoptics than convolution.

III. Results

Fig. 1 shows a parallel-plate transmission line with TEM mode analyzed by the sequential FDTD Diakoptics [3], [4]. During Step 1 the impulse responses of two outer modules are calculated, as shown in Fig. 2. This impulse response has infinite-duration, that is easily characterized by SI approach within 90 time steps. To simulate the inner module (3), one

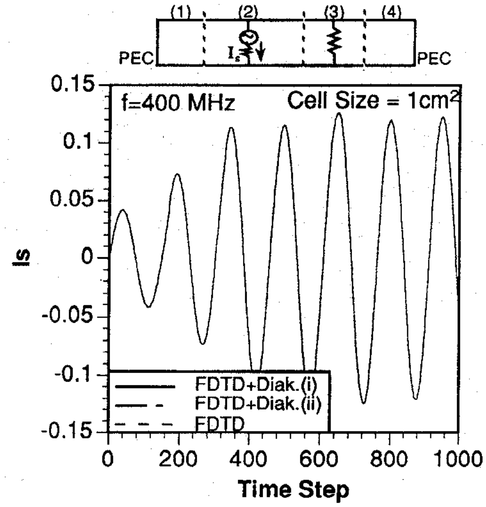

Fig. 4. Transient response simulated by FDTD method and sequential FDTD Diakoptics with (i) convolution approach, and (ii) SI approach.

TABLE I
Comparison of Simulation Time (in Time Steps) Between (i) Convolution Approach, and (ii) System Identification Approach

	Impulse Duration (i)	No. Coeff. in Diff. (ii)	Simulation Time (i)	Simulation Time (ii)
Uniform Line [7]	300 (Approx.)	80	300	60
Shorted Line (Fig. 2)	Infinite	80	Time of Interest	90
Cascaded (Fig. 3)	Infinite	80	Time of Interest	90

convolution with the result from Fig. 2 is needed at the interface between (3) and (4). Fig. 3 is the impulse response of cascaded modules (3) and (4), that can be also obtained by applying SI technique on module (3) terminated with a difference equation of module (4). Fig. 4 shows excellent agreement between the circuit responses simulated by the FDTD Diakoptics with SI technique and the FDTD. This example also demonstrates the accuracy of SI approach on cascaded modules.

Table I compares approaches (i) and (ii) for three types of impulse responses to show the efficiency of SI technique. For a infinite-duration impulse response, the SI approach is necessary to make its computational time finite. For an uniform line, its impulse response can be approximated by 300 time steps. Even for a finite-duration response, SI technique can also reduce the computational time and memory.

IV. Conclusion

The convolution operation in time-domain Diakoptics is accelerated by the system identification technique. In this letter, this technique is applied to cascaded circuit modules to verify its accuracy. The SI technique has particular efficiency for an infinitely-long impulse response system, that can be characterized with a small number of time steps and coefficients. For the multimode problems in [9], the SI technique can be used to accelerate the simulation of each element in an impulse response matrix. This technique can also be applied to the time-domain Diakoptics in TLM.

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