Modeling of Waveguide-Based Spatial Power Combining Systems

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Abstract

A modeling scheme is proposed and tested for the analysis of waveguide-based quasi-optical systems. The system is partitioned into blocks, each block is characterized by its Generalized Scattering Matrix (GSM) which in turn are cascaded to obtain the model of the complete system. Blocks with active devices are accounted for in the GSM by means of circuit ports. The calculated and measured results for a Ka-band double layer patch array is presented. A good agreement between theory and measurement is obtained.

I. Introduction

Quasi-optical power combining systems have recently received considerable attention [1]-[5]. Conceptually they are low loss systems and hence high efficiencies should be achievable. To obtain the optimum performance efficient modeling tools are essential. However, commercial microwave simulators are unable to simulate electrically large systems, as shown in Fig.1 with oversized waveguide that can accommodate many propagating modes.

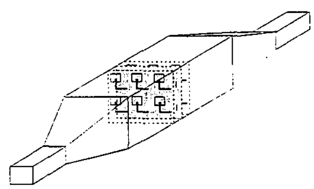

Fig. 1. A multilayer structure in metal waveguide showing cascaded blocks

In this paper we propose a flexible modeling scheme based on the GSM method to efficiently simulate waveguide-based quasi-optical systems. The system is partitioned into modules and each module is modeled separately. The scheme is tested using a double layer patch-slot-patch transmit/receive antenna array placed in a transverse plane inside a waveguide and excited by a horn antenna.

II. System Partitioning

A typical quasi-optical system consists of passive components (horns, polarizers, lenses, etc.) and active components (grid arrays, patch arrays, etc.). Modeling such systems can be memory demanding and very time consuming. The most efficient way to model these systems is to partition them into blocks. Each block is characterized by its own GSM. This ensures that propagating mode coupling is accounted for as

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well as evanescent mode coupling. Since each block is considered separately, the GSMs are computed using the most efficient EM technique for each particular block (eg. MOM, mode matching, and FEM). Cascading all blocks leads to a matrix describing the entire linear system response.

III. GSM Calculation

The system shown in Fig.1 is divided into three blocks, transmitting horn, receiving horn and a double layer array. Each block is simulated by a separate EM routine.

A. Array Simulation

A common method to obtain the GSM of a multilayer structure is to derive a specific Green's function for the structure and then apply the MOM to the entire structure. This leads to a linear system of equations for the unknown currents. The GSM is then computed using the induced currents generated from all incident modes. This requires a different Green's function for every structure as well as a large memory requirement as the number of layers increase. An alternative approach, implemented here, is to develop two simply derived Green's functions. One for an electric and another for a magnetic source on an interface of two different dielectrics in an infinite waveguide to model patches and slots respectively. The GSM is calculated for each interface in a similar manner as discussed above. This approach leads to flexibility in the analysis, since only two Green's functions at the most are used to model all multilayered structures.

The double layer array consists of three interfaces (patch-slot-patch) Each interface is modeled separately using an efficient Method of Moment-Generalized Scattering Matrix technique [9], [10]. The method first calculates the MOM impedance matrix for an interface from which a GSM matrix is calculated directly without the intermediate step of current calculation. This enables the modeling of arbitrary shaped structures and the calculation of large number of modes needed in the cascade to obtain the required accuracy. Since the conventional GSM is a modal matrix, it includes information about device ports. To be able to model device ports it is essential to include it in the GSM for the active interface (patch-interface) [8].

B. Horn Simulation

The GSMs for the transmitting and receiving horns are calculated using the mode matching technique. The mode matching technique is known to be an efficient method for calculating the GSM of horn antennas. The GSM of the waveguide transition was obtained from an analysis that uses mode matching technique [6]. For horns used in this paper the length of the Ka to X band waveguide transition is 16.51 cm. The two important parameters in using the mode matching program are the number of steps and the number of modes considered. The number of sections needed depends on the flaring angle of the transition and on the frequency of operation [7]. For choosing the step size, the $\lambda/32$ criteria suggested by Liu et al. can be used.

A double step plane junction is shown in Fig. 2. The smaller waveguide dimensions are X_1 and Y_1, and the larger waveguide dimensions are X_2 and Y_2. At the double plane step discontinuity, incident and reflected waves for all modes (evanescent and propagating) are excited, thus the total field can be expressed as a superposition of an infinite number of modes. The total power in all modes on both sides of the junction is matched according to the mode matching technique. The GSM for the whole waveguide transition is obtained by cascading the GSM for all the small sections.

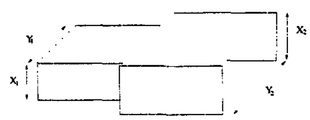

Fig. 2. A double step junction

IV. Results and Discussion

Numerical results are obtained and verified by measured data. In the first example a single unit cell is centered in an X-band waveguide as shown in Fig. 3. The circuit was fabricated on a 0.381-mm-thick Duroid substrate with $\epsilon = 6.15$. The GSM, for each layer, is calculated for 512 modes. The horns are simulated using 80 modes. The calculated transmission coefficient S_{21} is shown in Fig. ??.

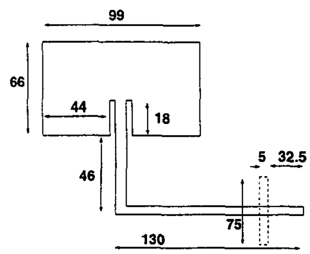

Fig. 3. Geometry of the patch-slot-patch unit cell, all dimensions are in mils

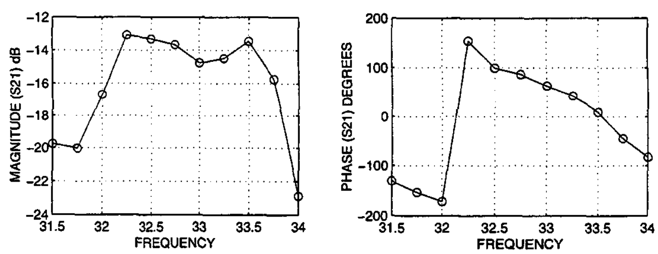

Fig. 4. Magnitude and phase of transmission coefficient S_{21}

The second example is a two by two patch array. The same number of modes is considered as in the first example. The results for the transmission coefficient S_{21} is shown in Fig. 6 and agrees well with measured results.

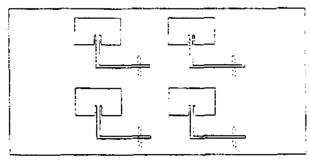

Fig. 5. A two by two patch-slot-patch array in metal waveguide

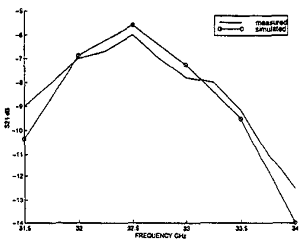

Fig. 6. Magnitude of transmission coefficient S_{21}

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