Rigorous Conductor Modeling of Signal Integrity in Integrated Circuits

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The accurate simulation of geometrically complicated electromagnetic (EM) problems with many degrees of freedom is of vital importance in many engineering applications. We present herein a frequency-domain multi-solver domain decomposition method (MS-DDM), and apply it to accurately analyze signal integrity in multi-scale product-level ICs. Instead of using impedance boundary condition to approximate the conductor loss effect, we consider a surface integral equation domain decomposition method (SIE-DDM) for finite conductors modeling in integrated circuits (ICs). In particular, we propose a novel formulation to rigorously account for the conductor loss due to finite conductivities in metals.

The fundamental strategy of the MS-DDM is to decompose the entire computational domain into many subregions based on the local material properties and geometrical features. For the IC application, it is natural to decompose the model into dielectric subregion and conductor subregion. Subsequently, we employ the most suitable computational electromagnetic (CEM) technique for each of the subregions. For the dielectric subregion, finite element (FE) based non-overlapping DDM method is efficient to solve the complex multi-scale EM problem and account for the non-uniform material properties in this subregion. For the conductor region, the skin and proximity effects are significant at high frequencies and the FE method shall require considerable dense volumetric mesh for the high-density subregion. Thus, SIE-DDM is desirable to solve the conductor sub-domains. Each local conductor sub-domain is enclosed by a closed surface and solved individually through the generalized combined field integral equation (GCFIE) with excitations that include radiations coming from all the other sub-domains. The continuities of tangential electric and magnetic fields on the interfaces between touching sub-domains are implicitly enforced via the optimized Robin type transmission conditions (TCs).

To further accelerate the performance of the GCFIE method, a hierarchical multi-level fast multipole method (H-MLFMM) is adopted to accelerate the matrix vector-multiplication (MVP) and reduce memory consumption for the SIE methods, especially for the low frequency and multi-scale problems. We shall present numerical results of IC package problems, and demonstrate the accuracy and flexibility of the proposed MS-DDM.