Computer Aided Engineering Environment for Spatial Power Combining Systems

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Abstract. Development of a computer aided engineering environment that supports the design of spatial power combining systems is proposed. A complete integrated thermal/electromagnetic/circuit simulation capability using a mix of commercially available tools from various vendors will be compatible to the new tools being developed for spatial power combining systems. This paper focuses on and presents results for the electromagnetic field analysis, harmonic balance analysis, and rapid transient analysis part of the design environment. Also the integration of commercially available software is used to define the geometry layouts of the structures analyzed in this paper.

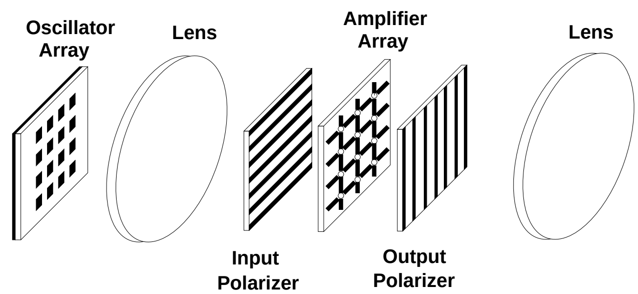

Figure 1: A cascaded oscillator and amplifier spatial power combiner.

1. Introduction

Consider the spatial or quasi-optical (QO) power combining system shown in Fig. 1. The commercial microwave tools available today are unable to simulate such a complex system. In order to obtain an accurate model of this system or any other spatial power combining system, a complete computer aided engineering (CAE) environment is needed. This CAE environment needs to contain analysis using rapid transient analysis, transient thermal and nonlinear analysis, and steady state thermal and nonlinear analysis. Also needed is electromagnetic (EM) modeling of unit cells and weakly coupled unit cell models [1, 2], QO dyadic Green's function development [3–5], method of moments (MoM) EM field analysis tools using QO Green's functions [4, 5], and finite-difference time-domain (FDTD) modeling of unit cells [6]. The unit cell model is applied first to get a fast response of the system which then the complete finite system can be modeled for a more accurate description of the system.

These tools are being devolved with the capabilities of interfacing with commercially available microwave CAD tools and thermal CAD tools. Spatial power combining systems are not sufficiently regular (planar) for commercial $2\frac{1}{2}$D tools and are too large (several wavelengths) for conventional 3D analysis such as finite element method (FEM) or the FDTD method. The maturity of many commercial microwave CAE tools require that commercial tools be integrated into the design flow wherever possible. Accurate modeling and nonlinear analysis are required for harmonic loading considerations, what-if studies, and optimization. Behavioral modeling is the key to integrating simulation modeling tools where results of one simulator can be used with another. CAE tool integration is needed with emphasis on passive modeling, nonlinear simulation, nonlinear dynamics, and EM field modeling. Integration of thermal analysis is essential for optimization of power amplifiers.

In this paper linear and nonlinear analysis of finite grid arrays is presented. The analysis is done using harmonic balance and rapid transient analysis with the EM modeling done using the MoM. A description of the hardware language and geometry layout for the grid structures is also presented.

2. Hardware Language and Geometry Layout

For the EM simulator to be useful in a CAE environment, a new hardware language was developed

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using existing CAD tools such as Cadence Design Systems. Cadence offers a versatile layout editor Virtuoso that can be used to graphically draw the layouts of the structures such as a 3×3 grid array shown in Fig. 2. Not only is the geometry drawn but also other parameters needed for the simulation such as the relative permittivity and thickness of the dielectric and the locations of the ports are included (see Fig. 2). The file thus generated is stored in a Caltech Intermediate Format (CIF) format. This format is then parsed to extract the necessary geometric information which is required by the EM simulator. The language basically describes the system to be analyzed as drawn by the user.

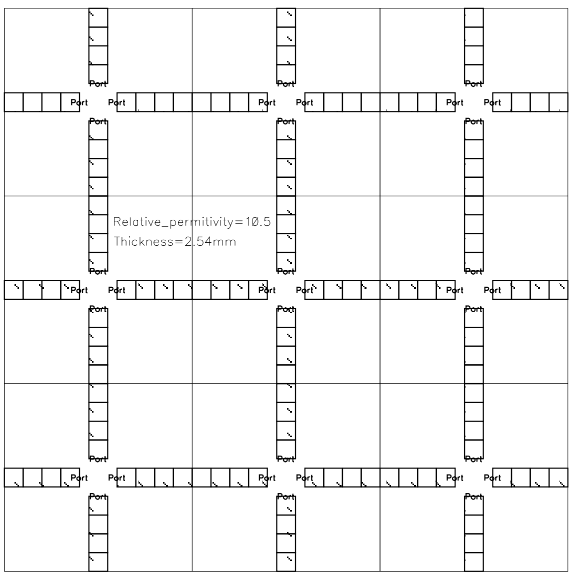

Figure 2: A 3×3 grid array drawn using the Cadence layout editor Virtuoso.

After the modified CIF format has generated the necessary geometric information and the structure parameters as inputed by the user, it needs to be parsed to the simulator program. This is done with a CIF parser where the necessary geometric information and parameters are given to the outer shell of the program which in this case is the C shell. In the case of the grid array the necessary information is just the position of the basis functions used for the calculation of fields by the MoM. These basis functions are calculated at the intersection of two cells as shown in Fig. 2 where the parser gives the coordinate of this point. In addition to this the parser also provides parameter information. The parser is a C program that reads the CIF description of the geometry generated by the Cadence layout editor and converts the information to a form more suitable to be analyzed by the EM simulator. The CIF file generated by Cadence may be hierarchical. In this type of file a unit cell is replicated many times using the CIF call command. Therefore some calculations are needed to obtain the coordinates of all the elements (i.e., boxes and labels) in the grid.

3. Electromagnetic Modeling

The EM modeling is done using the MoM for the passive part of the circuit. The EM simulator is a full-wave MoM based simulator which employs QO dyadic Green's functions [4, 5]. This electromagnetic simulator employs an efficient Galerkin moment method technique with sub-domain sinusoidal basis functions. What makes this moment method analysis unique is that it is formulated using a combination of spatial and spectral domains taking full advantage of the strengths of each method to ensure accurate and efficient evaluation of the moment matrix elements. Incorporated into the moment method simulator are quasi-optical dyadic Green's functions which are derived by separately considering paraxial fields (quasi-optical modes) which are largely responsible for distant interactions in the quasi-optical system and the corrected open space (nonmodal) interactions responsible for near neighbor coupling. The method presented here is for analysis of structures of finite dimensions. All other quasi-optical modeling that has been done only considers the unit cell of the array and hence does not include mutual coupling from other unit cells. The EM simulator is capable of going from DC to any frequency which is an important requirement in CAD.

The MoM EM simulator is a mixed FORTRAN and C program with the FORTRAN part doing all the numerical computations and the C portion controlling the FORTRAN part. The C shell of the EM simulator is responsible for time and memory efficiency with the use of dynamic memory allocation and hash table algorithms for efficient fills of the moment matrix. The C part efficiently fills the moment matrix by only calling the FORTRAN program to compute the distinct elements in the moment matrix. The C program does this with a hash table algorithm that efficiently determines what particular moment matrix element needs computing. The hash table algorithm sets up a hash table which stores the computed moment matrix results. When the distance between a source and a test basis element equals that of another source and test basis element, instead of computing the field reactions again the appropriate entry from the hash table is obtained thus saving time and increasing efficiency.

4. Harmonic Balance Analysis

Harmonic balance is used to model the steady state nonlinear effects of the system. It incorporates the linear effects of the passive part of the system which is modeled by the EM simulator. In general circuit simulators require a nodal admittance description which requires the node voltages. These must be defined in terms of a common reference point which generally does not exist in QO systems compared to the microstrip structures which are analyzed in commercially available tools.

A unit cell of a grid amplifier, shown in Fig. 3, is modeled using the nonlinear harmonic balance simulator. The passive part of the unit cell was modeled by the MoM EM simulator described in the previous section. The unit cell has a dimension of 16 mm $\times$ 16 mm with the grid leads having a width of 2 mm. It is printed on a dielectric substrate with $\epsilon_r = 10.5$ and a thickness of 2.54 mm. Two MESFETs are placed in the gap region of the unit cell and are biased as shown in Fig. 3 [7]. The gain of the unit cell was computed with and without polarizers and is shown in Figs. 4 and 5, respectively. The measurement data comes from Kim [7].

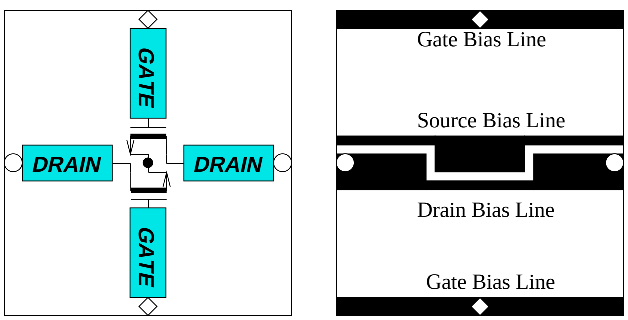

Figure 3: Unit cell amplifier configuration.

5. Rapid Transient Analysis

In power combining arrays, frequency and phase synchronization are necessary to achieve coherent power combining. This is true in conventional as well as quasi optical power combining arrays. For a given oscillators, it is difficult to determine a priori if the array will synchronize. For small arrays of a few oscillators it may be possible to perform a linearized analysis to determine the stability of the system. However, as the number of oscillators increases this becomes more and more tedious. Additionally, in large arrays where there are many degrees of freedom, a linearized analysis may not provide as meaningful results. Thus, another means of analyzing the array is necessary.

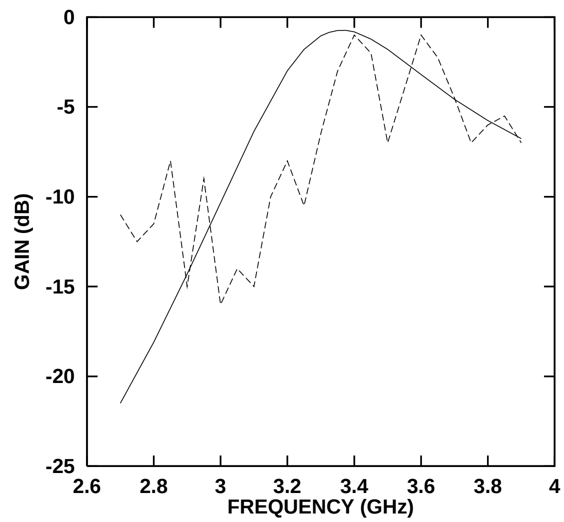

Figure 4: Amplifier gain without polarizers: solid line, simulation; dashed line, measurement.

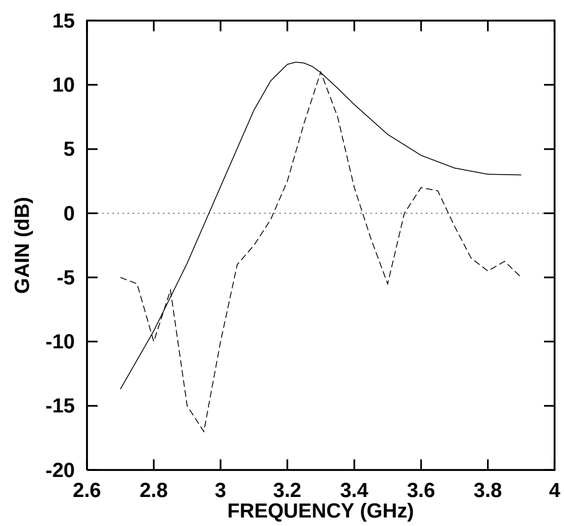

Figure 5: Amplifier gain including polarizers: solid line, simulation; dashed line, measurement.

One means to determine the frequency and phase synchronization characteristic of an array of oscillators is through examining the transient response of the system. This will yield information regarding if the array will synchronize as well as how long it will take for the array to reach the synchronized state. Fig. 6 shows a canonical circuit of a conventional oscillator. Here, $G_d(A)$ and $B_d(A)$ represents the device output admittance with negative resistance (i.e. GUNN, IMPATT diodes, MESFET, HBT transistors), G_L is the load conductance or, in this case, the input admittance of the antenna, L and C are the tank inductance and capacitance respectively [8]. Both L and C are derived from the imaginary part of the input admittance of the antenna.

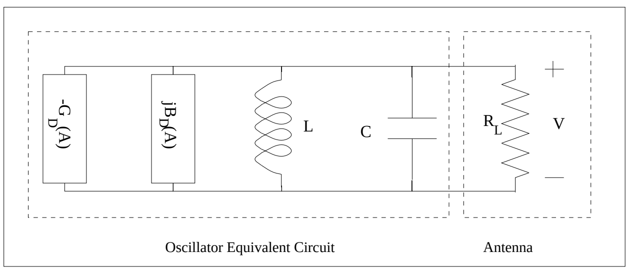

Figure 6: Canonical circuit of a conventional oscillator.

The transient response of the system consisting of 9 oscillators is shown in Fig. 7. The 9 oscillators shown in Fig. 7 each had random phases where each oscillator had a different phase. The passive part of the grid consisted of a 3×3 grid array with a unit cell having the same dimensions as in the harmonic balance simulation and with the same substrate parameters.

6. Conclusions

A computer aided engineering environment for spatial power combining has been presented. Results include harmonic balance and rapid transient analysis of a unit cell amplifier and a 3×3 grid array oscillator. In both analysis, the passive part of the grid was modeled using a full-wave moment method simulation and commercially available software was integrated to define the geometry layouts of the grid structures.

Acknowledgment

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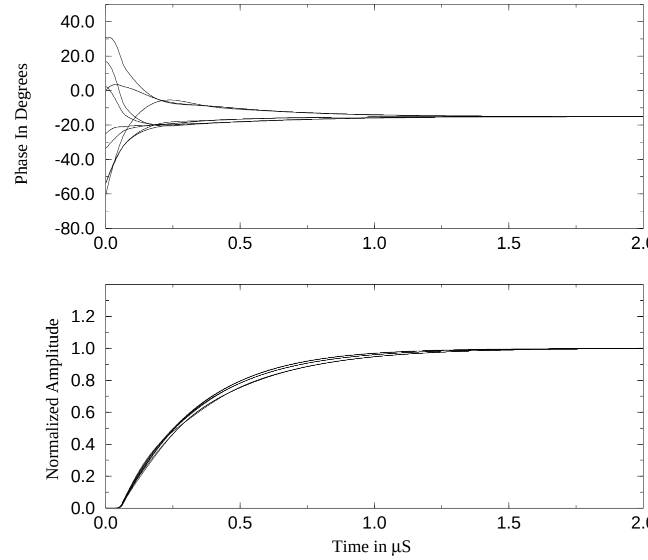

Figure 7: Transient response of the 3×3 grid oscillator array.

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