A Finite Double-Layer Slot Array Structure for Spatial Power Combining Amplifiers

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1 Introduction

Arrays of active antennas are finding applications in spatial power combining systems and in phased array radars. In a spatial power combiner the power produced by a large number of solid-state amplifier cells is combined in free space to produce potentially large amounts of millimeter-wave power [1]. Phased array radar systems with each element having an active module also combine power spatially, but more importantly enable tight control of radiated beam characteristics. There are two significant characteristics of these systems from a modeling perspective. One of these is that the active device is closely coupled into the electromagnetic environment, and the impedances the device sees are critically determined by the antenna characteristics. The second is that the antennas are usually tightly packed so that the antennas are coupled, possibly strongly. These considerations require accurate electromagnetic modeling of the entire structure and a strategy for interfacing the electromagnetic model with circuit models. We have previously analyzed a grid amplifier spatial power combiner where amplifier cells are located at the intersections of a conductor grid [2]. The grid forms the input and output coupling antennas. In this paper we address the modeling of an array of stripline coupled slot antennas. A simplified view of this system is shown in Fig. 1(a) and the unit cell in Fig. 1(b). The unit cell has an amplifier, typically a MIMIC 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. This system has high isolation between the input and the output field. One of the challenges is to select and design this type of array to satisfy good transmission between the input and the output. The aim of the work presented her is the development of models of the slot array for use in a nonlinear circuit simulator.

2 Theory

The analysis presented here uses a Mixed Potential Integral Equation (MPIE) and the Method of Moment (MoM) technique to achieve a Full-Wave analysis of the structure [3]. The model of the structure in Fig. 1 is based on the equivalence principle and decomposes the structure into three different regions. Thus the Method

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of Moment matrix becomes

$$\begin{bmatrix} \left[\Delta H_1{}^{in}, f_{1p}\right] \\ \left[E_2{}^{in}, f_{2p}\right] \\ \left[\Delta H_3{}^{in}, f_{3p}\right] \end{bmatrix} = \begin{bmatrix} [Y_{11}] & [U_{12}] & [Y_{13}] \\ [W_{21}] & [Z_{22}] & [W_{23}] \\ [Y_{31}] & [U_{32}] & [Y_{33}] \end{bmatrix} \begin{bmatrix} [M_1] \\ [I_2] \\ [M_3] \end{bmatrix} \tag{1}$$

where $[Y]$, $[U]$, $[W]$, and$[Z]$ are the mutual coupling integrals between slots and stripline. $[M_1]$, $[I_2]$, and $[M_3]$ are the unknown coefficients of the basis functions on the receiving slot, stripline, and transmitting slot respectively. $\left[\Delta H_1{}^{in}, f_{1p}\right]$, $\left[E_2{}^{in}, f_{2p}\right]$, and $\left[\Delta H_3{}^{in}, f_{3p}\right]$ are the excitation vectors from the incident fields.

The Method of Moment matrix in (1) is divided to three sub-matrices: array structure matrix; the left side matrix; and the right side matrix as shown in (2). The Green's functions of the array structure have been determined as [4]. The left and right side Green's functions are calculated separately and they depend on the cascading structures. The matrix in (1) is therefore calculated as

$$\begin{bmatrix} \left[Y^l\right] & [0] & [0] \\ [0] & [0] & [0] \\ [0] & [0] & [0] \end{bmatrix} + \begin{bmatrix} [Y_{11}^a] & [U_{12}^a] & [Y_{13}^a] \\ [W_{21}^a] & [Z_{22}^a] & [W_{23}^a] \\ [Y_{31}^a] & [U_{32}^a] & [Y_{33}^a] \end{bmatrix} + \begin{bmatrix} [0] & [0] & [0] \\ [0] & [0] & [0] \\ [0] & [0] & [Y^r] \end{bmatrix} \tag{2}$$

where $\left[Y^l\right]$ and $[Y^r]$ are the mutual coupling integrals for the left and right sides respectively as shown if Fig. 2(a) and $[Y^a]$, $[U^a]$, $[W^a]$, and $[Z^a]$ are the mutual coupling for the closed array structure. This cascadable representation of the electromagnetic environment is important to the integrated device-circuit-field analysis system we are developing.

The reflection coefficient and the input impedance on the stripline is calculated from the standing wave pattern of the electric current. The radiated field from the receiving and transmitting slots are calculated from the magnetic currents.

3 Numerical Results

In Fig. 2(b) the reflection coefficient is calculated for a slot of 14 mm length and 0.2 mm width, with a stub of 4.5 mm length. The substrate hight h is 0.79 mm and the dielectric constant $\epsilon_r=2.3$. The structure was simulated for an incident plane wave on one side and the transmitted field was calculated on the other side. Figs. 3 (a) and (b) are plots of the electric fields on the receiving and transmitting slots, and the electric current on the stripline. Fig. 4 shows field profiles at the output of the 3x3 array at different 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 linear.

4 Conclusion

The work presented here is an approach to handling large systems such as quasi-optical amplifiers using full electromagnetic modeling. The separation of the electro-

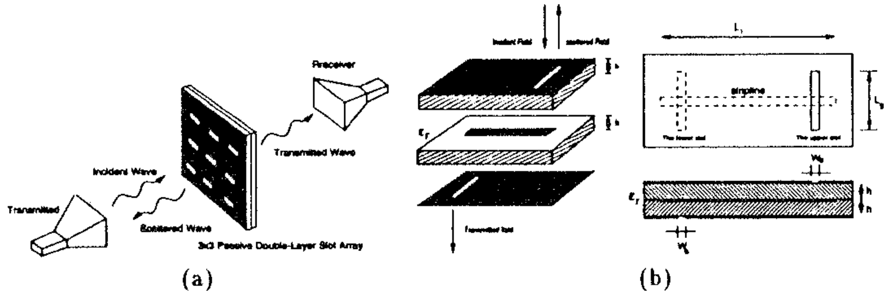

Figure 1: (a) Quasi-optical power combining system (b) unit cell.

magnetic model into partitioned regions 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.

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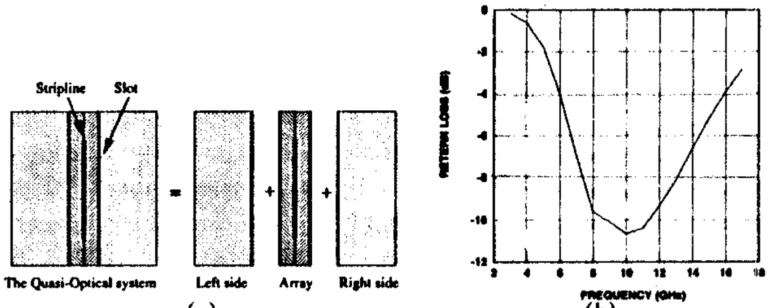
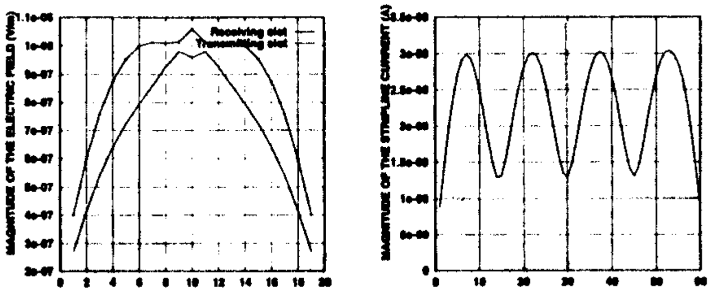


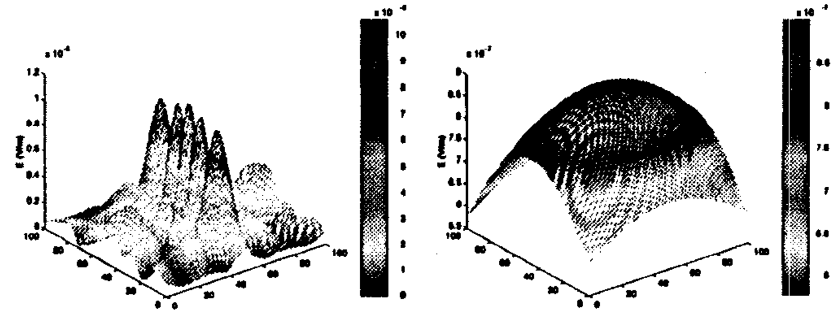
(a) (b)

Figure 2: Slot array system (a) Electromagnetic model ; (b) Magnitude of the reflection coefficient .



(a) (b)

Figure 3: The magnitude of the slots electric fields and the stripline current at 10 GHz: (a) slots electric fields and (b) stripline current.



(a) (b)

Figure 4: The magnitude of the electric field at a distance z from the slot array surface: (a) $z = \lambda$. (b) $z = 10\lambda$.