Accepted to the Special Session APSS7 – “Wavelets In Electromagnetics” and Student Paper Competition

Multilayer Package Modeling Using the Multi-Resolution Time Domain Technique

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Abstract

The Multi-Resolution Time Domain Technique is applied to the modeling of multilayer packaging structures. In particular, the performance of a multilayer balun is evaluated using MRTD and the results are compared to those obtained using the FDTD technique as well as a commercial simulator. The abilities of MRTD to handle complex structures and as non-uniform cells are highlighted.

I. Introduction

On-package passives are quickly being adopted as a way to shift required components from expensive on chip areas to less expensive packaging structures. In order to further reduce size, these components can be fabricated using a multilayer process. Examples of such integration have been widely reported in the literature [1-2]. As multilayer components become more common, a method is needed to readily design and accurately model these components. An excellent candidate for this is the Multi-Resolution Time Domain Technique (MRTD) [3].

An example of a structure that can be modeled using this technique is a multilayer balun. A balun designed to operate in the 2.4 GHz range was designed for this purpose. The geometry of the balun is well suited to MRTD modeling because of the complicated structure of the metals and the small feature size. The balun is modeled using both commercial and non-commercial tools, and the advantages of MRTD over these tools are demonstrated.

II. Balun Design

Baluns, from **Bal**anced to **Un**balanced transformer, are required in a wide variety of microwave applications such as antennas, balanced mixers, push-pull amplifiers, multipliers and phase shifters [4]. Essentially, a balun transforms a balanced network to an unbalanced one and vice-versa.

Baluns can be designed using coupling techniques [5]. A classic example involves using three transmission lines. Two short-circuited transmission lines are placed in close proximity to an open line such that they couple. The open line is a half wavelength long at the operating frequency and the short-circuited lines are approximately a quarter wavelength long. This being the case, a standing wave will form a short circuit at the center of the open line. Here the current will be at its maximum value. A short distance away from the center and on either side of it, the voltage will be equal in magnitude but with opposite phase. The two short circuit line sections are coupled from both ends of the open line. A signal incident at the half-wavelength line induces signals at the output of the quarter-wavelength lines with equal amplitude but opposite phase.

In order to save space on the substrate, one alternative is to implement the lines as spirals. This reduces the size of the overall structure. Further size reduction achieved through the coupling that results from using spiral lines, which reduces the needed line length in the balun. At 2.4 GHz, the overall length of the half wavelength section using a spiral line is reduced to approximately 0.6 of its straight-line length. Therefore, the final length of the line becomes 0.3λ.

Spiral baluns can be implemented using different topologies. A multi-layer process permits several degrees of flexibility as far as layout is concerned. The balun in this paper is developed for multi-layer ceramic technology in a stripline topology. Fig. 1 shows a typical stripline implementation of the balun.

III. Modeling

The balun is designed to function over a wide frequency band. It has a nonsymmetrical multilayer structure. These characteristics suggest that a time domain simulation is appropriate for the device. However, the balun has a relatively large size compared to its smallest dimension. In a conventional finite difference time domain (FDTD) [6] simulation, the small feature size means that a cell size several times smaller than this feature must be used. This leads to extremely large grids, which causes long execution times and large memory usage. These complications make this structure an ideal candidate for the multi-resolution time domain technique (MRTD).

MRTD can compensate for the difficulties of modeling large structures by allowing large cells with multiple conductors to be used in the simulation. Using Haar wavelets, this can be implemented readily [7]. This feature is demonstrated in Fig. 2. The scaling functions as well as wavelet resolutions with domains that intersect with PECs and thus exist in two distinct regions (metal and nonmetal) have their magnitude set to zero. The first resolution of wavelet that can be updated has domain boundaries on the PEC interface(s). All wavelets of higher resolution can also be used and their values are calculated using even or odd image theory. The accurate modeling of multiple conductors per cell is realized using high space resolution of wavelets around the PEC's and interpolation in time. The choice of the lowest wavelet resolution to be used is performed automatically in the preprocessing stage. In this fashion, memory usage and execution time are only increased in areas of small feature size, not in the entire simulation. Furthermore, the resolution is adaptively increased when needed. If the field in an area is quasi-static, the resolution need not be as high as an area with highly dynamic field variation. Thus, the multi-resolution ability is well suited for modeling the balun.

The balun modeled in this paper is presented in Fig. 3. All lines in the structure are 13 mils wide. All layers are separated by 3.7 mils. Ground planes are located on the layers above and below the structure. Via holes are modeled as squares, 5 mils per side. There are four vias in the structure. The first via links the input line (port 1) to a line at the bottom layer. The second via links this line to the center of the right spiral on center layer. This enables the spiral to be fed from the center. The other vias provide the ground connections for the top and bottom spirals. The balun was modeled using FDTD, in addition to a commercial simulator, IE3D [8]. The FDTD simulation was performed in order to verify the results of the commercial simulator as well as to provide a reference for MRTD simulations. The total number of cells in the simulation is approximately 1.26 million (221x24x238), leading to a large execution time on a single processor computer. An MRTD simulation with the use of wavelets up to the 3rd resolution greatly reduces the memory (82x18x84) and the execution time (x4) requirements for this structure.

In order to accurately model the structure, the FDTD cell dimensions in the plane of the spirals are made so that each line is ten cells wide (to create a cell width of 1.3 mils). The other dimension is constructed so that there are six cells between layers (cell depth of 0.62 mils). The device is attached to stripline at all ends. Ten cells of UPML terminate all lines.

The device is fed with a Gaussian derivative pulse in time. The maximum frequency of the pulse is 10GHz. The pulse is arranged in space so as to create a uniform sheet of electric field in the direction transverse to the input line. The vertical E fields above and below the line have equal amplitudes and opposite signs. This creates an equal voltage between the line and each ground plane (odd symmetry – stripline excitation). This pulse is fed into port 1 in order to measure the response from ports 2 and 3. All ports are measured by determining the voltage between the center of the line and the top ground.

IV. Results

The desired response of the balun is to reduce power by half (3 dB) and create a 180 degree phase difference between ports 2 and 3. The output is measured on a transmission line (stripline). The magnitude anywhere on the stripline should be the same (minus some negligible loss). The phase, however, differs with position. It is very important, therefore, to measure the phase the same distance from both ports (or perform a transformation to account for the difference in distance). In this simulation, both ports are measured at an equal distance from the output of the balun.

The input and output voltages were transformed to the frequency domain in order to determine the S-parameters. To determine the input waveform, an additional simulation was run on a thru line with dimensions identical to the feed line. S_{21} and S_{31} were determined by dividing the output frequency responses by the input frequency response. Fig. 4 is a plot of the magnitude of S_{21} and S_{31} for both simulators; Fig. 5 is a plot of the phases.

The results of the FDTD, the MRTD and the IE3D simulation are very similar. The major difference between the two is the lower magnitude of S_{21} and S_{31} in the time-domain simulations. This is caused by reflection from the structure in the FDTD/MRTD simulations that does not appear in the IE3D simulation. However, this represents a real and important characteristic of the circuit, the return loss. To best utilize this circuit, a matching network must be developed to reduce or eliminate the return loss. It should be noted that the slight difference between the phase of the IE3D and FDTD simulation is caused by the observation being made at slightly different points in the circuit. The relative difference between the two ports is similar in the simulations.

I. Conclusion

The performance of a multilayer balun is modeled using FDTD and MRTD techniques as well as commercial simulators. Though both time-domain techniques provide satisfactory results, the MRTD scheme allows for faster and more computationally efficient numerical evaluations, due to its adaptive intracell multi-conductor representation capability. This advantage can be critical for complex multilayer RF packaging structures with large size and very fine metallic details.

VI. Acknowledgements

The authors wish to acknowledge the Yamacraw Initiative of the State of Georgia, the Georgia Tech. Packaging Research Center, and the NSF Career Award.

VI. References

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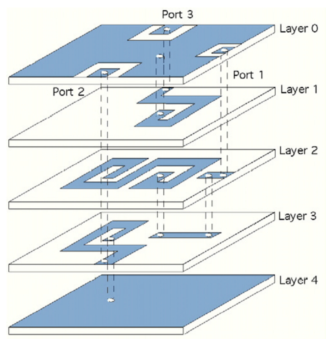

Fig. 1: Stripline Implementation of Spiral Balun

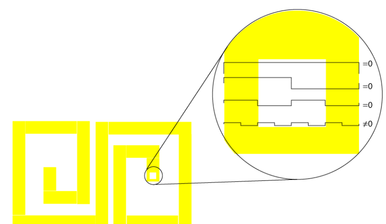

Fig. 2: MRTD Wavelet Resolution Example

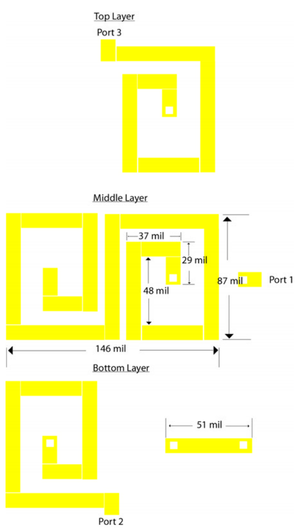

Fig. 3: Schematic of Balun

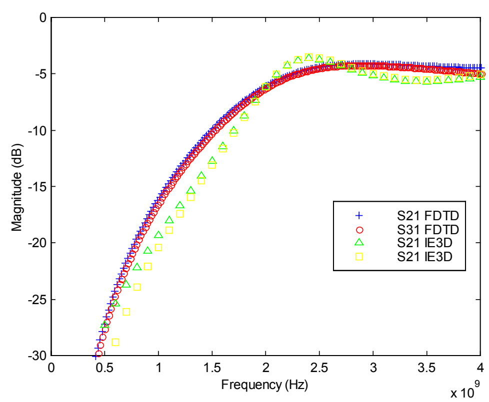

Fig. 4: Magnitude Response of Balun

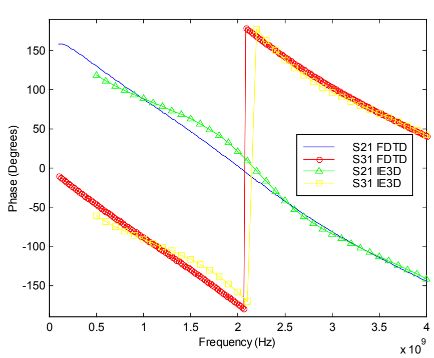

Fig. 5: Phase Response of Balun