Short Papers

An Application of FD-TD Method for Studying the Effects of Packages on the Performance of Microwave and High Speed Digital Circuits

Ke-Li Wu, Chen Wu, and John Litva

Abstract—**The finite-difference time-domain (FD-TD) method is combined with an appropriate time-frequency discrete conversion technique to analyze packaging and time domain transition effects of microwave and high speed digital circuits. The output response of a given input pulse is obtained by linear convolution of the input signal with time domain system function, which is obtained through FD-TD simulation of the whole packaging system including coaxial to microstrip line transitions. As an example, a shielded microstrip line which is connected with coaxial lines, is analyzed and measured. The comparison between experimental and numerical results shows very a good agreement.**

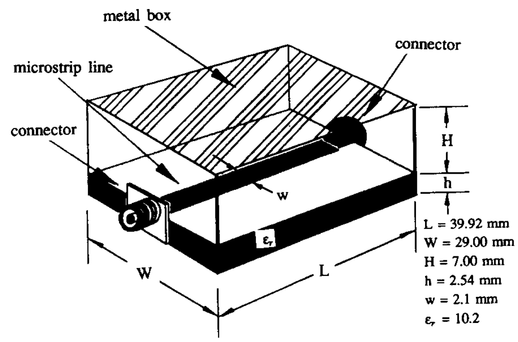

Fig. 1. A shielded microstrip line connected with coaxial lines.

I. INTRODUCTION

With the development of high speed digital circuits and monolithic microwave integrated circuits (MMIC's), the detrimental effects of electronic packages and other transitions associated with housing these circuits have become topics of considerable interest in the last few years. Of particular interest are the internal resonances of an enclosing structure, as well as the distortion in the shape of electrical pulses, which leads to a reduction in the transmission efficiency of signals propagating through these structures. It is obviously important to develop accurate and robust full-wave numerical models, which are capable of coping with the shielding and transition effects, for high performance circuit designs.

The problems related to packaging side effects have been investigated in the spectral domain by a number of workers. One representative model is that developed by [1]. The reciprocity theorem is used to set up the model and the analysis is carried out using the moment method. Although this model is a significant step towards the goal that is being espoused by an increasing number of researchers, it is found that there are still some drawbacks in the model. For example, the higher order modes near the coaxial to microstrip transition have not been completely taken into account because the coaxial feed is described by a simple magnetic frill current which involves only the TEM mode in the coaxial line. As well, the relative convergence of the Green's function makes it difficult to obtain a reliable solution.

The FD-TD method has been widely used to solve electromagnetic problems. In this short paper, the three-dimensional FD-TD method is applied to model a representative electronic package and associated transitions. In particular, the model developed earlier [2], [3] for the coax-to-microstrip transition is incorporated with the solution procedure. Since the size of the FD-TD's lattice is fairly small compared with the wavelength of interest, higher order modes in the vicinity of the coaxial to microstrip transitions are easily incorporated into the model.

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Since a nonphysical excitation plane issued in launching a numerical pulse at the input port, the difficulty in the investigation of a pulse distortion is one of launching pulse of a given shape. Therefore, we cannot directly simulate the output for a given input. However, we can reach the same objective indirectly by using the system function. The system function can be found by deriving the impulse response for certain bandwidth. To establish the system transfer function of a packaged circuit either in time or in frequency domain, the discrete Fourier transform (DFT) will be used to convert sequences of discrete data from time-domain into frequency-domain and vice versa. Once the discrete transfer function is found, the discrete linear convolution is used to determine the output from an input. As a typical example, a prototype of a microstrip line in a shielded metal box with coax-to-microstrip transitions is made as shown in Fig. 1. The experimental results are in good agreement with numerical results.

II. FD-TD SIMULATION

It is well known that, in the application of the FD-TD method, the electromagnetic fields are directly discretized in time and in space. The curl operators in the Maxwell's equations are implemented using the central difference scheme proposed in [4], which is referred to as Yee's lattice. The second order accuracy is achieved by the algorithm when using the first order central difference scheme. After setting up appropriate boundaries, consisting of electric conductor walls and absorbing boundaries, the analysis is initiated by introducing an impulse function at some appropriate location and updating the field quantities at the grid points in a time sequential manner. For the sake of simplicity, no further details of the FD-TD method will be discussed here. The algorithm has been described extensively in the literature.

In this application, the coaxial line of a circular cross section is approximated by a stair casing boundary as shown in Fig. 2. Through a large number of numerical examples, it can be concluded that, although the inner and outer conductors of a coaxial line are approximated by staircasing, the accuracy is still retained as long as the characteristic impedance and the dimensions of the approximated line are close to that of the original one. Since the input and output planes are located in TEM coaxial lines, the first order absorbing boundary condition works very well in this study.

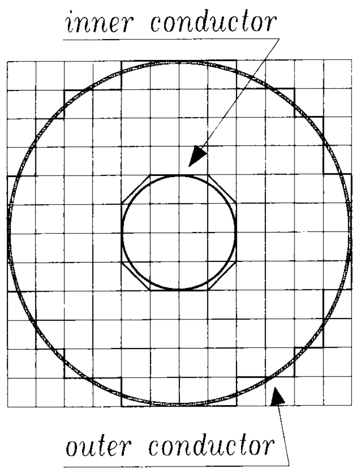

Fig. 2. A stair casing approximation of a 50 Ohms coaxial line.

The system transfer function for a packaged circuit can be derived from its impulse response. However, it is difficult to get an ideal impulse in a numerical process. To get the system function, a Gaussian pulse is used as the excitation, which is applied in the coaxial line of input port. This fictitious source at the excitation plane will become a TEM wave after propagating a few lattices away from the plane. After the Gaussian pulse has travelled through a package system, input and output pulses can be sampled at an appropriate reference plane. The discretized frequency domain transfer function can then be determined using:

$$S_{21}[f_k] = \frac{\mathrm{DFT}\{V_o(n\Delta t)\}}{\mathrm{DFT}\{V_i(m\Delta t)\}} \tag{1}$$

$$k = 1, 2, \ldots, N_T, \quad n = 1, 2, \ldots, N_o, \quad m = 1, 2, \ldots, N_i \tag{2}$$

where $V_i(m\Delta t)$ and $V_o(n\Delta t)$ are the sampled input and output voltages, respectively. To be more specific, V_i refers to the N_i data samples of the signal at the input port and V_o to the N_o data samples of the signal at the output port, and Δt is the time step used in FD-TD simulation. N_T is usually equal to N_o or N_i, whichever is greater. The shorter of the two sequences must be extended by adding zeros until its length is equal to N_T. The fast Fourier transform (FFT) is used here to implement Discrete Fourier Transform (DFT), which converts the data from the time domain into the frequency domain. The frequency domain transfer function is of most interest to the microwave circuit designer. It is assumed here that the time step used in the FD-TD algorithm satisfies the stability condition and is therefore small enough so that the Nyquist rate is satisfied to cover the frequency bandwidth of interest.

III. Signal Conversion Techniques

In a high speed digital circuit design, one is interested to know the distortion of an input pulse after it passes through a packaging system. Such distortion is mainly caused by three factors, in addition to the properties of circuit itself: 1) the dispersion down the printed transmission line, where the propagating wave is not a pure TEM wave; 2) mode coupling intransition discontinuities; and 3) internal resonances in an enclosing packaging metal box. In fact, all these factors have been included in the system transfer function. As a result, for a given input pulse, the output pulse can be obtained by convolving the input pulse with the system transfer function in the time domain.

Before implementing the linear convolution, we need to be aware of two conditions that must be satisfied when choosing the length of the sequences to be convolved, i.e.:

1) The original input pulse must be sampled sufficiently often, say at M points so that $\frac{1}{\Delta t} > 2\Delta f_{\max}$, where $\Delta f_{\max}$ is the maximum frequency bandwidth of interest.
2) To avoid the spectrum overlap in carrying linear convolution through the periodic convolution, the sequences of V_i, V_o and the input pulse sequence with M points should be extended to the length of N, which is greater than or equal to $M + N_T - 1$, by adding zeros.

According to *Symmetry Properties* of DFT, S_{21} $[f_k]$ must satisfy the following conditions:

$$\mathrm{Re}(S_{21}[f_{N-k}]) = \mathrm{Re}(S_{21}[f_k]) \tag{3}$$

and

$$\mathrm{Im}(S_{21}[f_{N-k}]) = \mathrm{Im}(S_{21}[f_k]) \tag{4}$$

where $k = 1, 2, \ldots, (N-1)/2$ when N is odd or $k = 1, 2, \ldots, (N/2) - 1$ when N is even. These properties are important because when one converts an experimental frequency domain system function into the time domain, the function must be modified to meet the symmetry properties mentioned above.

From modified time domain sequences of V_o and V_i, one can find the discrete frequency domain system function in a relatively straight forward manner. The product of the resulting frequency domain sequence with the DFT of N point input pulse must also satisfy the symmetry properties. The inverse DFT of this product results in a real time-domain sequence, which is the output time domain response.

IV. Numerical and Experimental Results

To verify the proposed model, a prototype of the microstrip line in a metal box with coaxial to microstrip transitions is analyzed and measured. Fig. 3(a) and (b) shows the system transfer function obtained by experiment and the FD-TD method, where $\Delta z = \Delta x = \Delta y = 0.3125$ mm, $\Delta t = 0.57\Delta h/C$ and C is the speed of light. Details with regards to the discretization used at the coaxial to microstrip junction is given in Fig. 2. It can be seen that the numerical and experimental results are in good agreement both in magnitude and in phase. Because of a large mismatch between the coaxial line and microstrip line at high frequency (due to the dispersion in the microstrip line), the transmission properties will become unpredictable. In this example, it occurs when the frequency is higher than 12 GHz. Fig. 4 shows the input and the output of a rectangular pulse through the prototype, where the spectrum of the ideal rectangular shaped input pulse, with a rise time of 59.4 ps and pulse width of 154.5 ps, is truncated at 20 GHz. The output response are obtained by the linear convolution of the input pulse with its system transfer function shown in Fig. 3. The solid line is the result using the transfer function calculated by the FD-TD method and the dashed line is obtained by the measured transfer function. Due to the dispersive property of the microstrip line, the rectangular shaped pulse is greatly distorted after it passes through the system. The effects of the metal box and the transitions are better observed from the frequency domain transfer function. It should be mentioned that due to the errors in the errors in the dimensions of the prototype, some degree of discrepancy between simulated and measured results can be observed.

V. Conclusion

A model of packaging and transition effects for microwave and high speed digital circuits is developed based on the 3D full-wave

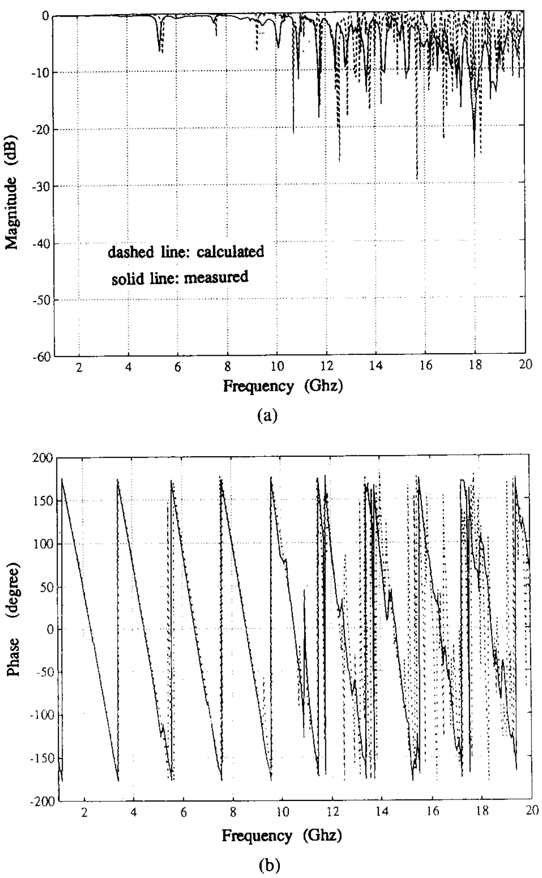

Fig. 3. (a) The magnitude of the system transfer function for the packaged circuit shown in Fig. 1. (b) The phase of the system transfer function for the packaged circuit shown in Fig. 1.

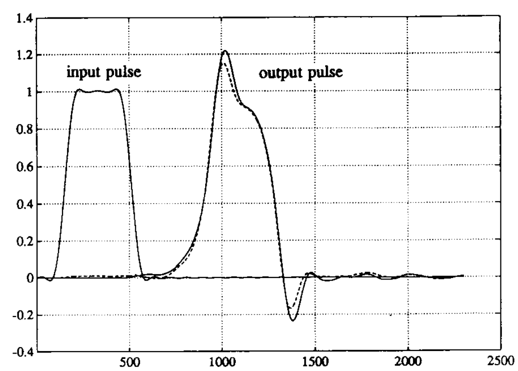

Fig. 4. The input and output pulses of the packaged circuit shown in Fig. 1.

numerical technique—the FD-TD method. The emphasis has been put on the combination of the FD-TD method with the time-frequency domain discrete conversion techniques. A typical problem is analyzed by this model for the purpose of verification. Digital signal processing techniques are used with the FD-TD algorithm in this analysis. The comparison of numerical results with experimental results is in a good agreement. The variable grid model will be adopted to improve the efficiency of the model in the next phase of the research.

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The Dominant Mode in a Parallel-Plate Chirowaveguide

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***Abstract*—It has been reported that the lowest cutoff frequency of the modes in a parallel-plate chirowaveguide is not zero. In this paper, we show that a dominant mode of trivial cutoff frequency may be supported by such a chirowaveguide. The mode exhibits the characteristics of a TEM mode when the chirality of the medium vanishes or the operating frequency is very low. An analogous mode also exists in a bianisotropic chiral coaxial line, i.e., the structure formed by more than one conductor.**

I. Introduction

Recently a number of papers on the theory or analysis of chirowaveguides has been published. Engheta *et al.* [1]–[2] studied the possible propagating modes in a cylindrical chirowaveguide and proposed the method for analyzing such structures using the theory of coupled modes. Investigation into the characteristics of the modes in a parallel-plate chirowaveguide was made and notable features of chirowaveguides, e.g., bifurcation of the modes, which may have many potential applications, have been reported [1]–[2].

According to [1], [2] no modes may propagate below nontrivial frequency, i.e., the lowest cutoff frequency in a chirowaveguide. However, the lowest cutoff frequency of the parallel-plate chirowaveguide was found to be nonzero [1]–[2]. Moreover, this frequency does not

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