Study of Design Parameters in Waveguide-Based Spatial Power Combining Amplifier Arrays Using FDTD

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Abstract — **Performance measures such as active reflection coefficients, inter-element coupling and excitation uniformity for spatial power combining arrays are investigated. A coax-fed patch antenna array inside an oversized dielectric loaded waveguide is analyzed using a standard finite difference time domain (FDTD) approach with unsplit perfectly matched layer (PML) formulation. Results for a passive 4x4 waveguide-based quasi-optical array are presented as an example. The effects of design parameters (such as inter-element spacing and the distance of the array to the waveguide walls) on the performance of the array has been investigated for the 4x4 array example.**

I. INTRODUCTION

The idea of combining the power in free space from many solid state devices (spatial or quasi-optical power combining) was first demonstrated using the grid amplifier [1]. Similar amplifiers that utilize the concept of placing an array in the far field of a transmitting antenna followed [2-4]. The major challenge with this concept is the confinement of the radiated/transmitted beams in open air. Waveguide-based spatial power combiners that were developed later addressed this problem by having the array inside the oversized waveguide or in the near field region of the feeding antenna [5,6]. In addition, waveguide-based spatial power combiners can be analyzed more accurately due to their closed structure.

As spatial power combining systems continue to achieve higher power levels at microwave and millimeter wave frequencies after a decade of development, recent research on spatial power amplifiers have concentrated on increasing the power output levels, power added efficiencies and power combining efficiencies of the existing systems [7,8]. Excitation of the spatial amplifier arrays is an important factor in achieving efficient power combining. Even though use of hard horns improves the power combining efficiency [5], the interaction between the hard horn and the amplifier array or how the array behaves inside an oversized waveguide is yet to be investigated for optimum performance. In order to achieve an optimum array design, accurate electromagnetic modeling of spatial power combining arrays is essential.

Previous method of moments (MoM) based modeling attempts were concerned with arrays inside regular overmoded waveguides [9,10]. MoM approach becomes more difficult to apply with the presence of dielectric walls inside the waveguide. This is because of the existance of LSE and LSM modes in the oversized dielectric loaded rectangular waveguide. In this paper, FDTD modeling was chosen since it provides accurate analysis of complicated structures that involve different dielectric materials. Other advantages include the convenience of changing the simulated geometry easily and obtaining a wide range of the frequency response for the system through a single run.

In this paper, analysis of a 4x4 coax-fed patch antenna array inside a dielectric loaded waveguide will be presented as an example. Field uniformity (for simultaneous excitation), active reflection coefficients (for designing/choosing the active devices) and inter-element coupling (for enhancing the power combining efficiency) are the important peformance measures that were considered. Parameters affecting the active impedance, coupling among the patch antennas and field distribution inside the dielectric loaded waveguide in the presence of antenna array are investigated as a function of the array configuration.

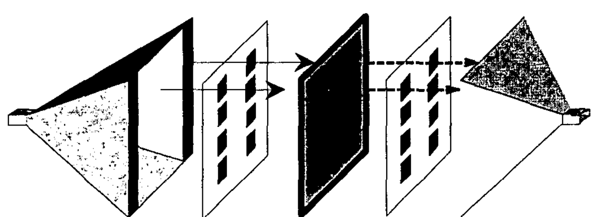

Fig. 1 A general waveguide-based spatial power combining system.

II. THEORY

The most general form of a waveguide-based spatial power combining system consists of a feed waveguide (horn), an input antenna array to divide the power, active devices, an output antenna array to coherently combine

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and radiate the power as shown in Fig 1. One can also place a collecting horn in front of the transmitting array to collect the power (forming a conventional two port amplifier).

The structure that is to be analyzed here consists of an array of coax-fed patch antennas inside a hard walled

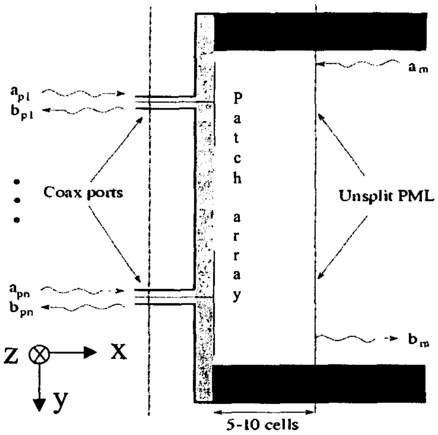


Fig. 2 The analyzed structure (top view).

waveguide as shown in Fig 2. The theory developed in this work is compatible with generalized scattering matrix (GSM) cascading of different spatial amplifier modules [9].

For this purpose a custom FDTD code was written. The coaxial feeds were approximated by a rectangular model rather than a staircase approximation for the concentric cylinders. Mur's first order absorbing boundary condition (ABC) was used to terminate the coaxial lines. A transparent sinusoidally modulated Gaussian source centered at 10 GHz was used for all the simulations. The waveguide port was terminated by the D, E, H implementation of PML [11]. This implementation has the benefit of being independent of the dielectric materials and conductivity values inside the computation volume. In

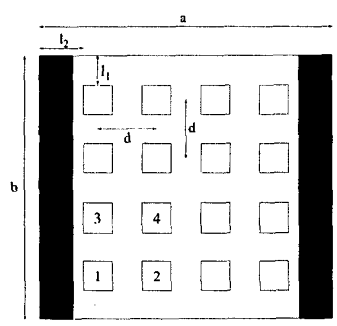


Fig. 3 Different array parameters and element numbering

order to calculate input reflections at all the ports, each port was excited individually when the rest of the ports including the waveguide port were terminated with a matched load. Active impedance calculation was carried out by exciting all of the antenna ports simultaneously and looking at the reflections at each port.

III. Results and Discussion

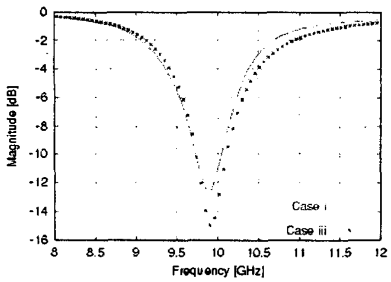
A 4x4 array that consists of coax-fed microstrip patch antennas with dimensions 8.1 mm x 10.6 mm was analyzed as an example. Fig. 3 shows a view of the array on the yz plane as seen from the waveguide side. The substrate was chosen to be RT/Duroid 3003 with a thickness of 0.75 mm and ε_r of 3.0. The dielectric on the sidewalls of the oversized waveguide was chosen to provide a uniform field distribution across the waveguide at the resonant frequency of the patch antennas [5]. Active reflection coefficients, coupling among the elements, and field distribution across the array aperture were investigated for three different cases shown in Table I. The parameters that were changed include inter-element spacing (d), and the distance of the array to the waveguide H-plane walls (l_1) as seen in Table I and Fig. 3. The dimensions of the oversized waveguide are indicated by "a" and "b".

Table I: Parameters that are varied in the simulations

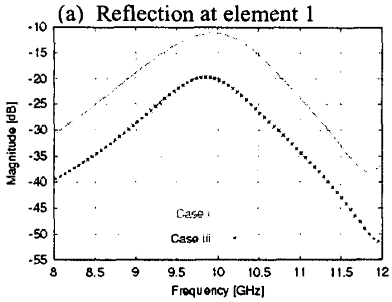
	D (λ)	a (cm)	b (cm)	l_1(λ)	l_2(λ)
Case i	0.4	6.0	5.0	0.34	0.34
Case ii	0.5	6.9	5.9	0.34	0.34
Case iii	0.5	6.9	5.0	0.11	0.34

From case i to case ii, the inter-element spacing was changed and from case ii to case iii the distance of the array to the upper and lower waveguide walls was changed. Fig. 4a shows the self-reflection at element 1 when the rest of the ports are terminated. Fig. 4b-d show couplings from element 1 to neighboring cells (when element 1 is excited) which are under -10 dB. Fig. 5a-d show the active reflection coefficients of the four antennas at the lower left corner of the array for the three cases. It is seen that the antenna resonant frequency varies as a function of array spacing. This frequency shift is dependent on the element location (plots for case i in Fig. 5a-d) and is not apparent in Fig. 4a where only element 1 was excited and the rest of the ports were terminated. This suggests that the array behaves differently when all of the antennas are excited simultaneously due to the changes in the load inside the overmoded waveguide.

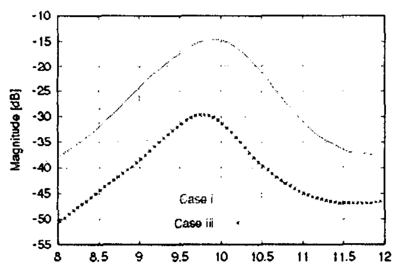
Changing the parameter l_1 does not seem to cause a significant change on the active reflection coefficients (cases ii and iii in Fig. 5a-d). However, as it is evident from cases ii and iii in Fig. 6 this parameter makes a difference in the uniformity of the z component of the electric field across the waveguide aperture. As it is apparent from Fig. 4b-d narrower antenna spacing introduces higher coupling among antennas whereas wider antenna spacing would degrade the field uniformity across the aperture of the array by exciting higher order modes.



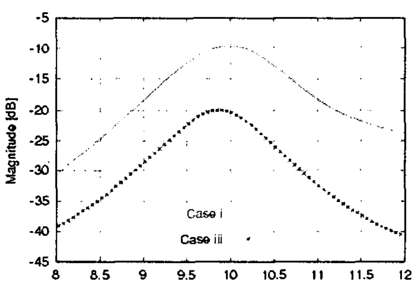
(a) Reflection at element 1



(b) Coupling from element 1 to 2



(c) Coupling from element 1 to 4



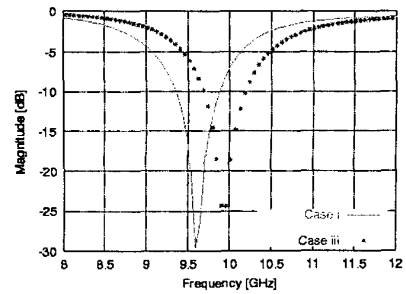
(d) Coupling from element 1 to 3

Fig. 4 Reflection and coupling coefficients at element 1

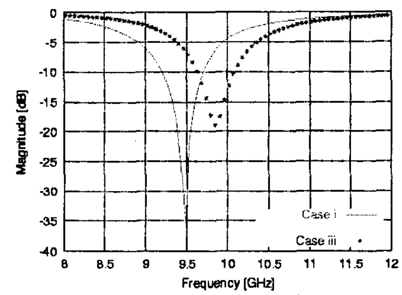
Another observation from cases ii and iii in Fig. 4b-d is that the coupling among antennas depends also on the distance of the array elements from the waveguide walls.

IV. CONCLUSION

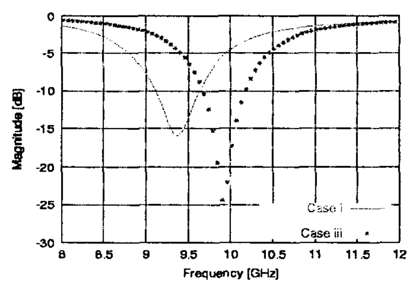
This paper presented a study of the effect of the design



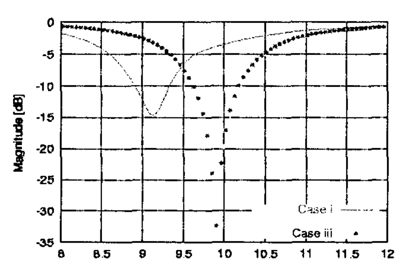
(a) Active reflection coefficient for element 1



(b) Active reflection coefficient for element 2

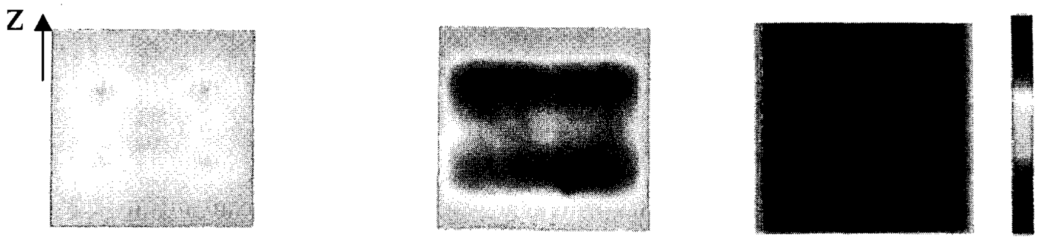


(c) Active reflection coefficient for element 3

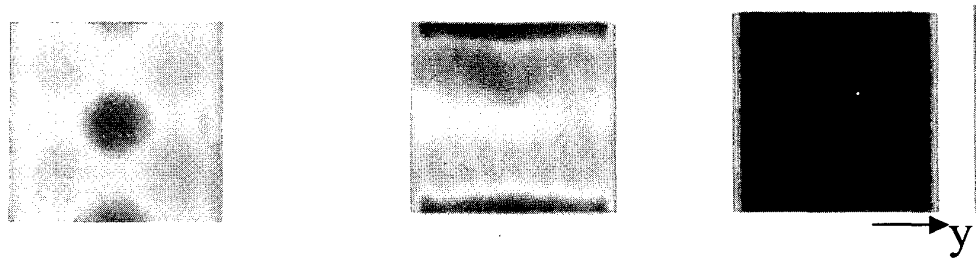


(d) Active reflection coefficient for element 4

Fig. 5 Active reflection coefficients for different elements



(a) E_z across the waveguide aperture at 3200 time steps



(b) E_z across the waveguide aperture at 3400 time steps

Fig. 6 Time domain field plots of the z component of the electric field at a distance of 0.3λ away from the surface of the array into the waveguide after steady state has been reached for a 10GHz sinusoidal excitation at all ports.

parameters on the performance of waveguide-based spatial power combining arrays using a custom FDTD analysis with unsplit formulation. This analysis can provide the necessary information for the optimization of the parameters such as inter-element spacing and the distance of the array to the waveguide walls in order to increase the power combining efficiency of the waveguide-based spatial power combiners.

ACKNOWLEDGEMENT

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