A CAD ALGORITHM FOR COUPLING BETWEEN DIELECTRIC COVERED MMICS IN MULTI-CHIP ASSEMBLIES

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ABSTRACT

An algorithm is presented for determining the coupling between sealant covered MMICs in a multi-chip module. This technique is computationally simple, appropriate for use with layout based circuit CAD software, and uses no numerical electromagnetics. It has been tested by comparison to fullwave electromagnetic simulation.

INTRODUCTION

To achieve the goal of virtual prototyping of microwave and millimeterwave (MW/MMW) designs, many capabilities must be improved dramatically in the current set of Electronic Design Automation (EDA) tools. One of these capabilities is quick and accurate simulation of a completed MW/MMW Multi-Chip Assembly (MCA). The CAD technique presented in this paper has been developed for calculating the coupling between the block dielectric covered MMICs in a MCA. Coverings such as this occur when a sealant is applied for protection. As we will show, sealant coverings can increase the coupling between MMICs by tens of dB. Figure 1 shows the basic configuration of a hypothetical MCA containing two MMICs embedded in substrate 1 and each covered with a sealant of thickness d_s.

Reference [1] describes an averaging algorithm for calculating the coupling between bare MMIC dies embedded in an interconnect substrate. That algorithm assumes that all layers are laterally homogeneous dielectrics. In what follows, however,

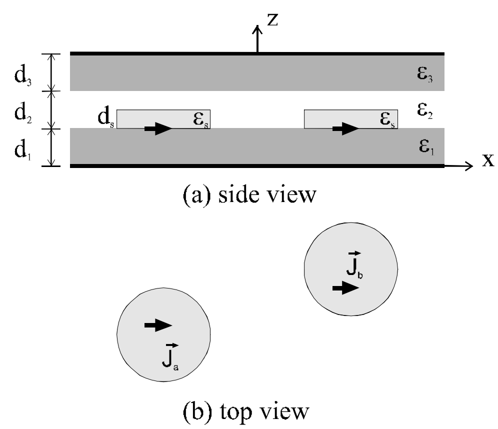


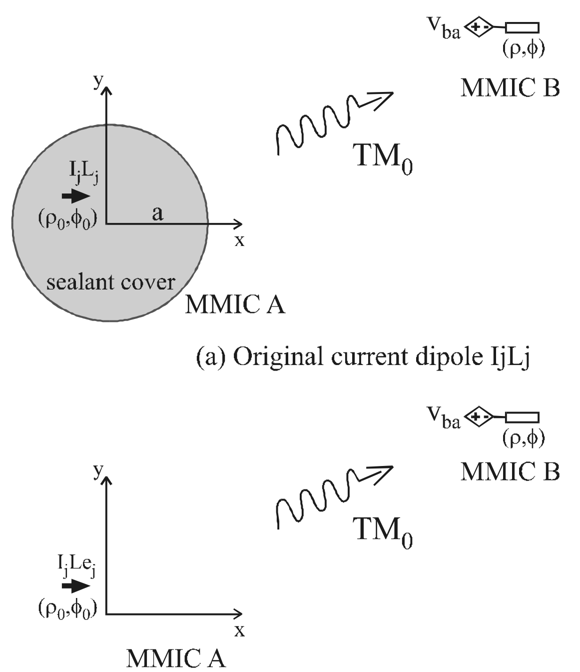
Figure 1. Configuration of the MCA with block dielectric covered MMICs

the middle layer of the MCA is laterally inhomogeneous due to the presence of sealant islands covering each MMIC. In order to compute the effect this inhomogeneity has on MMIC to MMIC coupling, it is necessary at present to use a Method of Moments or, most likely, a Finite Element simulator. For large complicated MMICs, this is totally impractical and unnecessary.

In this paper, we describe a technique that changes the inhomogeneous problem to a homogeneous one. Then we use the equivalent dipole technique described in [1] to predict the coupling between dielectric covered MMICs. The new algorithm uses computational resources roughly equivalent to a microwave circuit simulator, but orders of magnitude less than is used by an FEM simulator.

SIMPLIFICATION TECHNIQUE

In our algorithm, we predict the coupling between two MMICs, A and B, by determining the voltages induced on the components that comprise MMIC B by the currents on the components that comprise MMIC A. Since the dielectric block cover causes more energy to radiate from MMIC A, larger voltages are induced on the receiving component of MMIC B. The simplification technique is to find an equivalent uncovered component that induces the same voltages on MMIC B as the dielectric covered component. By replacing all the dielectric block covered components with their equivalent uncovered components, we reduce the inhomogeneous problem to a homogeneous problem.



(a) Original current dipole IjLj

(b) Equivalent current dipole IjLej

Figure 2 The equivalent current dipole produce the same voltages on MMIC B

Figure 2 shows the inhomogenous-to-homogenous simplification. Two approximations are made in the problem. First, since MMICs A and B are widely separated, it is assumed that their coupling is due only to $\mathrm{TM_0}$ parallel plate waves. Second, because a sealant cover is usually shaped like a square with round corners or some other quasi-circular shape, we assume for simplicity that the cover is cylindrical.

The original inhomogenous problem is illustrated in Figure 2(a). As discussed in reference [1], each radiating component of MMIC A is approximated as an electrical dipole that has a moment, $I_j\vec{L}_j$, where

$$I_j\vec{L}_j = \iint \vec{J}_j(x,y)dxdy \qquad (1)$$

and $\vec{J}_j(x,y)$ is the current density on the component j. I_j is the terminal current of the component and is calculated by a standard circuit simulator. $\vec{L}_j$ is the effective length of the dipole and represents the energy radiating performance of the component. It can be determined from approximate knowledge of $\vec{J}_j$.

When a dielectric block covers MMIC A, the radiating characteristics of each circuit element are changed by a factor we define as F_j. The adjusted effective length can be written as

$$\vec{L}e_j = \vec{L}_j \cdot F_j \qquad (2)$$

In Figure 2(b), $I_j\vec{L}e_j$ is the equivalent current dipole without a dielectric cover that produces the same voltage on each component in MMIC B as the original dipole $I_j\vec{L}_j$ in Figure 2(a).

Since the factor F represents the change in the $\mathrm{TM_0}$ wave at (ρ, ϕ) due to the effect of a sealant cover on a current dipole, we can express F as

$$F = \Psi_{sc}(\rho,\phi)/\Psi_{ns}(\rho,\phi) \qquad (3)$$

where Ψ_{sc} and Ψ_{ns} are the z directed magnetic potentials of the $\mathrm{TM_0}$ wave in the substrate created by a dipole at (ρ_0, ϕ_0) with and without sealant cover respectively. A magnetic potential Ψ of $\mathrm{TM_0}$ wave can be obtained using transverse resonance method. Ψ_{sc} must be expressed in two regions, $\rho > a$ and $\rho < a$, where a is the radius of a cover centered at the origin. The $\mathrm{TM_0}$ wave in each region is determined by its vertical layer structure. At the boundary $\rho = a$, the continuities of Ψ_{sc} and $\frac{\partial}{\partial\rho}\Psi_{sc}$ are required. The magnitudes of Ψ_{sc} and Ψ_{ns} are determined from the unit dipole located at (ρ_0, ϕ_0) which is expanded into a sheet current density having Fourier amplitudes $\{J_{0n}\}$. Ψ_{sc} and Ψ_{ns} are then determined using the tangential continuities of the E field and,

$$H_{\phi 0n}(\rho_0^+) - H_{\phi 0n}(\rho_0^-) = J_{0n} \quad (4)$$

where $H_{\phi 0n}$ is the ϕ directed magnetic field corresponding to the n'th term in the Fourier series for the magnetic potential, Ψ. ρ_0^+ and ρ_0^- are the location outside and inside of ρ_0 respectively. Due to the space limitation and the complexity of the formations, the detail derivation and formula of F is not given in this paper.

ALGORITHM

Figure 3 illustrates the algorithm we propose for the coupling between dielectric block covered MMICs. This algorithm is developed for use in conjunction with a layout based circuit CAD software. We apply it on HP EEsof Microwave Design System (MDS) [3].

The algorithm starts from the layout of the MCA assuming, for example, two MMICs. First, the schematics of MMIC A and B are extracted from the layout. By exciting the ports of MMIC A in the circuit simulation, we obtain the input currents I_m for each component in MMIC A.

The equivalent length is then determined for each component in MMIC A and MMIC B. This can be done analytically in most cases. In Figure 3, $\vec{L}_m$ and $\vec{L}_n$ represent the dipole lengths, and $\vec{P}_m$ and $\vec{P}_n$ represent the locations of the components. The layer structure of the MCA and dielectric blocks on MMIC A and B are also known from the layout. The equivalent uncovered dipole lengths $\vec{L}e_m$ and $\vec{L}e_n$ are then evaluated with the simplification technique described previously.

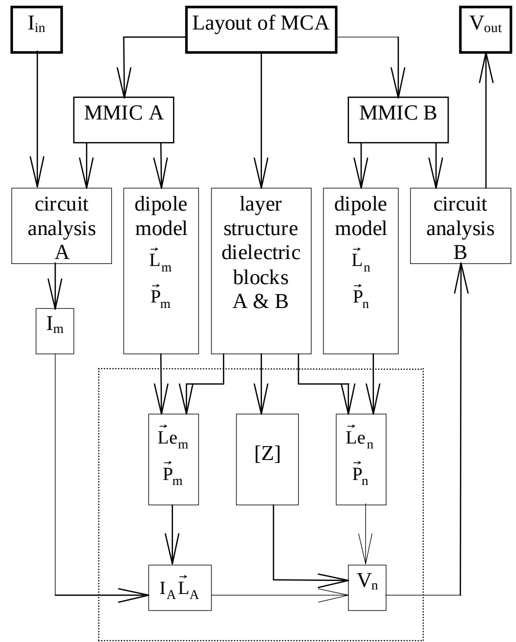


Figure 3. Flow diagram of the algorithm

By combining I_m, $\vec{L}e_m$ and $\vec{P}_m$, the x, y and z directed macro-dipoles (I_xL_x, I_yL_y and I_zL_z) in MMIC A are determined. $\vec{P}_x$, $\vec{P}_y$ and $\vec{P}_z$ are the locations of the macro-dipoles. From these, we calculate the induced voltage, V_n, on the n'th component of MMIC B by

$$V_n = \vec{L}e_n \cdot [Z] \cdot I_A \vec{L}_A \quad (5)$$

where $I_A\vec{L}_A = I_xL_x\hat{x} + I_yL_y\hat{y} + I_zL_z\hat{z}$ and $\vec{L}e_n$ is the equivalent length of the n'th component. [Z] is analytically determined from the configuration of the MCA.

The last step is to plug voltage sources, V_n into the circuit of MMIC B and then use the circuit simulator to get the voltages at the output ports of MMIC B. Further processing can easily calculate the S parameters that described the coupling between a port on MMIC A and one on MMC B.

In Figure 3, all the procedures outside the dot line frame are done with the aid of MDS. An external program does the calculation inside the frame.

VERIFICATION

In order to assess the accuracy of this algorithm, we have compared the result of our algorithm to the one obtained from a full wave analysis using Sonnet's ***em*** [4], a method of moments simulator. Sonnet's Dielectric Bricks™ allow inclusion of different dielectric materials in the same planar layer. We utilize this feature to simulate the

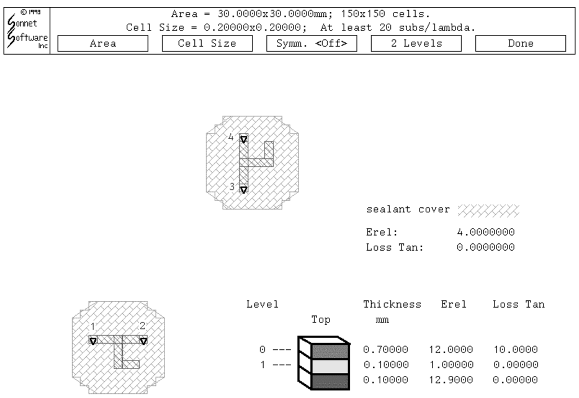


Figure 4. em set up for analysis of coupling between two 2-port stub/thru line circuits under dielectric block covers

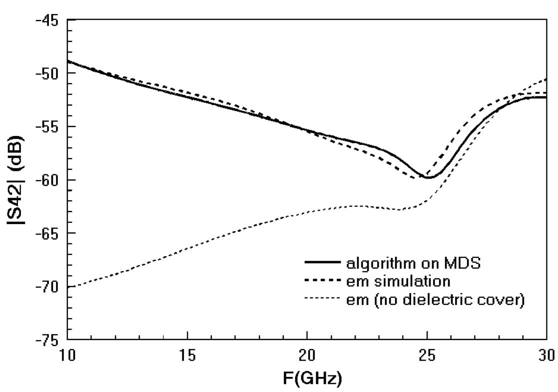


Figure 5. S parameter magnitude of the coupling between ports 2 and 4 of the circuit illustrated in figure 3. The dashed thin line shows coupling without dielectric covers.

coupling between dielectric covered MMICs. However, it is very CPU time and memory intensive.

We have chosen two 2-port microstrip stub circuits for our verification tests. Each circuit is connected to 2 ground ports though 2 via holes and covered by a dielectric cover. Figure 4 shows the configuration of these two circuits in the em simulator.

Figure 5 shows $|S_{42}|$ in dB computed using our algorithm and using the em simulation. The difference between the two results is within about 1.5dB in the -50 to -60 dB range. The third curve in the figure is the em simulation result for the same two circuits without dielectric covers. It shows that the dielectric covers have a significant effect on the coupling between the two circuits - about 20 dB at low frequencies. Our algorithm correctly predicts this effect.

Our algorithm used in conjunction with MDS simulates 200 frequency points between 10 to 30GHz in 10 seconds. Sonnet' ***em*** spends about 7 hours to finish 40 frequency points simulation. This algorithm uses three orders of magnitude less time than the full wave EM simulator.

ACKNOWLEDGMENT

This work was supported by DARPA/Raytheon under a Thrust 1 MAFET contract.

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[1] Jackson, R.W. and Z. Wang, "Circuit Based Model for Coupling Between MMICs in Multi-Chip Assemblies," **IEEE Microwave Theory and Techniques** Symposium Digest, pp. 1377-1380, June 1996.

[2] Harrington, R.F. *Time Harmonic Elecromag-netic Fields*, McGraw Hill, NY,1961

[3] ***MDS***, produced by Hewlett-Packard Company, Santa Rosa, CA, USA

[4] ***em*** is a trademark of SONNET Inc. Old Cove Road, Suit 203, Liverpool, NY, USA