Circuit Based Model for Coupling Between MMICs in Multi-Chip Assemblies

by

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Abstract

This paper describes a circuit model for the approximate determination of the coupling between MMICs in a multichip module. The model is developed from basic electromagnetics and relies on averages of the currents on the various MMICs. The technique is suitable for use in layout based circuit simulators and uses no numerical electromagnetics.

Summary

Many microwave modules, now and in the recent past, consist of MMICs and supporting components enclosed in some type of housing or package. Figure 1 illustrates such an assembly. Current efforts in module development revolve around: (1) reducing the size, weight, and cost of the package and (2) developing CAD techniques for predicting the performance of the completed assembly. This paper is concerned with the latter topic.

Microwave CAD of a module currently consists of simulations where the components within the module are coupled using circuit theoretic techniques. Other electromagnetic coupling (relating to layout or packaging) is neglected. If, after building the module, it turns out that the neglected coupling significantly affects module performance - causing oscillation for example - then the package must be redesigned. For low cost packages, this is especially difficult and time consuming.

Inter-chip coupling could be evaluated from a full electromagnetic simulation of the module and all the circuit currents in it. However, such a simulation is currently unrealistic and the detail it would provide is not necessary. An approximate analysis that can be done quickly would be much more useful. Reference [1] describes a circuit modeling technique that predicts resonance coupling in a microwave housing; however, for typical MMICs its implementation is prohibitively complex.

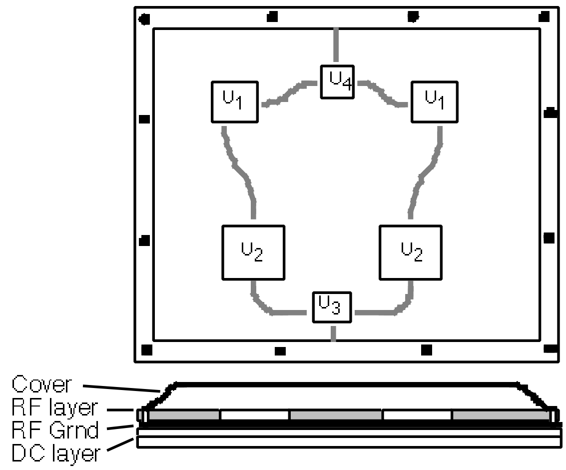

Figure1 Illustration of a multichip module

The algorithm we present would be used as a supplement to a circuit simulation package and could work in conjunction with layout capable software. It does not require any numerical electromagnetics and would not put the demands on memory and CPU that are normally associated with numerical electromagnetics. No numerical preprocessing or post processing of any significance is necessary.

The Algorithm

Figure 2 illustrates the algorithm we propose. The goal is to determine the voltages induced on the components that comprise MMIC

B by the currents on the components that comprise MMIC A.

The figure shows an illustration of components in a hypothetical MMIC A, a short circuit stub, a shorted inductor, and a length of transmission line. Each component contributes to the field that couples to MMIC B. Since these components are all small relative to the characteristic wavelength in the package (TM_0 wave), we approximate each of them with an electric dipole that has a moment, $\vec{L}_j I_j$. I_j is the terminal current of the component and can be calculated by a standard circuit simulator. $\vec{L}_j$ is the effective length of the dipole and is calculated from,

$$\vec{L}_j = \frac{1}{I_j} \iint_j J_j(x,y)dxdy \qquad (1)$$

where it will be noted that the I_j in the expression normalizes the amplitude of the current. As a result, $\vec{L}_j$ is a type of form factor for the j'th component. It can be calculated by hand from an approximate J(x,y) and stored along with a component's circuit model in a simulator's library.

Again referring to Figure 2, the dipole moments of all the components in MMIC A are summed to form the dipole moment of the entire MMIC, $I_A \vec{L}_A$. For a typical MMIC, this summation could include hundreds of elements.

To find the field at MMIC B, $\vec{E}(\vec{\rho}_B)$, due to the dipole at A, we assume that only the TM_0 parallel plate mode couples the two circuits. This is a reasonable assumption for any package that includes a metallic cover plate[2]. For the x directed field at B due to x directed current at A, the relationship is simply,

$$\left[\vec{E}_x(\vec{\rho}_B)\right]_A \approx -Z_{xx}\left(\left|\vec{\rho}_B - \vec{\rho}_A\right|\right) L_{xA} I_A \qquad (2)$$

where Z_{xx} is analytically determined and contains information about frequency and the layering and size of the module.

Lastly, we determine the voltages that are induced on the components in MMIC B. These voltages are then modeled in the circuit simulator using voltage sources connected in series with the terminals of each component. For the i'th 1-port, the voltage can be found from the reciprocity relation [3]

$$V_i = -\frac{1}{I_i} \iint_B dx\,dy \left[\vec{E}(x,y)\right]_A \bullet \vec{J}_i(x,y) \qquad (3a)$$

where the subscript A indicates that the field in the integrand originates from circuit A. Assuming that all components are small with respect to the variation of $\vec{E}(\vec{\rho}_B)$, Equation (3a) can simplified to,

$$\begin{aligned} V_i &\approx -\left[\vec{E}(\vec{\rho}_B)\right]_A \bullet \frac{1}{I_i} \iint dx\,dy\, \vec{J}_i(x,y) \\ &= -\left[\vec{E}(\vec{\rho}_B)\right]_A \bullet \vec{L}_i \end{aligned} \qquad (3b)$$

where $\vec{L}_i$ was originally defined in Equation (1) and is the effective length of the i'th component in MMIC B. The placement of the voltage generators is illustrated at the bottom of Figure 2 for an open circuit stub, a grounded capacitor-stub combination, and a transmission line.

The algorithm described above makes no mention of the location of the dipoles that represent the transmitting circuit. In fact, the dipole components are placed at the center of current (like center of mass) for the MMIC. The center of x directed current is different than the center of y directed current and different also from the center of z directed current. At one frequency the x directed currents on one side of the MMIC will be larger than all others and the center of x directed current will be located there. At a different frequency, the center may move to a different side. Thus the dipole location may move around versus frequency. The centers of current can easily be calculated by summing the dipoles of each MMIC component weighted by its position vector.

Verification

In order to assess the accuracy of this algorithm, we have compared the results of using our algorithm to those obtained from a full wave analysis using Sonnet's ***em*** [4], a method of moments simulator. Two example results are discussed below for packages without lateral side walls.

Figure 3 compares the transadmittance between open circuit stubs that are fed through vias from the bottom plane of the test package. There dimensions are each .2 mm X .6 mm on the surface of a .1 mm substrate with $\varepsilon_r = 12.9$. A free space layer (.1 mm), a damping layer (.7 mm, ε_r = 12-10j), and a perfectly conducting cover make up the layers above the circuit. The stubs are co-linear and separated by 3 mm. The circuit model admittance is compared to the admittance obtained by ***em***. Other orientations and separations have also been checked.

Figure 4 shows the coupling between two 2-ports, for two. Each 2-port consists of a transmission line with a shunt connected open circuit stub. In both cases, the transmission between port 2 of one circuit and port 3 of the other is computed using the dipole approximation and compared to the computationally intensive, but rigorous, MoM result. The circuits are separated from each other by 5 mm and their longest dimension is 1.4 mm. In case 1, both circuits are oriented in the same way relative to one another. In case 2, the second circuit is rotated by 90°.

Acknowledgement

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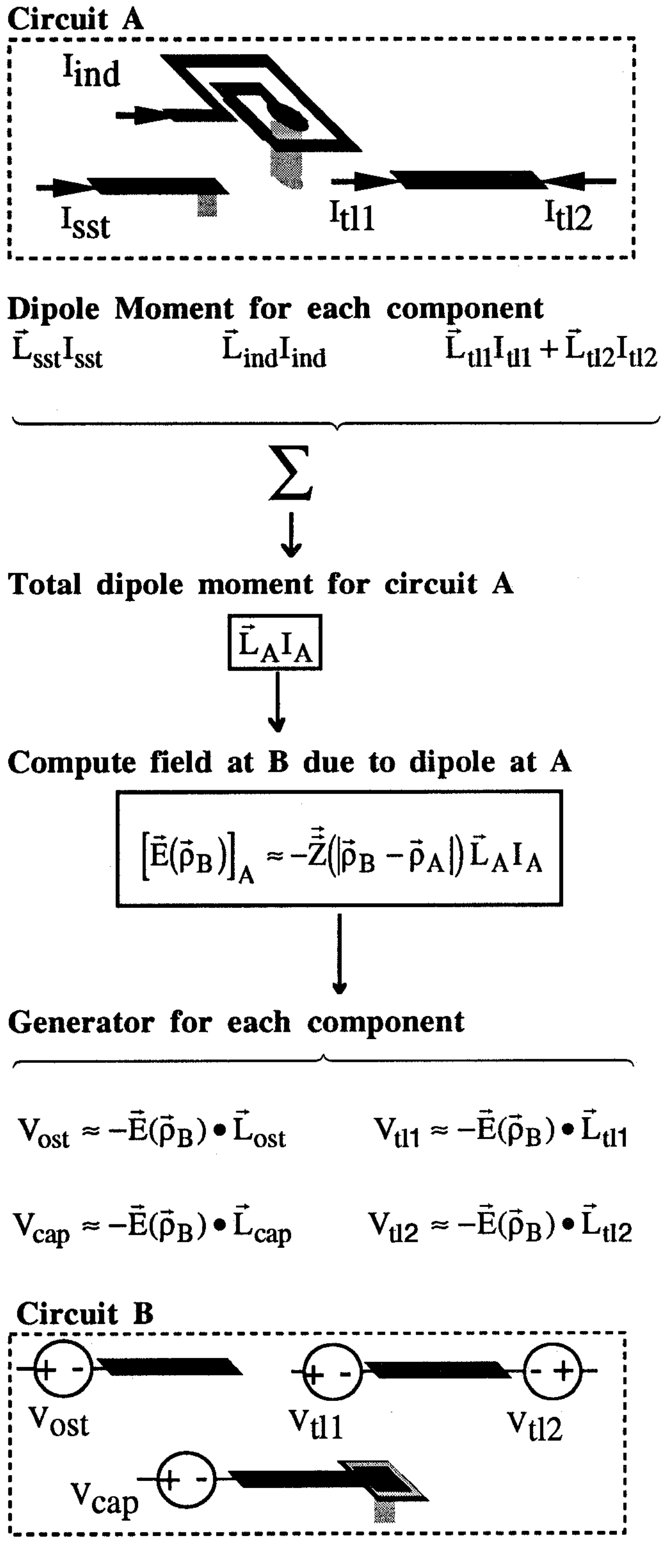
[1]Burke, J.J. and R.W. Jackson, "A Simple Circuit Model for Resonant Mode Coupling in Packaged MMICs," **IEEE Microwave Theory and Techniques** Symposium Digest, pp. 1221-1224, June 1991.
[2]Jackson, R.W., "The Use of Sidewall Images to Compute Package Effects in MoM Analysis of MMIC Circuits," **IEEE Trans. on Microwave Theory and Techniques,** Vol. 41, pp. 406-414, March 1993.
[3] Harrington, R. F., *Time Harmonic Electromagnetic Fields*, McGraw Hill, NY,1961
[4] ***em*** is a trademark of SONNET Inc., 135 Old Cove Road, Suite 203, Liverpool, NY, USA.



$$\vec{L}_{sst}I_{sst} \qquad \vec{L}_{ind}I_{ind} \qquad \vec{L}_{tl1}I_{tl1} + \vec{L}_{tl2}I_{tl2}$$

$$\vec{L}_A I_A$$

$$\left[\vec{E}(\vec{\rho}_B)\right]_A \approx -\vec{\vec{Z}}(|\vec{\rho}_B - \vec{\rho}_A|)\vec{L}_A I_A$$

$$V_{ost} \approx -\vec{E}(\vec{\rho}_B)\bullet\vec{L}_{ost} \qquad V_{tl1} \approx -\vec{E}(\vec{\rho}_B)\bullet\vec{L}_{tl1}$$

$$V_{cap} \approx -\vec{E}(\vec{\rho}_B)\bullet\vec{L}_{cap} \qquad V_{tl2} \approx -\vec{E}(\vec{\rho}_B)\bullet\vec{L}_{tl2}$$

Figure 2. Outline of algorithm for coupling MMIC A to MMIC B

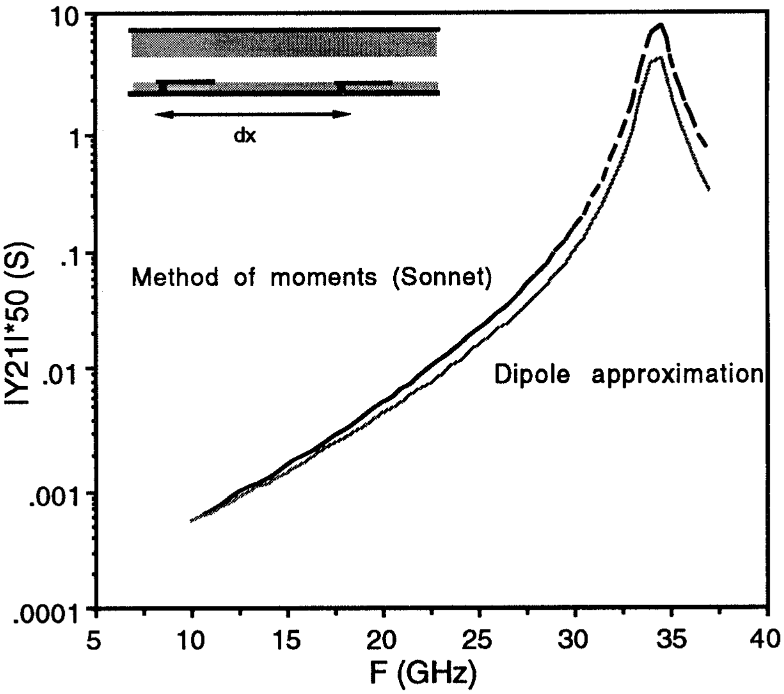


Figure 3 Transadmittance between two one port stubs. Side view in inset.

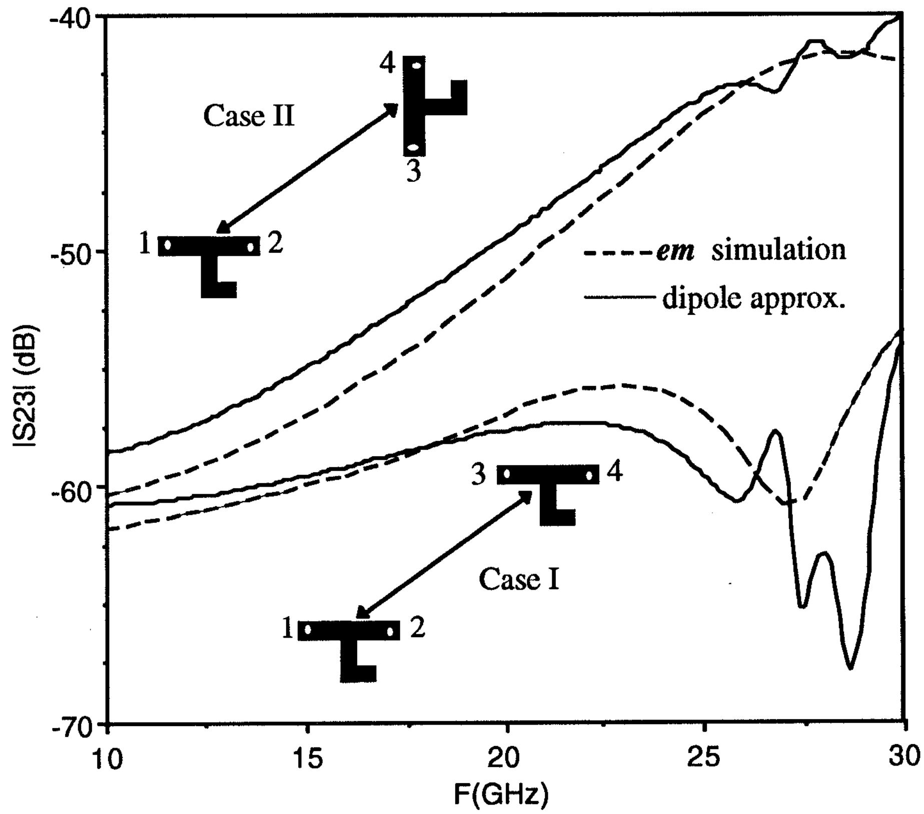


Figure 4.Coupling between two 2-port microstrip stub circuits separated by 5 mm. Case I with circuits co-oriented. Case II with one circuit rotated 90°.