Experimental and Theoretical Investigations of Folded-Slot Antennas for Quasi-Optical Arrays

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Abstract - Folded slots are attractive for active arrays because of their broad bandwidth and simplicity. They have been used recently in a quasi-optical amplifier array. However, little is known about these antennas on thin substrates. The finite-difference time-domain (FDTD) method is applied to the analysis of cpw-fed folded-slot antennas. This paper compares the theoretical results and measured data and provides some design information for folded slots.

I. Introduction

The folded-slot antenna has been used as the radiating element of the quasi-optical amplifier array with relatively broadband [1]. Folded-slots were chosen because they are simpler to make (one mask step) and can be more easily integrated with three-terminal devices. However, there is very limited information available for the characteristics of the folded slots on dielectric substrates, such as radiation patterns and input impedances, which are important to the amplifier design. Among many numerical techniques for electromagnetic problems, the finite-difference time-domain (FDTD) method is relatively efficient and can handle most of the circuit configurations. It has been widely applied to various electromagnetic situations, such as two- or three-dimensional scattering problems, modeling of planar microstrip circuits, and coplanar waveguide structures [2]-[4]. In addition, it can account for the radiation by circuit elements which is not allowed by other techniques without special treatments. These characteristics make FDTD method the most suitable technique for analyzing different types of planar antennas on dielectric substrates with various thicknesses. In this paper, we use FDTD method to simulate a cpw-fed folded-slot antenna on a thin substrate in order to accurately predict the input impedance for better match to the amplifier, as well as to adjust the dimensions of the antenna to obtain broader bandwidth.

II. FDTD Algorithm

The formulation of FDTD technique is derived directly from Maxwell's equations, which makes it very easy to comprehend. By standard FDTD method, the Maxwell's curl equations can be discretized as [3]

$$E_{x,i,j,k}{}^{n+1} = \frac{\varepsilon_{i,j,k}}{\varepsilon_{i,j,k} + \sigma_{i,j,k}\Delta t} E_{x,i,j,k}{}^{n} + \frac{\Delta t}{\left(\varepsilon_{i,j,k} + \sigma_{i,j,k}\Delta t\right)} \left[\frac{\left(H_{z,i,j,k}{}^{n+\frac{1}{2}} - H_{z,i,j-1,k}{}^{n+\frac{1}{2}}\right)}{\Delta y} - \frac{\left(H_{y,i,j,k}{}^{n+\frac{1}{2}} - H_{y,i,j,k-1}{}^{n+\frac{1}{2}}\right)}{\Delta z} \right] \quad (1)$$

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where Δt is the time increment; Δy and Δz are the space increments in y and z directions, respectively. Here, we only show the equation for E_x component; the equations for five other components can be derived similarly [3]. At the dielectric-air interface, the average of the two dielectric constants, $(\varepsilon_r + 1)/2$, is used as explained in [4]. Mur's first approximate absorbing boundary condition for tangential E-fields is used [5]. For example, at x=0, E_z is given by the following difference equation,

$$E_{z,0,j,k}{}^{n+1} = E_{z,1,j,k}{}^{n} + \frac{v\Delta t - \Delta x}{v\Delta t + \Delta x}\left(E_{z,1,j,k}{}^{n+1} - E_{z,0,j,k}{}^{n}\right) \qquad (2)$$

where Δx is the space increment in x direction and v is the velocity of the wave. The absorbing boundary conditions for E_y and those on the other planes are similar to the one for E_z. The amplifier array using folded slots as the radiating elements is shown in figure 1. A Gaussian pulse with unit amplitude was excited at the source plane, as shown in figure 2. The source plane is treated as a magnetic wall as used in [3] to reduce the distortion of the excited pulse. The computation is repeated until all of the field intensities go to almost zero. Then the response in time domain is Fourier transformed to obtain the frequency-domain parameters of this antenna.

III. Simulation and Experimental Results

The same folded slot used in [1] was fabricated on Rogers Duroid 6010 with a dielectric constant of 10.8 and thickness of 0.635mm. The cpw-fed line is 50Ω with the width of the center conductor equal to 1.5mm and gaps equal to 0.5mm. In FDTD algorithm, Δz is chosen such that substrate thickness is equal to 3 Δz ; that is, Δz is 0.212mm. Δx and Δy are both 0.5 mm; Δt is equal to 0.44 ps and the total dimensions is 60x60x30. The field distributions just beneath the metal after several time steps are shown in figure 3. Notice that the peaks of pulses are less than one because of the dispersion in the substrate with high dielectric constant. The slight asymmetry of the field distribution on the symmetrical structure is due to the definition of the grid points in Yee's algorithm [6].

Preliminary measurements on a similar folded slot were make using a HP 8720 network analyzer, and the real and imaginary parts are shown in figure 4. This folded slot is resonant at 3.9 GHz with impedance around 185Ω which is consistent to the value in [7]. A comprehensive comparison of experiment and theory for a variety of slots and substrates will be presented in the conference.

IV. Conclusion

The simulation results using FDTD method as well as the measured data of the folded slot antenna are presented in this paper. Using FDTD technique, the wave propagating in the circuit can be visualize in time domain which is much easier to be understood instead of that in frequency domain. The folded slot is a suitable choice for radiating element of quasi-optical amplifier because of its relatively wider bandwidth compared to other resonant antennas. More simulations are planed with various dimensions of the folded slots in order to obtain accurate values of input impedance and broader bandwidth.

V. Acknowledgments

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VI. References

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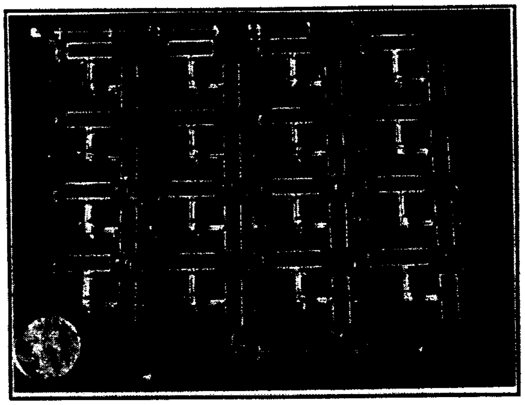

Figure 1 : Picture of the quasi-optical amplifier array using folded slots [1]. The center frequency is 4.2 GHz with 10% bandwidth.

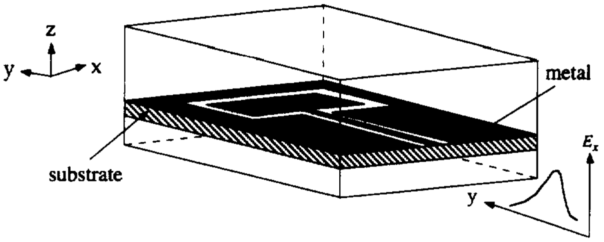

Figure 2 : Illustration of the cpw-fed folded slot in the computation domain and the excited pulse.

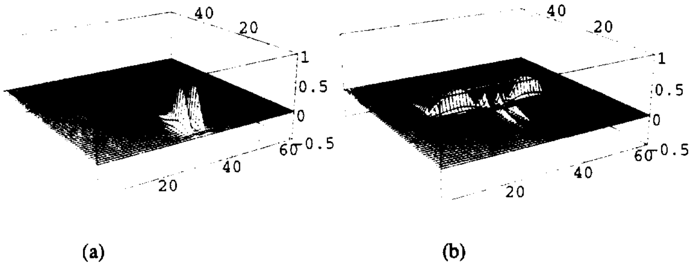

Figure 3 : Field distributions, $\sqrt{E_x^2 + E_y^2}$, just below the metal after (a) 200 steps, (b) 450 steps.

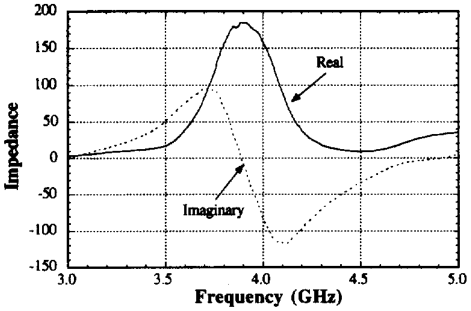

Figure 4 : Measured input impedance versus frequency