ELECTROMAGNETIC MODELING AND SIMULATION OF ELECTRONIC PACKAGES

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Abstract

In this paper, we illustrate the results of application of a general purpose Maxwell solver for the derivation of equivalent circuits of various components of an electronic package that can be inserted in a SPICE-type circuit simulation program to investigate the electrical performance of the package. Although a number of different techniques are presently available for the electromagnetic modeling of transmission lines and discontinuities in these lines, the Finite Difference Time Domain (FDTD) algorithm is found to be best-suited for our purpose, and is used exclusively to derive the results presented in this paper.

1. Introduction

Recent trends toward a rapid increase in the interconnect densities, and the availability of fast risetimes devices, have accentuated the problems related to signal degradation, clock skew, crosstalk and power supply noise in electronic packages. Availability of accurate and efficient tools for the electromagnetic modeling and simulation of the electrical performance of an electronic package in its design stage can be of great assistance to the design engineer.

A variety of techniques are available for the quasi-TEM analysis of packaging interconnects comprising of multiconductor transmission line systems and discontinuities in these systems. These include the Method of Moments (MoM), the Boundary Element Method (BEM), the Finite Element Method (FEM) and the Partial Element Equivalent Circuit (PEEC) approach. They have been discussed in a number of review publications, e.g., Hayes and Barrett [1], Ruebli [2], Brauer et al. [3], and Mittra and Gordon [4]. Frequency-dependent analyses based on MoM and FEM have also been developed and are presented in publications by Rubin [5] and Mittra and Lee [6]. However, there still exists a need for a general-purpose Maxwell solver that can derive the R, L, G, C parameters of transmission lines, as well as equivalent circuits for the discontinuities in these lines, that are valid over a broad frequency range encompassing both the low and high frequency ranges. In this paper, we illustrate the application of a general-purpose Maxwell solver based upon the Finite Difference Time Domain (FDTD) algorithm which is well-suited for the above purpose. The FDTD method was originally introduced by Yee [7], and has been recently employed by a number of authors for packaging applications [8]. We show how this method can be employed not only for the field solution, but for the extraction of the equivalent circuits for transmission lines and other more complex geometries, e.g., bends and through-hole vias, that are well-suited for insertion into circuit simulators packages, e.g., SPICE, to predict the electrical performance of a package.

The conventional Yee-FDTD algorithm is quite straightforward to implement and the details of the procedure, which have appeared in numerous publications, will be omitted here. Basically, in the FDTD algorithm, Maxwell's differential equations are discretized over the Yee unit cell [7] shown in Fig. 1.

Figure 1. Yee cell for the uniform grid.
The important steps in the solution procedure based on FDTD are as follows:

(i) Start by meshing the computational domain containing the geometry to be analyzed using the so-called Yee grid that comprises interlocking electric and magnetic field cells in a Cartesian coordinate system.

(ii) Truncate the mesh using either a perfect electric conductor, perfect magnetic conductor, or an appropriate absorbing boundary condition (ABC) [6, 9, 10].

(iii) Identify the material properties of the media in each cell.

(iv) Launch the incident field.

(v) Solve the electric and magnetic fields in each of the respective cells by using an explicit, leap-frogging procedure.

(vi) Integrate the electric and magnetic fields along appropriate paths to yield the temporal voltage and currents at the desired sampling points.

(vii) Derive the other desired quantities, e.g., the scattering parameters as functions of frequency, by Fourier transforming the time domain voltage and current data.

In the next section, we illustrate the application of the FDTD method to the modeling of transmission lines.

2. Transmission Line Analysis

Consider the three-dimensional problem of a finite length stripline, whose dimensions are given in Fig. 2. We excite the line with a quasi-TEM field distribution varying sinusoidally in time at a frequency which is below the cut-off of the higher order mode in the guide.

![Figure 2. The stripline analyzed using FDTD. The strip dimensions are 0.150 mm wide and 0.025 mm thick.](image)

We truncate the mesh in the front and the back of the guide using absorbing boundary conditions. We let the FDTD recursive algorithm proceed until the solution converges. We determine the voltage and current at a number of sampling points from the field computation by appropriately integrating the electric and magnetic fields (see Becker et al. [11] for details). We determine the characteristic impedance from the ratio of the voltage and the current, and the propagation constant from the phase delays between the sampling points.

An important attribute of the above procedure is that the frequency-dependent characteristics of the transmission line are readily obtained from the method by using either a superposition of several sinusoids or a pulse for the excitation of the line. As an example of the frequency dependence, we show the frequency variations of the effective dielectric constant and the characteristic impedance, respectively, in Figs. 3 and 4. The data obtained by Zhang and Mei [12], and those derived by using empirical formulas, are also shown for comparison. Before closing this section we mention that an extension of the above approach can be readily extended to analyze coupled lines as well.

![Figure 3. The effective dielectric constant as a function of frequency for a microstrip line. Results are compared with data from Zhang and Mei, and two empirical formulas from [14].](image)

![Figure 4. The characteristic impedance of a microstrip line. The results are compared with data from Zhang and Mei and an empirical formula [14].](image)
3. Discontinuity Problem

We turn next to a typical discontinuity problem, e.g., the through-hole via, to illustrate the versatility of the time domain solver. Consider the geometry shown in Fig. 5 illustrating a via connecting two different layers of multilayer circuit board. As before, the lines are terminated by absorbing boundaries, and an incident TEM field is launched at the input port with a Gaussian distribution in time. Next, the voltages and currents are determined at the sampling or 'measurement' points shown in Fig. 5, and the frequency-dependent scattering parameters are subsequently extracted by post-processing the data using the DTFT (discrete-time Fourier transform) procedure. These scattering parameters, viz., $S_{11}(\omega)$ and $S_{21}(\omega)$, are shown in Fig. 6 for frequencies up to 40 GHz, although these results are not useful above 30 GHz, owing to the excitation of the $TE_{10}$ mode in the structure.

The circuit model shown in Fig. 7 represents the via structure of Fig. 6. The circuit element values are found to be: $C_1 = 0.119 \text{ pF}$, $C_2 = 0.075 \text{ pF}$, $L_1 = 0.47 \text{ nH}$, $L_2 = 0.062 \text{ nH}$. It is interesting to note that these values, which are frequency-independent, can still reproduce, accurately, the frequency response of the via up to 20 GHz.

![Figure 5](image)

**Figure 5.** A side view of a rectangular via connecting two striplines on different levels in a multi-layer circuit board configuration. The striplines are 0.25 mm by 1.25 mm, the via is 0.5 mm by 0.75 mm, and the reference planes are separated from the via by 0.25 mm.

![Figure 6](image)

**Figure 6.** The via scattering parameters from FDTD

Once the scattering parameters for the via are determined, an equivalent circuit model may be obtained.

4. Generalizations & other Applications

The FDTD approach described above has been generalized to non-orthogonal coordinates and has been applied to a number of problems of interest, e.g., the cylindrical via with a circular pad [13] and a microstrip bend with an arbitrary angle [14] and the modeling of power plane noise (R. Mittra, D. Becker and P. Harms, to appear in Special Issue of IEEE Transactions on Circuits and Systems).

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References


