A HIGH LEVEL COMPILER FOR THE ELECTROMAGNETIC MODELING OF COMPLEX CIRCUITS BY GEOMETRICAL PARTITIONING

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ABSTRACT

An electromagnetic geometrical compiler is introduced. The compiler takes the structure being investigated and breaks it down into blocks via many levels of structural decomposition. The structure once thus decomposed is then analyzed from the bottom up using the method of moments. By using this procedure, large and complex structures can be analyzed quickly and with little computer memory.

INTRODUCTION

Full Electromagnetic (EM) modeling of a structure is required where the structure being investigated consists of many nonstandard components, and is run at such a high frequency or density that the coupling between any of these components cannot be neglected by easily predetermined rules. Typical EM modeling for these high frequency effects consists of the use of spectral domain or quasi-dynamic techniques for determining the mutual coupling effects. When the structure becomes complex geometrically, the computation time required for the analysis of that structure becomes excessive unless numerically efficient techniques are incorporated [1-5]. For example, in a paper published in last year's MTT-S digest, Jansen et. al. analyzed an interdigital bandpass filter which required 50000 unknowns for its solution [6]. It should be mentioned that this is just a simple problem. A software package was developed at the University of Waterloo to perform the analysis of complex structures using the method of moments (MoM) which incorporates many efficiency improving techniques [7,8]. For example the same bandpass filter example as computed by Jansen was calculated using this code and the number of unknowns required to obtain the same accuracy was only 330 [9]. Computer memory limitations and problem solution time excesses occur when the structure being investigated becomes very large. By incorporating the diakoptic theory into the MoM program, the matrix inversion problem and the memory problems are eliminated [10].

At this point it appears that all the problems are solved, but there is still the problem of describing the structure to be investigated to the computer in such a fashion that the above mentioned techniques can be applied effectively. This is where a compiler which takes the structure being investigated and breaks it down into blocks via many levels of structural decomposition becomes important.

COMPILER LAYOUT

The layout of the compiler lets one take a geometrically complicated circuit and break it down into more manageable substructures. These substructures can be broken down themselves into even more manageable substructures. This is known as ***building the tree***. The process continues until the structure can be defined in terms of elementary blocks. These blocks are the basic cells in the definition of this structure.

II

An elementary block consists of one of the following geometries:

RECT A rectangular block which has six describing parameters. The describing parameters are:

Point 1 (P1), Point 2 (P2), Width (W), Number along the width (NW), Number along the length (NL) and Transverse.

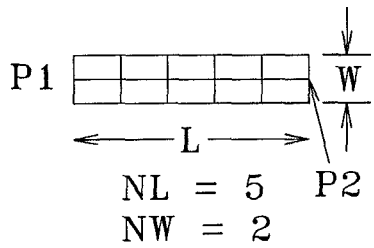

Figure 1 RECT: The rectangular elementary block.

P1 and P2 describe the starting and stopping points of the rectangle. In Fig 1 they are indicated as being midway along the width (W) of the block. NW is a parameter indicating how many charge patches should be used to divide the width of the element. NL is a similar parameter for the length. Transverse is a logical parameter which describes whether the block's transverse source distribution should be described as constant over each cell, or via the $1/(1-(2x/w)^2)$ distribution typical of an infinitely thin isolated strip.

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QUAD A quadrilateral block which has seven describing parameters:

Point 1 (P1), Point 2 (P2), Point 3 (P3), Point 4 (P4), Number along the width (NW), Number along the Length (NL) and Transverse.

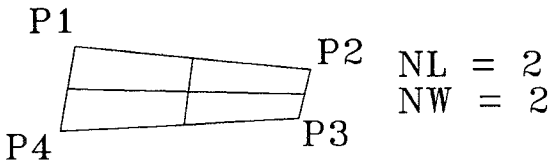


Figure 2 QUAD: The quadrilateral elementary block.

P1 through P4 describe the four corners of the quadrilateral block in a clockwise manner. NW, NL and Transverse are parameters similar to those for the RECT elementary block.

TRI A triangular block which has four describing parameters:

Point 1 (P1), Point 2 (P2), Point 3 (P3) and Transverse.

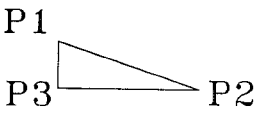


Figure 3 TRI: The triangular elementary block.

P1 through P3 describe the three corners of the triangular block in a clockwise manner. Transverse is a parameter similar to that for the RECT elementary block.

The versatility of the shapes of the elementary blocks allows most planar MIC structures to be described either approximately or exactly using those blocks. Those structures which do not use curved metallization patterns can be described exactly, while those structures which do use curved metallization patterns can be approximated.

At this point the structure has been broken down in a tree like fashion just as a compiler parses a program. The next step is to compute the structure by applying the rules of the compiler grammar, i.e. mutual coupling rules through user defined ports on the structures. This process is known as ***traversing the tree structure***. In traversing the tree, the compiler generally starts at the root node of the tree and then descends down to terminating substructures which for this compiler are the elementary blocks. In the descent to a terminating substructure, the compiler follows a logical set of rules to ensure that all terminating substructures are handled. Once the terminating substructure has been reached, the compiler then moves up the tree applying the appropriate rule to the substructure. For the geometrical compiler, the rule applied to the terminating substructure is the MoM (utilizing such tools as complex images, multi-pipes, basis transformation techniques, etc. [7,8]). Once the lowest level substructures have been calculated, the next level in the tree is tackled. This level consists of computing the interstructure coupling of these substructures through such tools as the diakoptic theory [10] or the reduced source distribution technique [11]. The processing of levels continues until one reaches what is known as the root level, i.e. where the port to port characteristics of the overall structure are calculated.

AN EXAMPLE OF THE APPLICATION OF THE COMPILER

Building the Tree

A reactively matched amplifier example (Fig 4) will be used to illustrate the ***building of the tree*** for a fairly complicated circuit.

The amplifier consists of three spiral inductors, five overlay capacitors, one resistor and one FET. The substrate that they are embedded in (or on) is unimportant since the compiler can analyze any layered substrate structure [12].

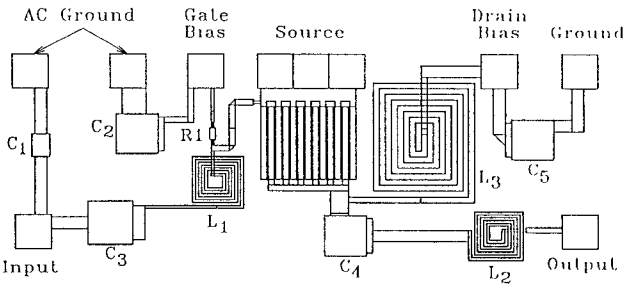


Figure 4 An example reactively matched amplifier circuit ***structure.***

The first step in the analysis with the compiler is to break the structure into substructures. This is equivalent to the root of the tree structure with its first level substructures. Towards this end, the reactively matched amplifier is broken into five first level substructures numbered one through five (fig 5). If any of these substructures were identical, an analysis of one would yield a solution for all that are identical. Thus the breaking of a larger structure into identical substructures achieves immense computational savings since the compiler would deal with all of these substructures by analyzing just the one of them. In this example, the substructures are different from one another.

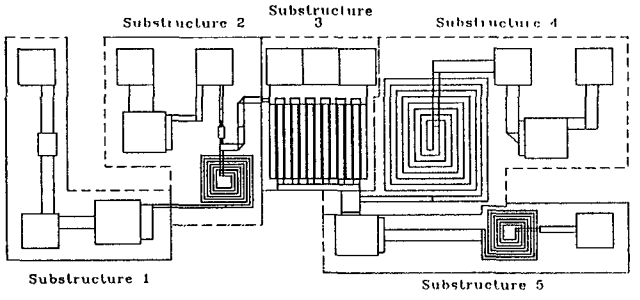


Figure 5 The first level ***substructure*** decomposition.

The second step in the tree building process consists of further dividing each of the first level substructures into second level substructures. This is illustrated for substructure 5 of the amplifier circuit (Fig 6). In this example the substructure is broken down into three second level substructures, labelled 5,1 through 5,3. The first index of the label indicates the first level substructure number, i.e. 5 in Fig 5, while the second index indicates the second level substructure number, 1-3 in Fig 5.

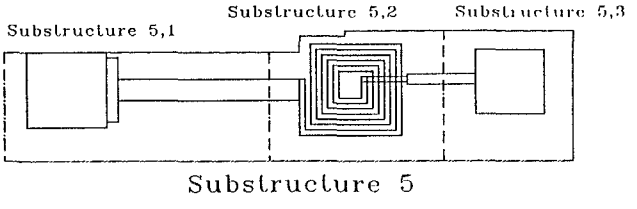


Figure 6 The second level ***substructure*** decomposition.

The third step in the tree building process consists of further dividing each of the second level substructures into third level substructures. This is illustrated for substructure 5,1 of the substructure 5 circuit (Fig 7). In this example substructure 5,1 is broken down into three third level substructures, labelled 5,1,1 through 5,1,3. The third index of the label indicates the third level substructure number. The breaking down of the circuit in terms of substructures could continue beyond this level, but the third level substructures in this example are simple enough to be described by a small number of elementary blocks.

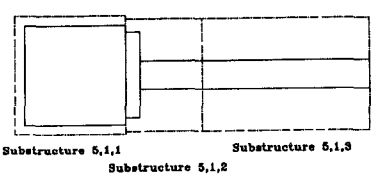
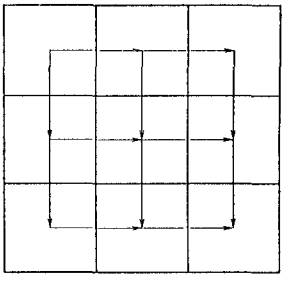


Figure 7 The third level ***substructure*** decomposition.

The final step in the tree building process consists of describing the third level substructure in terms of elementary blocks (Fig 8). In this case the substructure can be defined in terms of one block only with three patches across the width and three patches along the length.



Substructure 5,1,1

Figure 8 The decomposition of the third level substructure into a ***block.***

Traversing the Tree

When ***traversing the structure***, the MoM is applied to the lowest level substructures. Thus for substructure 5,1,1 there would be two basis function solutions $\psi^1_{5,1,1}(x',y',z')$ and $\psi^2_{5,1,1}(x',y',z')$ corresponding to the two ports which describe the substructure. The superscripts correspond to the port number.

Continuing the tree traversal, consider the second level substructure 5,1 of figure 6 again. At the substructure 5,1 level, the basis functions required to describe this substructure are obtained by a superposition of the basis functions of the substructures 5,1,1 through 5,1,3:

$$\psi^1_{5,1}(x',y',z') = \sum_{i=1}^{3}\sum_{j=1}^{2} \psi^j_{5,1,i}(x',y',z')\alpha^1_{i,j}$$

$$\psi^2_{5,1}(x',y',z') = \sum_{i=1}^{3}\sum_{j=1}^{2} \psi^j_{5,1,i}(x',y',z')\alpha^2_{i,j}$$

By obtaining a superposition of basis functions of this sort, more complicated current distributions can be used as basis functions at the higher levels. Using these basis functions in the MoM also includes all the mutual coupling between the elements. This procedure is basically an application of the Diakoptic theory [10].

The basis functions for the 5,1 level are used to obtain the basis functions for substructure 5. The basis function for substructure 5 is obtained via a superposition of the basis functions for the substructures which make up substructure 5, i.e. substructures 5,1 through 5,3.

$$\psi^1_5(x',y',z') = \sum_{i=1}^{3}\sum_{j=1}^{2} \psi^j_{5,i}(x',y',z')\alpha^1_{i,j}$$

$$\psi^2_5(x',y',z') = \sum_{i=1}^{3}\sum_{j=1}^{2} \psi^j_{5,i}(x',y',z')\alpha^2_{i,j}$$

Again all mutual coupling between the substructures is included via the coupling between the basis functions.

At the root level of the tree, the current distribution of the overall structure, i.e. the reactively matched amplifier, is obtained as a superposition of the solutions at the previous levels. This is accomplished in the same manner as for the previous two levels:

$$\psi^1(x',y',z') = \sum_{i=1}^{5} \sum_{j=1}^{Nport_i} \psi_i^j(x',y',z')\alpha_{i,j}^1$$

$$\psi^2(x',y',z') = \sum_{i=1}^{5} \sum_{j=1}^{Nport_i} \psi_i^j(x',y',z')\alpha_{i,j}^2$$

Thus ψ^1 and ψ^2 represent the overall current distribution for the amplifier, and are used in calculating the Z-parameters and the S-parameters for the structure.

IMPORTANT CONSIDERATIONS FOR THE COMPILER

Tightly Coupled Structures

Tightly coupled structures can perturb the typical transverse current distribution assumptions in a MoM description. This is handled by precalculating the transverse current distribution on a substructure [13], or allowing the MoM extra degrees of freedom in calculating the transverse current distribution.

Source Fringe Fields

Interconnection of substructures typically involves a perturbation of the assumed or precalculated current distribution of a substructure. This problem is avoided by filtering the fringe field current perturbations [14].

Memory Considerations

By describing structures in terms of substructures which in turn are finally described as blocks, the largest problem that needs to be solved at one time is either the largest substructure problem, or the interconnected structure problem at any particular level in the system description. Any identical substructures and the smaller MoM matrix sizes reduce both the computer time and the computer memory required.

REFERENCES

[1] D.C. Chang, "Numerical modeling of passive network and circuit components in Monolithic Microwave integrated circuits (MMIC)," presented at the International Conference on Directions in Electromagnetic Wave Modeling, Oct. 22-24, 1990, New York, NY.

[2] N. G. Alexopoulos, "Modeling high frequency interconnections from a radiation point of view," presented at the Workshop on High Frequency Interconnects, 1989 IEEE MTT-S International Microwave Symposium, June 16, 1989, Long Beach, CA.

[3] L.P.B. Katehi, "High frequency numerical modeling of passive monolithic circuits and antenna feed networks," presented at the International Conference on Directions in Electromagnetic Wave Modeling, Oct. 22-24, 1990, New York, NY.

[4] R.W. Jackson, "Full-wave, finite element analysis of irregular microstrip discontinuities," IEEE Trans. on Microwave Theory Tech., Vol.37, No.1, Jan. 1989, pp.81-89.

[5] J.C. Rautio and R.F. Harrington, "An electromagnetic time-harmonic analysis of shielded microstrip circuits," IEEE Trans. on Microwave Theory Tech., Vol.35, No.8, Aug. 1987, pp.726-730.

[6] W. Wertgen and R.H. Jansen, "Iterative, monotonically convergent hybrid-mode simulation of complex multiply-branched (M)MIC conductor geometries," 1990 IEEE MTT-S International Microwave Symposium, May 8-10, 1990, Dallas TX.

[7] Y.L. Chow, G.E. Howard and M.G. Stubbs, "The field theoretic MMIC computation enhanced by the variational technique," Digest of 5th Annual Review of Progress in Applied Computational Electromagnetics, Monterey, CA., March 20-24, 1989, pp.78-80.

[8] Y.L. Chow, J.J. Yang, D.G. Fang and G.E. Howard, "A closed form spatial Green's function for the thick microstrip substrate," accepted for publication in the MTT trans. on Microwave Theory and Tech.

[9] Communications with EEsof Inc. personnel, 1990.

[10] G.E. Howard and Y.L. Chow, "Diakoptic theory for microstripline structures," 1990 IEEE AP-S International Symposium Digest, May 7-11, 1990, Dallas, TX., pp.1079-1082.

[11] G.E. Howard and Y.L. Chow, "Reduced source distributions for calculating the mutual impedances of complex structures," submitted to 1991 URSI International Symposium.

[12] D.G. Fang, J.J. Yang and G.Y. Delisle, "Discrete image theory for horizontal electric dipoles in a multilayered medium," IEE Proceedings, Vol. 135, Pt. H, No.5, Oct 1988, pp.297-303.

[13] J.J. Yang, G.E. Howard and Y.L. Chow, "Complex image method for analyzing multiconductor transmission lines in multilayered media," submitted to 1991 AP-S International AP-S Symposium.

[14] G.E. Howard and Y.L. Chow, "Removal of source fringe effects in the diakoptic theory," submitted to 1991 URSI International Symposium.