A New Coulomb Gauge Based Electric Field Integral Equation Method

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The electric field integral equation (EFIE) method is one of the most commonly-adopted computational electromagnetic methods. Its popularity stems from the efficient surface triangulation, excellent numerical precision, and the powerful capability of handling open and complex geometries. However, when the frequency tends to zero, the method-of-moment (MoM) solution of EFIE using the Rao-Wilton-Glisson (RWG) basis functions suffers from the low-frequency breakdown, where the contribution from the vector potential is extremely imbalanced with that from the scalar potential. As a result, the matrix representation of EFIE operator is highly ill-conditioned and cannot be inverted reliably and efficiently.

Over the past few years, various approaches have been proposed to overcome the problem. However most existing methods formulate EFIE using the Lorentz-gauge Green's function.

In this paper, an alternative new form of EFIE is proposed by using the Coulomb-gauge Green's function and its quasi-static approximation. Different from the commonly adopted Lorentz-gauge EFIE, the Coulomb-gauge EFIE separates the solenoidal and irrotational surface currents explicitly, which captures inductive and capacitive responses through electrodynamic and electrostatic Green's functions, respectively. With the help of the quasi-static approximation of the Coulomb-gauge Green's function, the Coulomb-gauge EFIE is reformulated with a more elegant mathematical form and suitable to remedy the low-frequency breakdown of the EFIE operator. By applying existing techniques such as the loop-tree decomposition, frequency normalization, and basis rearrangement, the Coulomb-gauge EFIE also can solve the low-frequency problem properly. Through comparative studies between the Lorentz-gauge and Coulomb-gauge EFIE approaches from mathematical, physical and numerical aspects, the Coulomb-gauge EFIE approach shows the capability of solving low-frequency applications and achieves almost the same accuracy and computational costs compared to its Lorentz-gauge counterpart. This work provides a new angle and method for solving low frequency integral equations.