ABSTRACT

CALDERÓN PRECONDITIONERS AND WIDEBAND DECOUPLED INTEGRAL FORMULATIONS

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Integral equations are used to analyze scattering from electromagnetic fields incident upon a perfect electrically conducting (PEC) object. Some common formulations are the electric field integral equation (EFIE), magnetic field integral equation (MFIE), and combined field integral equation (CFIE). Each of these formulations has challenges. The operator in the EFIE is ill-conditioned, and the formulation is non-unique. The operator in the MFIE is well-conditioned, but the formulation is also non-unique. The CFIE (a weighted sum of the EFIE and MFIE) is also ill-conditioned, but the formulation is unique. Due to provable uniqueness, the CFIE is often used in scattering analysis for closed, PEC objects.

One approach to improve conditioning for the CFIE is to use well-known Calderón identities and precondition the EFIE with the EFIE. These identities prove the EFIE operator acting on the EFIE operator is equal to a sequence of second-kind MFIE type operators. The Calderón preconditioner is often constructed with a lossy wavenumber to preserve the uniqueness of the CFIE formulation. The EFIE acting on the EFIE is analytically well-behaved but fraught with difficulties once the equations are discretized using the Method-of-Moments technique. The crux of the problem is the EFIE operator maps a div-conforming function to a curl-conforming function. Quasi-curl-conforming-divergence-conforming basis sets such as Buffa-Christiansen functions are needed to properly discretize the formulation, and these functions require significant, additional computation compared to the divergence-conforming RWG functions often used to
This thesis takes a different starting point to solve the scattering problem for PEC objects. Instead of the CFIE, the decoupled field integral equation (DFIE) and decoupled potential integral equation (DPIE) are used to avoid low-frequency and dense-mesh breakdown, topology breakdown, and resonances (all of which contribute to ill-conditioning) for PECs. Also, the operators in the DPIE and DFIE map curl-conforming functions to curl-conforming functions and divergence-conforming functions to divergence-conforming functions. However, these formulations are not generally well-conditioned at high frequencies.

The primary contribution of this thesis is a new set of Calderón identities which may be used to construct O(N) preconditioners for a unique and wideband well-conditioned formulation of the DPIE or DFIE constrained to PEC objects. The new formulations are accelerable with fast methods like the multi-level fast multipole method (MLFMM) and open the door to quick and accurate computation of scattered fields from multi-scale and electrically large PEC objects using only RWG functions.