XRL: A Surface Integral Equation-based Simulator for Resistance and Inductance Extraction

Mingyu Wang* [(1)], PingLiu[(1)] Jihong Gu[(2)] , and Abdulkadir C. Yucel[(3)]
(1) Xpeedic Co., Ltd., Shanghai 201210, China
(2) School of Microelectronics (School of Integrated Circuits), Nanjing University of Science and Technology, Xiaolingwei No.200, Nanjing, Jiangsu, China
(3) School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore

The resistance/inductance (RL) parameters extracted under the magneto-quasi-static (MQS) assumption are crucial for the power/signal integrity studies. To extract these parameters, many simulators have been developed so far. Among those, FastHenry (M. Kamon et al., IEEE Trans. Microw. Theory Techn., 42, 9, 1750-2758, 1994) and VoxHenry (A. C. Yucel et al., IEEE Trans. Microw. Theory Techn., 66, 4, 1723-1735, 2018) simulators solve the volume integral equation (VIE) on filament and voxel discretized structures, respectively. However, their volumetric discretization renders them inefficient when applied to complicated packaging structures. Apart from VIE-based simulators, various surface integral equation (SIE)-based simulators were developed for RL extraction. FastImp (Z. Zhu et al., IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., 24, 7, 981-998, 2005) is a popular wide-band simulator. It leverages pre-corrected fast Fourier transform (pFFT) to accelerate matrix-vector-multiplications (MVMs) but requires a large number of unknowns (around seven times the number of panels used to discretize the structures) to be solved during the solution of SIEs. Recently, a loop analysis-based SIE solver for RL extraction was proposed (Z. Zhu et al., IEEE Trans. Microw. Theory Techn., early access, 2023). However, its equivalent surface impedance (ESI) model is not sufficiently accurate to extract RL at the low-frequency regime.

In this study, an SIE-based simulator for RL extraction, called XRL, is proposed. The proposed XRL solves the SIE after discretizing the conductor surfaces via triangular and rectangular elements. The surface currents on these elements are discretized by novel centroid-midpoint (CM) basis functions. Such basis functions map the current vectors on edges to the panel centers. By doing so, the integrations on the traditional edge-based basis functions are converted to those on the panel-based pulse basis functions. Such conversion allows for reducing the computational requirements of the fast MVMs via pFFT or fast multipole method (FMM) by a factor of 1.5~2. Furthermore, it drastically reduces the matrix-fill time (the execution time of integration), makes the implementation of matrix-fill routines straightforward, and yields remarkably less setup time for the preconditioner. Furthermore, the XRL employs a highly accurate ESI model that ensures the accuracy of RL extraction at the low-frequency regime. Our preliminary results on an example scenario of two parallel $100\mu\text{m}\times100\mu\text{m}$ square coils show that the proposed XRL is even more efficient and accurate than commercial simulators, such as Ansys Q3D. For the relatively same number of panels used to discretize square coils, XRL provides self and mutual inductances and self-resistance with L2 norm errors of 1.11, 0.11, 4.03 (%), respectively, while the errors of those obtained by Q3D are 0.42, 0.58, 8.28 %. While both simulators require the same memory, XRL and Q3D require 28 and 84 seconds for extraction, showing that the proposed XRL requires 3x less computational time than Q3D. In the talk, the implementation details of the proposed XRL and additional numerical examples showing its efficiency and accuracy will be shared.