ADAPTIVE MODELING AND DESIGN OF HIGHLY INTEGRATED 3D MICROWAVE-MILLIMETER WAVE RADIO FRONT-ENDS

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Abstract

The FDTD and the Haar-based MRTD algorithms are applied to the full-wave modeling of highly integrated 3D microwave and millimeter wave radio front-ends that require the optimization of various components as well as the minimization of the crosstalk between them. The numerical results have demonstrated a very good computational efficiency in the calculation of the scattering parameters, the Q-factor, as well as in the estimation of the radiation pattern, of the packaging effects and of the parasitic crosstalk between neighboring geometries

I. Introduction

The current drawbacks of most commercially available microwave and millimeter wave front-ends are their relatively large size, heavy weight primarily caused by discrete components such as the filters, and separately located modules. Multi-layer ceramic (e.g.LTCC) [1] and organic-based SOP (Fig.1) implementations are capable of overcoming this limitation by integrating components as part of the module package that would have otherwise been acquired in discrete form. On-package components not only miniaturize the module, but also eliminate or minimize the need for discrete components and thereby reduce the assembly time and cost as well. In this paper, we demonstrate an example of the design and optimization of fundamental components, such as embedded inductors, packaging-adaptive antennas and MEMS switches as well as minimization of the crosstalk between neighboring transmission lines that are commonly used for the feeding of neighboring MMIC's.

II. FDTD/MRTD Techniques

The FDTD [2] method is one of the most mature and versatile time-domain numerical techniques and it has been used for a wide variety of structures. The use of variable gridding along with effective parallelization approaches allows fine details of large structures to be modeled. Curves and diagonal elements can be modeled using stair stepping. In addition, a wide variety of FDTD enhancements make possible the modeling of small gaps, multidielectric/membrane configurations and resonating passives. Macroscopic results, such as S-parameters and impedances, can be determined by probing and comparing voltages and currents at different points in the structure. The MultiResolution Time-Domain Technique (MRTD) [3] is an adaptive generalization of the FDTD technique that is based on the principles of Multiresolution analysis and makes use of wavelets to alleviate the computational burdens of FDTD for complex or large structures, such as multilayer packages or MEMS, where the position of the boundaries is time-changing and the membrane thickness is much smaller than any other detail in the transverse direction. The MRTD technique allows the cell resolution to vary with both time and position. The wavelets (Fig.2) can be used to represent higher levels of detail along with higher frequency content. As fields propagate through the structure the resolution can be varied to allow for the rapidly changing fields. In addition, the optimization of solid-state and nonlinear devices requires the

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effective modeling of complex structures that involve mechanical motion and wave propagation. Due to computational constraints, most commercial simulators utilize various approximations in order to provide fast and relatively accurate results. The drawback of these approaches is that transient phenomena and nonlinearities are not modeled effectively, leading to the degradation of system-level performance. Alternatively, full-wave techniques provide higher accuracy but suffer from excessive execution time requirements, thus making their efficient numerical implementation very critical. The MRTD technique has provided a mathematically correct way to significantly decrease execution-time and memory requirements while avoiding any approximations.

III.Applications

Embedded transmission lines are commonly used in as feeding networks of MMIC's in multilayer packages, where the use of non-continuous grounds could lead to increased crosstalk effects. In this paper, the FDTD technique is used for the estimation of the coupling of the finite-ground microstrip lines of Fig. 3 [4]. The results for different line spacing and for a ground connecting via (optimized design) presented in Fig. 4 have been obtained by combining two simulations, an even and an odd mode excitation.

One of the critical passive components in RF application is the inductor. The Q-factor of the inductor significantly contributes to the phase noise of the voltage controlled oscillator and the gain of the power amplifier. A 2-turn planar inductor in organic material has been analyzed by FDTD that employs both variable grid and parallelization to increase efficiency and the results are compared with measured one [5]. The Q-value difference in Fig.5 is expected due to the fact that the simulation does not include the loss and roughness of the metal.

One example of a MEMS structure that benefits from simulation in MRTD [6] is the MEMS capacitive switch shown in Fig. 6. The gap between the plates in the switch is 1/175th of the substrate thickness. The simulation of this device in FDTD is tedious and slow because of the large number of cells that must be used in order to accurately represent the very small gap and substrate. In MRTD, the number of cells can be reduced by using the built-in adaptive gridding capability of the method.

The last simulated geometry is one packaging-adaptive multilayer antenna [7] designed for IEEE 802.11a 5.8 GHz band (Fig. 7). Two square patches have the same dimensions and are stacked on a grounded LTCC GL550 (ε_r=5.6) multi-layer substrate (layer thickness = 4 mils). The stacked patch is backed by a metal cavity while the lower patch is fed at its edge through a via from the filter. The return loss simulated is compared with the measured result in Fig. 8 and good agreement is noted. The radiation pattern results demonstrate that time-domain tools can predict correctly the bandwidth, as well as the packaging effect on the radiation pattern.

IV. Conclusion

The finite-difference time-domain (FDTD) and the multiresolution time-domain (MRTD), have been applied to the design of fundamental components of integrated microwave and millimeter-wave transceivers. They have demonstrated a very high efficiency in the calculation of the scattering parameters, the Q-factor, as well as in the estimation of the radiation pattern, of the packaging effects and of the parasitic crosstalk between neighboring geometries. In addition, their inherent capability of global electromagnetic field calculation allows for the identification of "hot spots" of high field concentration and for the derivation of physical-driven solutions for the improvement of the overall system-on-package efficiency.

Acknowledgments

The author wishes to acknowledge the support of the NSF CAREER Award under #9984761, the Yamacraw Design Center of the State of Georgia and the GT-Packaging Research Center.

References

[1] K.Lim *et al.*, "RF-System-On-Package (SOP) for Wireless Communications", IEEE Microwave Magazine, Vol.3, No.1, pp.88-99, March 2002.

[2] A. Taflove and S. Hagness, *Computational Electrodynamics: The Finite Difference Time Domain Method*, 2nd Ed., Norwood, MA. Artech House, 2000.

[3] N. Bushyager *et al.*, "Adaptive numerical modeling of RF structures requiring the coupling of Maxwell's, mechanical, and solid-state equations," *Proc. 17th Annual Review of Progress in Applied Computational Electromagnetics*, March 2001, pp.1-8, Monterey, CA.

[4] G. E. Ponchak *et al.*, "Coupling Between Microstrip Lines with Finite Width Ground Plane Embedded in Polyimide Layers", Proc. 2002 IEEE-IMS, Seattle, WA, June 2002

[5] M.F.Davis et al., "RF-Microwave Multi-Layer Integrated Passives using Fully Organic System on Package (SOP) Technology," Proc. IEEE International Microwave Symposium, Vol. 3, pp. 1731-1734. May 2001.

[6] N.Bushyager and E.M.Tentzeris, "Modeling and Design of RF MEMS Structures Using Computationally Efficient Numerical Techniques", Invited Paper in the 2001 Electronic Components and Technology Conference, May 2001, pp.324-327, Lake Buena Vista, FL.

[7] E.Tentzeris et al., "Design of Compact Stacked-Patch Antennas on LTCC Technology for Wireless Communication Applications", Proc. 2002 IEEE-APS, pp.500-503, San Antonio, TX, June 2002.

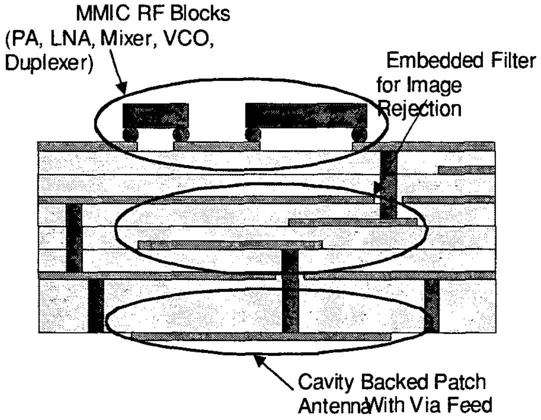

Fig.1 Integrated 3D Multilayer Transceiver

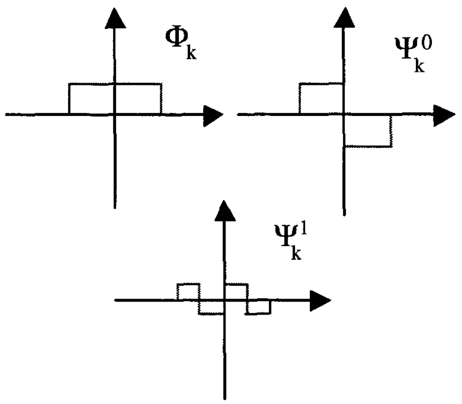

Fig.2 Haar Scaling (Φ) and Wavelet (Ψ)

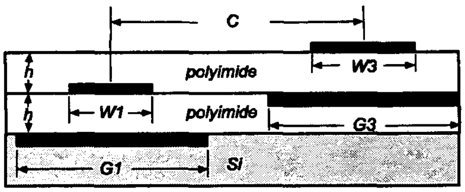

Fig.3 Embedded Finite-Ground Microstrips

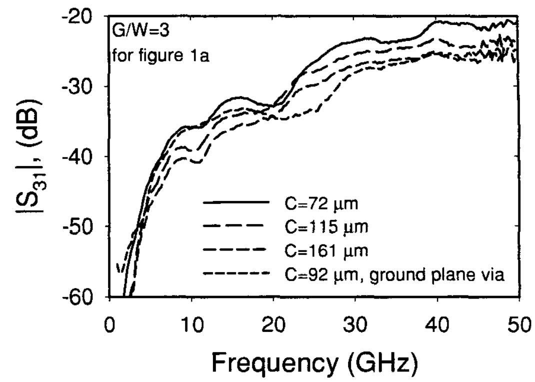

Fig.4 S_{31} for different line separations.

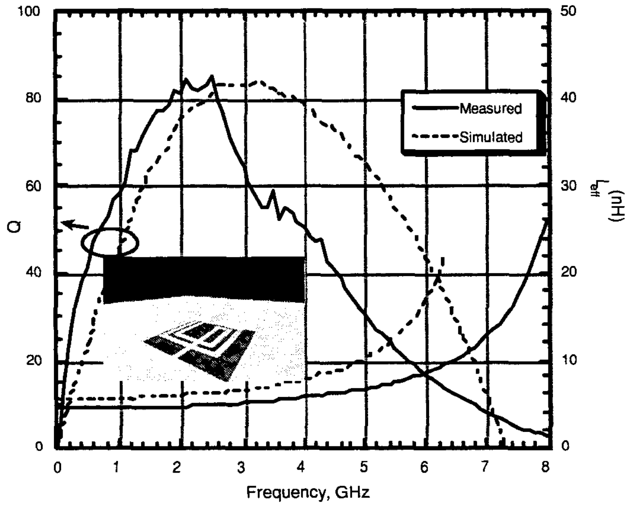

Fig.5 Organic-material Planar Inductor.

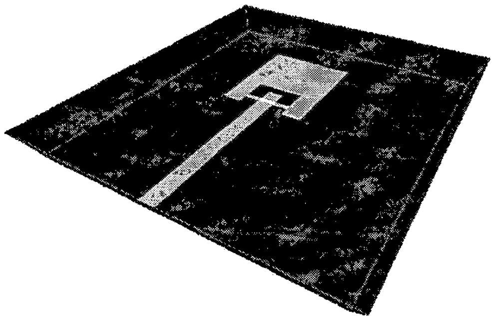

Fig.6 RF-MEMS Switch.

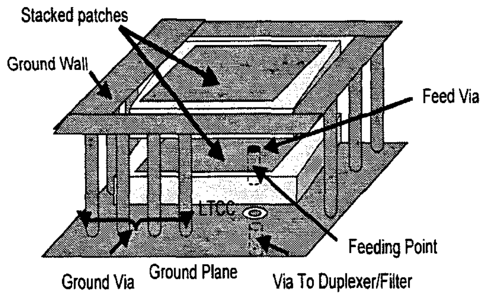

Fig. 7. Stacked patch antenna.

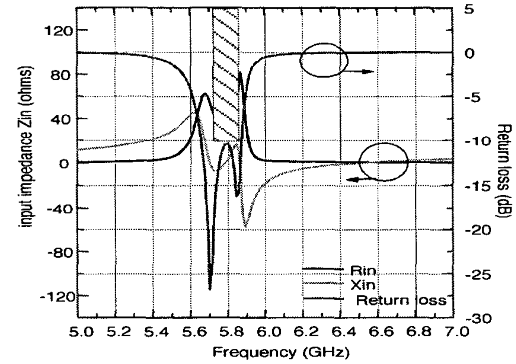

Fig. 8. Input impedance/Return Loss characteristic of the stacked patch