A PARTITIONING APPROACH TO LARGE SCALE ELECTROMAGNETIC PROBLEMS APPLIED TO AN ARRAY OF MICROSTRIP COUPLED SLOT ANTENNAS

Mostafa N. Abdulla, *Student Member, IEEE*, and Michael B. Steer *Senior Member, IEEE*
ERL laboratory, Department of Electrical and Computer Engineering
North Carolina State University, Raleigh, NC 27695-7914.

Abstract— **An electromagnetic modeling procedure for electrically large microwave and millimeter-wave systems with circuit-field interactions is presented. The concept of an electromagnetic terminal is introduced to interface separate electromagnetic models of the blocks in a partitioned network.**

INTRODUCTION

MICROWAVE technology has advanced to the point where electrically large systems, a wavelength or even several wavelengths in the three dimensions, are being developed. Electromagnetic modeling of these large systems along with linear and nonlinear circuit components is emerging as one of the great challenges in microwave and millimeter-wave computer aided engineering. The target problem in the current work is the quasi-optical power combining amplifier shown in Fig. 1 [7]. Each dimension of this amplifier is at least two wavelengths. The amplifiers are MMIC chips arranged in a 5×5 or perhaps larger array. Each amplifying unit cell of the amplifier is an amplifier with a microstrip coupled slot input antenna and a similar antenna at the output.

A simplified view of this system is shown in Fig. 2(a) and a unit cell in Fig. 2(b). The unit cell has an amplifier, typically a MMIC in the center of the stripline. In addition to the problem size, one characteristic of this system is the tight coupling of the nonlinear device to its electromagnetic environment.

There have been a few attempts to model systems with interacting fields and circuit elements.

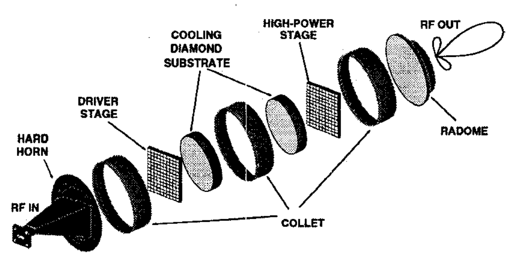

Fig. 1. Quasi-optical power combiner.

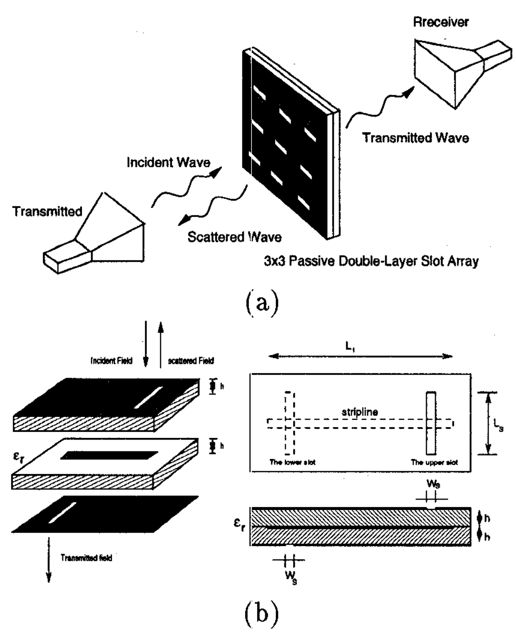

Fig. 2. Slot array system (a) experimental system;(b) unit cell.

0-7803-4471-5/98/$10.00 © 1998 IEEE

In transient analysis of distributed microwave structures lumped circuit elements can be embedded in the mesh of a time discretized electromagnetic field solver such as a finite difference time domain (FDTD) field modeler [1], [2]. There are also commercial products that allow the interfacing of electromagnetically derived models with circuits but for now only fairly simple systems with a few ports can be handled.

The work presented here is a progression of three separate developments. First, in [3], [4] Kunisch and Wolf introduced a technology for integrating port-based electromagnetic field models with nonlinear devices. Second in [5], and [6] a multiport network was used to enable electromagnetic models of individual interconnects to be assembled in a larger structure. This assemblage accounted for the interactions of the structures through the use of electromagnetic ports with electric and magnetic currents. Third a network model of a large quasi-optical structure was developed by Heron, Nuteson et al. in [8], [9].

The work in the current paper develops a network based model of the electromagnetic environment, whereby sections of the large electromagnetic structure are interfaced to each other at "electromagnetic terminals" and to the conventional nodal-based circuit at the ports. The depiction shown in Fig. 3 represents three unit cells. Each of the slot-stripline-slot blocks is interfaced to a nonlinear network using normal current/voltage defined terminals. The exterior of the block is represented by multiport networks at the input and at the output. Each of the ports corresponds to one of the basis functions used in the discretization of the field at the slot. These input and output ports are denoted electromagnetic terminals to distinguish them from the current-voltage terminals of conventional circuit analysis. The electromagnetic terminals are defined in terms of incident and reflected waves. The interfacing quantities at the "electromagnetic terminals" can be of any type as long as the same basis is used for the evaluation of the networks on either side of the interface. In

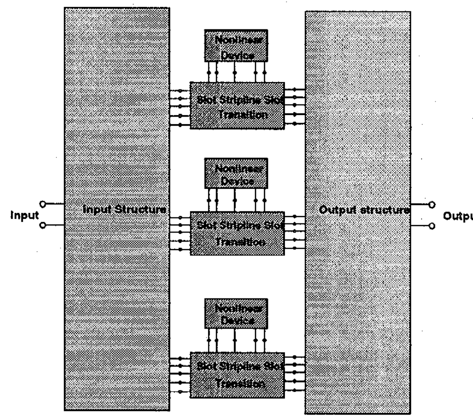

Fig. 3. Network model of larg partitioned electromagnetic system.

this work a method of moments (MoM) simulator was used and the interfacing quantities were the weighted basis functions of the incident and scattered magnetic field of individual cells. This is then a generalization of the scattering matrix concept with forward and backward traveling waves. The slot-microstrip-slot blocks were treated separately here as precautions (such as the use of photonic crystals) are taken in design to prevent direct cell-to-cell interaction.

The aim of the overall analysis is to develop a single network representing the linear network with the minimum possible representation of the linear sub-networks. Generally a nodal admittance matrix with rank equal to the number of interfacing terminals is desired.

Results

Figs.4 to 6 are plots of various electromagnetic and circuit quantities in the microstrip coupled slot portion of the system.

Fig. 7 and Fig. 8 are field profiles at the output of the array at various distances from the surface of the transmitting antennas. The formation of the main beam and the sidelobes can be seen clearly. In this simulation the amplifiers were unit gain linear amplifiers.

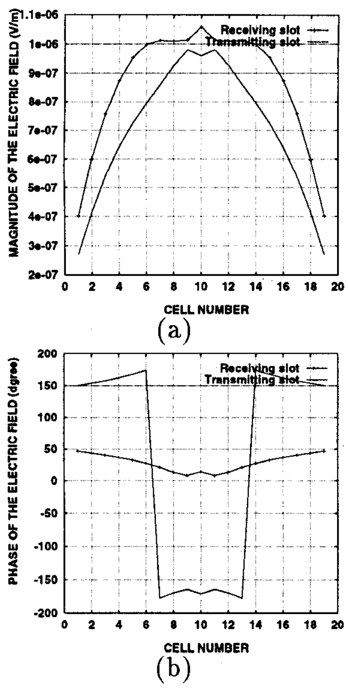

Fig. 4. The magnitude of the electric field on the input slots at 10 GHz: (a) magnitude; and (b) phase.

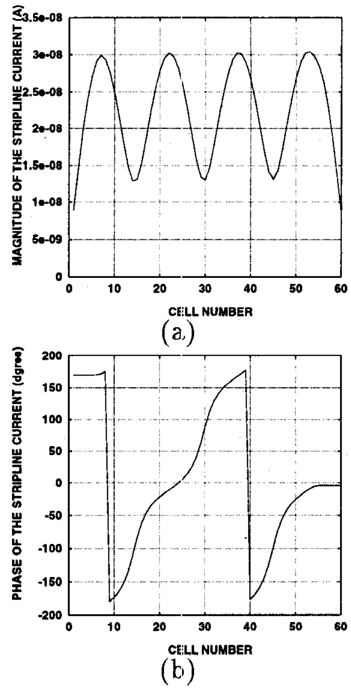

Fig. 5. The magnitude of the electrical current on the stripline at 10 GHz: (a) magnitude; and (b) phase.

Fig. 8 are the same field profiles as above but now one of the amplifiers turned off. These profiles were generated without the need of recalculating the field solutions.

Discussion

The work presented here is an approach to handling large systems such as quasi-optical amplifiers using full electromagnetic modeling. The interconnectivity of electromagnetic blocks could be handled using an electromagnetic simulator or in a circuit simulator. We have chosen to perform the interconnectivity in a circuit simulator because of the excellent methodology that has been developed for the analysis of circuits. The essence of a circuit simulator is enforcement of Kirchoff's current law. In the extension we have developed additional quantities introduced at the "electromagnetic interfaces." A circuit simulator enforces balancing of the electromagnetic quantities (the coefficients of the weighted basis functions) at the interface. The interface requires that the interface network be locally referenced [10] so that the electromagnetic quantities are not referenced to a global voltage reference node.

The separation of the electromagnetic model into partitioned networks facilitates optimization in design. Generally the design approach proceeds by first designing the individual unit cells and then arranging them in an array. In optimizing the array layout it not necessary to recompute the electromagnetic model of the unit cells. Recomputation of the electromagnetic blocks is only required when the specific geometry affecting the block is changed. The next step in the design process would be the optimization of the array geometry but this has not been possible up to now because it has not been possible to handle such a large structure.

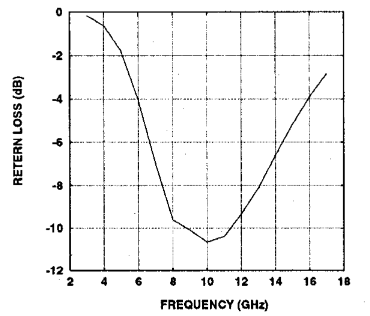

Fig. 6. Magnitude of the reflection coefficient seen from the output of the amplifier.

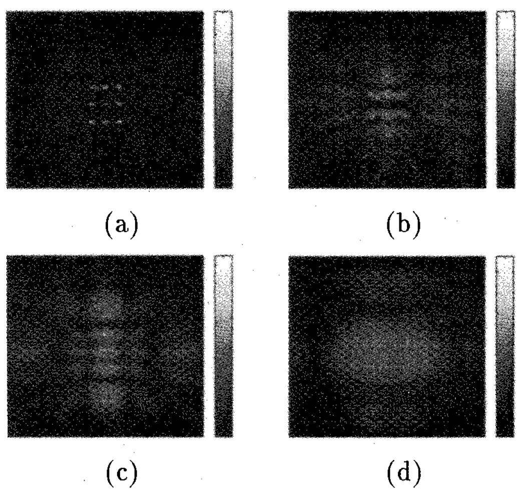

Fig. 7. The magnitude of the horizontally polarized electric field at a distance z from the slot array surface: (b) $z = \lambda/4$. (c) $z = \lambda/2$. (d) $z = 3\lambda$.

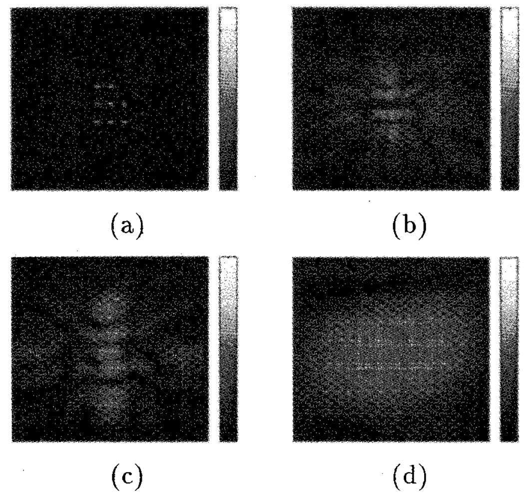

Fig. 8. The magnitude of the horizontally polarized electric field at a distance z from the slot array surface with one of the amplifier off: (b) $z = \lambda/4$. (c) $z = \lambda/2$. (d) $z = 3\lambda$.

References

[1] S. M. El-Ghazalyr and T. Itoh, "Electromagnetic interfacing of semiconductor devices and circuits," *Proc. of the 1997 IEEE MTT-S International Microwave Symposium*, Vol. 1, June 1997, pp. 151-154.

[2] P. Ciampolini, P. Mezzanotte, L. Roselli and R. Sorrentino, "Accurate and efficient circuit simulation with lumped-element FDTD technique ," *IEEE Trans. Microwave Theory Tech.* Vol. 44, Dec. 1996, pp. 2207–2215.

[3] J. Kunisch and Ingo Wolf, "The Compression Approach: A New Technique for the Analysis of Distributed Circuits Containing Nonlinear Elements," in *IEEE MTT-S Int. Microwave Symp. Workshop WSK*, 1992, pp. 16–31.

[4] J. Kunisch and Ingo Wolf, "Steady-State Analysis of Nonlinear Forced and Autonomous Microwave Circuits Using the Compression Approach," *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 5, No. 4, 1995, pp. 241-225.

[5] R. P. Parrikar and K. C. Gupta, "Multiport network model for CAD of electromagnetically-coupled microstrip patch antennas," *Proc. 1996 IEEE Antennas and Propagation Society International Symposium*, Vol. 2, 1996, pp. 1058-1061.

[6] K. C. Gupta and A. Sabban, "Effects of packages on parasitic coupling among microstrip discontinuities using multiport network," *IEEE Trans. Microwave Theory and Techniques*, Vol. 39, April 1991, pp. 704-712.

[7] J. Hubert, J. Schoenberg, and Z. B. Popovic, "High-power hybrid quasi-optical Ka-band amplifier design," *IEEE MTT-S International Microwave Symposium Digest*, Vol. 2, June 1995, pp. 585-588.

[8] P.L. Heron, J.W. Mink, G.P. Monahan, F.W. Schwering and M.B. Steer, "Impedance matrix of an antenna array in a quasi-optical resonator," *IEEE Trans. Microwave Theory Techniques*, Vol. 41, October 1993, pp. 1816-1826.

[9] T.W. Nuteson, G.P. Monahan, M.B. Steer, K. Naishadham, J.W.Mink, K. Kojucharoff and J. Harvey, "Full-wave analysis of quasi-optical structures," *IEEE Trans. Microwave Theory Techniques*, May 1996, pp. 701-710.

[10] A. I. Khalil and M. B. Steer, "Circuit Theory for Spatially Distributed Microwave Circuits," *In Review*.