Boundary element formulations provide an efficient framework for modelling electromagnetic interactions between sources and observers. By discretizing only the domain boundary, these methods eliminate the need to discretize the surrounding homogeneous medium, significantly reducing the number of unknowns. However, the resulting impedance matrix is dense, often necessitating preconditioning, matrix-vector acceleration techniques, and factorization strategies to enable efficient inversion using iterative or direct solvers. Furthermore, the discretized system may inherit the ill-posedness of the underlying continuous problem, leading to multiple or even non-existent solutions in the presence of noise, thus requiring regularization.

This thesis explores both the theoretical foundations and practical applications of the boundary element method. On the theoretical side, it examines the regularity properties of specific boundary integral operators in the context of their inversion. On the applied side, it introduces novel pseudoinverses for the inverse source problem in electromagnetics and investigates the quasistatic assumption and brain environment modelling—crucial for accurately pseudoinverting the measured electric potentials.

The structure of this thesis is as follows. After outlining the motivation behind this work in Chapter 1, Chapter 2 establishes the theoretical background of classical electromagnetism, with an emphasis on the electro-quasistatic regime and boundary formulations in both two and three dimensions, along with their discretization. Chapter 3 conducts a spectral analysis of key operators in two-dimensional acoustic scattering, examining their quasi-normality on non-circular boundaries—a property related to the convergence of iterative inversion methods and direct diagonalization approaches. Chapter 4 extends this spectral analysis to electromagnetic propagation between an equivalent boundary and an observer domain in the context of the inverse source problem. A novel pseudoinverse incorporating *a priori* constraints is introduced, enhancing the regularization of this otherwise ill-posed problem and improving near-field reconstruction from far-field observations.

Finally, Chapter 5 focuses on source localization in neuroimaging, analyzing low-frequency current propagation. To support the pseudoinversion of the quasistatic problem, the forward model is rigorously examined: the stationary Poisson regime is extended to account for charge effects and validated, the influence of different tissue properties on scalp potentials is assessed, and the significance of realistic geometric modelling is discussed. The conclusion and perspectives of the thesis are presented in Chapter 6.