FULL-WAVE DIAKOPTICS FOR FAST STRUCTURE OPTIMIZATION

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Abstract: The paper describes the extension of a numerical procedure, called diakoptics, that allows the electromagnetic field solutions by segmentations of a large structure in a rigorous manner. Using the Transmission-Line Matrix (TLM) that is fully compatible with diakoptics, one can optimize sub-volumes during subsequent simulations without meshing the whole structure. In this paper, some recent development to accelerate the procedure is presented and an extension to access data outside the meshed sub-domain under computation is presented and validated. Various examples including cavities, planar guides and scattering structures will be presented. It is shown that some substantial gain in computer expenditure can be obtained.

INTRODUCTION
In many applications for which radiation and coupling phenomena cannot be neglected, solutions require the solution of Maxwell's field equations. Numerous numerical methods have been proposed to solve these equations in a most rigorous way. They all have their advantages and drawbacks and the choice of one of them depends mainly on the application. For instance, the Finite Difference Time Domain (FDTD) [1] or Transmission-Line Matrix (TLM) [2] methods are well suited for complex geometry and their efficiency for analyzing antenna systems, guiding structures and even indoor propagation. In addition, these methods, which are typically implemented in time-domain, allow a wideband characterization and can easily handle non-linear problems. However, these methods (called volumic methods) are computer expensive procedures. In particular, they cannot cope with the analysis of large (multi-wavelength) structures within a reasonable period of time. As a result, even if the structure is relatively small, optimization or Computer Aided Design (CAD) procedures cannot be directly applied. When geometric or electromagnetic parameters of a small portion of a large problem are supposed to be optimized, subsequent simulations constitute a lengthy process. However, if one can solve only for the subvolume under investigation without meshing the rest of the structure, then an optimization procedure becomes feasible.

DIAKOPTICS
Diakoptics was first used by Kron [3] for solving power networks. Johns transposed the procedure for TLM computations [4]. The procedure consists of splitting a structure into sub-volumes and solving rigorously for each separate sub-volume as illustrated in figure 1. Suppose that a small sub-volume contains structures whose dimensions and/or constitutive parameters have to be modified for obtaining optimum performances or to meet specifications. Numerous runs must then be performed, requiring much computation expenditure.

![Figure 1: Illustration of diakoptics' procedure.](image)

Diakoptics allows a reduction of the computational domain that extends to the relevant sub-volume only. The procedure starts with the insertion of a so-called "Johns' boundary" that surrounds the sub-volume (figure 1a). Then the sub-volume is removed from the structure and the remaining volume is...
meshed with TLM cells for electromagnetic computations (figure 1b). Impulses are injected through the John's boundary and numerical responses of the meshed volume returning to the boundary stored in a three-dimensional matrix called the "John's matrix". This matrix constitutes an electromagnetic "print" of the remaining structure that corresponds to the discretized form of its space-time Green's function seen through the John's boundary. Then, any subsequent full-wave computation of the sub-volume can be performed without the remaining structure (figure 1c). The latter is accounted for by space-time convolutions at TLM nodes adjacent to the John's boundary. The process may be generalized to an arbitrary number of sub-volumes. However, computer cost reduction increases with the ratio volume/sub-volume. Note that John's matrix storage as well as convolution product computations can be greatly reduced by various procedures such as Laguerre's polynomials [5]. Thus, only few coefficients per response need be stored. Furthermore, recursive forms for convolution products can be used with these decomposition techniques to speed up computation and reduce memory storage.

**JOHNS' MATRIX EXTENSION**

Although the above procedure reduces the computer cost for structure optimization, the parameter of interest such as scattering parameters, reflection coefficient, impedance, etc. require electromagnetic quantity values outside the meshed sub-volume. One solution is to extend the sub-volume such as to include the cells where field values are needed. However, the price to pay is to reduce the advantage of using diakoptics as the ratio volume/sub-volume decreases. It is proposed here to include the responses of the relevant output quantities during the John's matrix generation procedure.

**John's matrix generation.** Consider again a segmented structure where the required TLM cells are beyond the John's boundary (figure 2a). Hence, the basic procedure consists of meshing the remaining volume and injecting one Dirac impulse successively to every node branch incident to the boundary and, for each impulse at branch m recording the time sequences reflected from branch n at the John's boundary. Thus, the basic procedure yields the tri-dimensional John's matrix \( g(m, n, k) \) where \( k \) is the time index. Note that if \( N \) is the number of branches adjacent to the John's boundary, and \( K \) the number of time samples per response, the number of terms to be stored is \( K N^2 \). Now suppose that one needs, for instance, the total electric field value at the output point O (see figure 2a) for determining a parameter relevant to the sub-volume optimization, the field time sequences are also recorded, thus, adding one layer to the John's matrix (figure 2b).

![Diagram](image)

*Figure 2: Diakoptics procedure for an output point O outside the sub-volume to be optimized.*

Generally speaking, there will be as many additional layers as the number of parameters needed. Note that only the parameter needs to be stored, even if several output points are needed to compute it.

**Reflected sequences from John's boundary.** Once the John's matrix has been computed and stored, the sub-volume to be optimized is meshed (see figure 2c) and the TLM computation can be carried
out. At the Johns’ boundary, incident voltage pulses \( V^i \) will trigger time responses at branch \( m \) that are reflected and computed from the time-space convolution given by:

\[
V^f(m,k) = \sum_{n=1}^{N} \sum_{k'=1}^{K} g(m, n, k) \ V^i(n, k-k'). 
\]  
(1)

The parameter value \( S \) computed at the output point is computed by:

\[
S(k) = \sum_{n=1}^{N+1} \sum_{k'=1}^{K} g(N+1, n, k) \ V^i(n, k-k'). 
\]  
(2)

where \( g(N+1, n, k) \) represents the Johns’ matrix additional layer (see figure 2b). If a source is present beyond the Johns' boundary, its contribution \( V^s(m, k) \) should be added to (1) and (2).

RESULTS

Consider the microstrip discontinuity whose half the structure is illustrated in figure 3a. Matched layers on five sides and a magnetic wall (PMW), to take advantage of the symmetry, limit the computational domain. The sub-volume (10 x 12 x 3 mm) enclosed by the Johns' boundary is meshed with 1-mm cubic TLM cells. Results illustrated in figure 3b show a perfect match between diakoptics and full-domain TLM solution for \( S_{11} \) computation at the output point.

CONCLUSION

A segmentation technique namely, "diakoptics" is extended to the general case. Most suitable to TLM full-wave modeling, this two-step procedure allows the analysis of sub-volumes of a structure in the most rigorous way. It is shown that the sub-volume doesn't need to include points at which quantities or parameters values have to be determined. They can be accounted for by extending the John's matrix appropriately. Comparison results show a perfect match between diakoptics and full-volume computation for a non-canonical example. Thus, the great potential of the technique for full-wave optimization is demonstrated and will be further enhanced when accelerating techniques for Johns' matrix generation and convolution products are conjointly applied. Application examples for various structures will be presented.

REFERENCES