Session 1A4
Robust and Efficient Electromagnetic Solutions for Large-scale Problems

On the Frequency Barrier of Surface Integral Equations from a Circuit Point of View

Lijun Jiang[1] **and Albert E. Ruehli**[2]

[1]Department of EEE, The University of Hong Kong, China
[2]Department of EMC, The Missouri University of Science and Technology
Rolla, Missouri, USA

Abstract— The failure to provide an accurate low frequency and even DC solution has been a key issue of research for integral equation based formulations. Loop-star techniques were conceived to extend the low frequency limit of SIEs such as EFIE methods. It has successfully improved the low frequency conditioning, but requires complicated graph oriented algorithm. In addition, this approach does not work for DC.

At the same time, the Partial Element Equivalent Circuit (PEEC) approach has been used to solve similar electromagnetic problems for packaging and interconnect applications. It uses the Modified Nodal Analysis (MNA) circuit solver formulation, which is employed in most of Spice circuit solvers. PEEC+MNA not only provide a well conditioned low frequency solution, but also a dc solution. The attached figure shows an equivalent circuit for this simplest PEEC model. Both PEEC and EFIE approaches separates the MoM impedance Z_{ij} into a separate inductance and a capacitance part for the electromagnetic solution. In fact, most important low frequency issues can be observed from this simple circuit. The capacitances will represent open circuits at low frequencies such that the MoM impedances will go to infinity. EFIE mixes the capacitance contribution with that of the inductance, which causes the underflow of the inductance effects. The PEEC method uses Kirchoff's Current Law (KCL) in MNA to enforce the continuity of the current. Both nodal potentials and currents are included as unknowns in PEEC. Hence, PEEC demonstrates much better conditioning than EFIE at the low frequency regime (not DC).

For a meaningful DC solution, two conditions are necessary. First, the losses must be included in the model. This is symbolized by the resistance in series to the inductances. Clearly, at DC, the inductances will become short circuits and the remaining circuit only consists of resistive losses. Second, the solver formulation must be separate the capacitive and inductive circuit such that a solution can be found in spite of the open circuited capacitances. It corresponds the Helmholtz decomposition between the electric field and the magnetic field. For this reason, PEEC use the MNA approach in solving the equations. Again, the key issue is that both the currents and the potentials must be included as unknowns. EFIE completely breaks at DC due to the decomposition.

In the presentation we will include example solutions and matrix condition numbers to support the discussion. Also, we consider the use of RWG basis functions to show that the popular approach can be formulated such that some of the properties of the PEEC method can be inherited to improve EFIE, such as the Augmented EFIE developed by Qian and Chew.