Summary

This thesis summarizes doctoral research activities on the development of new stable and accelerated solvers for electromagnetic integral equations and their applications. This work aimed at pushing the applications scenarios of numerical solver based on electromagnetic integral equations to new frontiers. The first phase included analytical and bibliographical research to better understand the issues that are encountered in some application scenarios. The results obtained during this phase have been published in the contribution "Adrian, Dely, Consoli, Merlini, Andriulli, *Electromagnetic integral equations: Insights in conditioning and preconditioning* , (IEEE Open Journal of Antennas and Propagation, 2021)". Electromagnetic integral equations are often solved via the boundary element method (BEM). The BEM has interesting properties that make it one of the most appealing choices between the available numerical methods for electromagnetic scattering problems. Unfortunately, besides its advantages, it also suffers from ill-conditioning of the linear system to be solved. Some of the most relevant sources of ill-conditioning are the low-frequency breakdown, the dense-discretization breakdown, and high-frequency related issues. For this reason, in the work "Merlini, Henry, Consoli, Rahmouni, Dély, Andriulli, *Laplacian Filtered Loop-Star Decompositions and Quasi-Helmholtz Laplacian Filters: Definitions, Analysis, and Efficient Algorithms*, (arXiv:2211.07704, 2022)" we introduced a new class of preconditioners that are capable of simultaneously solving both low-frequency and dense-discretization breakdowns. Some of the numerical results relative to one of the schemes proposed in this work are reported in fig. 1 (fLS labeled curves), where the condition number is low and clearly not varying with frequency nor discretizaion.

Moreover, a new fast direct solver (FDS) for electromagnetic integral equation in the high-frequency regime was developed. In addition to be numerically stable and fast even at very high frequency, the new FDS results in a non-hierarchical skeleton compression of the involved operators. The solver can be efficiently applied to solve the problem for several different excitations. This thesis extends and details the scheme proposed in "Consoli, Henry, Dély, Rahmouni, Guzman, Chhim, Adrian, Merlini, Andriulli, *On the Fast Direct Solution of a Preconditioned Electromagnetic Integral Equation* (International Conference on Electromagnetics in Advanced Applications, 2022)".

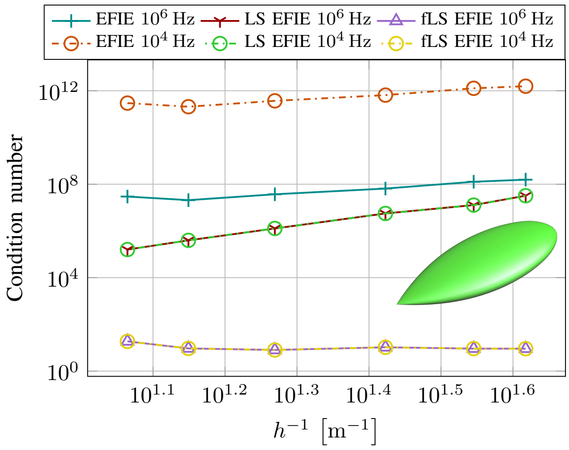

Figure 1: *Condition number of the EFIE, Loop-Star EFIE, and filtered Loop-Star EFIE as a function of discretization on the the NASA almond.*

Finally, among the applications of the developed solvers, a research front that was carried out during the doctoral studies concerns brain-computer interfaces (BCI). Our recent contributions on this front have been presented in "Micheli, Consoli, Merlini, Ricci, Andriulli, *Brain-Computer Interfaces: Investigating the Transition from Visually Evoked to Purely Imagined Steady-State Potential* (Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2022)". The scheme, based on visual imagery signals, overcomes the drawbacks of steady state visually evoked potential (SSVEP) based BCIs that, differently from our paradigm, need external stimuli for their functioning. Our current research on this front includes the creation of a new strategy that, leveraging brain imaging techniques based on electromagnetic integral equation solvers, improves the overall signal-to-noise ratio and, consequently, the accuracy of the BCI (preliminary results of the imaging technique are shown in fig. 2).

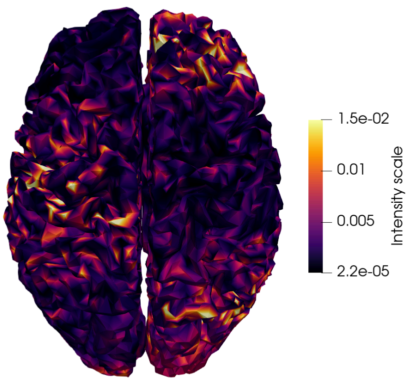

Figure 2: *Dipole activation obtained using ESI techniques on a trial of VI signals.*