Challenges for Computational Electromagnetics for Low Frequencies

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Full wave electromagnetic simulation of circuits in computer technology is a challenging problem, as it is in the domain where wave physics meets circuit physics, namely, it is the "twilight zone". In this regime, electromagnetic field does not behave fully as waves, but meanwhile, simple circuit theory such as KCL and KVL cannot fully capture the physics of the electromagnetic interaction. In this regime, two kinds of breakdown occur for computational electromagnetics: the low-frequency breakdown due to the inaccuracy in the integral equation, and the low-frequency breakdown in accelerators such as the fast multipole algorithm.

When the size of a geometry structure is much smaller than a wavelength, it is necessary to use a quasi-Helmholtz decomposition of the surface current to preclude the breakdown of the integral equation. Such a decomposition is achieved by using either the loop-tree basis or the loop-star basis for the quasi-Helmholtz decomposition. In this manner, the physics that corresponds the world of the capacitors, and that that corresponds to the world of the inductors can be correctly captured.

When the size of the geometry structure is comparable to wavelength, Rao-Wilton-Glisson (RWG) functions can be used to expand the current on the structure to capture the wave physics. Low-frequency breakdown problem can be delayed by using higher precision calculations when RWG functions are used.

As for the solution accelerator, we have recently proposed the mixed-form fast multipole algorithm that can work seamlessly from static to the microwave regime. It is both accurate and error controllable, as well as being memory efficient. However, there exist structures where both wave physics and circuit physics are important. This could be a large structure with many excruciating details as happens in a computer circuit, but the overall platform size is not small. In that case, it is more expedient to put Huygens' equivalence boxes around each region with fine details, and decouple the exterior problem from the interior problem. This can be regarded as having replaced a region with fine details with an N-port representation. Inside the Huygens' boxes, low-frequency techniques can be used to solve the problem so that low-frequency physics is correctly captured, with the ensuing geometry details. Outside the Huygens' boxes, when wave-like interactions are computed, less number of unknowns is needed to capture the wave physics, but meanwhile, the ability to model fine details is not foregone.