Contributions to the Characterization of Human Exposure to Low- and High-Frequency Electromagnetic Fields

Abstract of the habilitation thesis

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Electromagnetic fields are omnipresent in daily life, originating both as by-products of electricity generation, transmission and utilization, and as intentional emissions from various communication and broadcasting technologies. Their presence spans a wide frequency range, from static and low-frequency fields generated by power systems, up to radiofrequency and microwave fields used in wireless networks. The study of electromagnetic fields is therefore of dual importance: on one hand, ensuring the proper functioning and electromagnetic compatibility of electronic systems, and on the other hand, assessing and managing human exposure levels in accordance with international safety guidelines. This habilitation thesis summarizes my research contributions in the field of exposure assessment, combining experimental measurements, analytical methods and numerical modelling, with applications ranging from overhead high-voltage power lines (OHVPLs) to wireless communications.

The thesis *Contributions to the Characterization of Human Exposure to Low- and High-Frequency Electromagnetic Fields* is structured into six chapters, accompanied by a comprehensive bibliography of 155 references.

Chapter 1 provides a synthesis of my teaching, professional, and scientific activity at the "Gheorghe Asachi" Technical University of Iasi, covering more than 22 years. It highlights the courses delivered, textbooks published, academic and professional responsibilities, doctoral studies, and especially postdoctoral research, while also emphasizing the visibility and impact of my scientific work through publications, citations, and collaborations.

Chapter 2 summarizes the author's postdoctoral research on the simulation and theoretical characterization of low-frequency electric and magnetic fields generated by OHVPLs. The main contributions include the development of the software tools PowerELT and PowerMAG, designed to calculate the electric and magnetic fields of OHVPLs using a quasi-static analytical approach and capable of rapidly generating accurate lateral profiles and two-dimensional field distributions. Complementary 2D numerical models were also developed for both electric and magnetic fields, using the open-source Finite Element Method Magnetics (FEMM) software – with a proposed method to overcome initial computational limitations in determining the RMS electric field strength – as well as ANSYS Maxwell 2D, employed for advanced, integrated analysis of the two fields, all of them in accordance with standard exposure assessment procedures. Following extensive validation, these

software tools were applied in several studies to characterize exposure levels associated with various OHVPL configurations in the national power system (110 kV, 220 kV, and 400 kV).

Chapter 3 presents, in its first part, an accurate ANSYS Maxwell 2D model for the calculation and analysis of magnetic fields generated by single-core underground power cables with solid bonding (two-point bonded shields), in accordance with standard procedures for human exposure assessment. The model was validated using the analytical program CableMAG, which is based on the Biot-Savart law and the principle of superposition, and incorporates equations derived from IEC 60287-1-1 for calculating induced shield currents. The implementation and validation were carried out for a medium-voltage underground power line (12/20 kV), considering both trefoil and flat configurations, as typically employed in practice. In the second part, numerical and analytical results are presented, including lateral profiles of the magnetic flux density and induced shield currents for the two basic configurations, as well as additional numerical results obtained by extending the finite-element model to two adjacent three-phase circuits, analyzed in both trefoil and flat arrangements. In all cases, the reduction rate of the magnetic field due to induced shield currents was also evaluated.

Chapter 4 summarizes the author's recent research on the design, development, and calibration of dedicated sensors and instruments for the advanced characterization of electric and magnetic fields generated by HVOPLs. The main outcomes emphasize that the two instruments presented, EFS-01 and MAG-3D, provide high sensitivity, wide dynamic range, and an exceptionally flat frequency response, thus enabling accurate assessment of both fields even in environments with significant harmonic content. The EFS-01 electric field sensor (5 Hz – 2 kHz) is designed for simple and flexible operation, functioning either in conjunction with a portable signal analyzer or as part of an automated system, while the MAG-3D virtual gaussmeter (10 Hz – 2 kHz) offers extended measurement capabilities, including interactive magnetic field profiling and data logging, within a compact and user-friendly platform. Experimental measurements performed with these instruments exhibited a high degree of consistency with analytical and numerical simulations, thereby confirming their reliability and applicability across a wide range of exposure assessment scenarios.

Chapter 5 reviews the author's postdoctoral research (2011 – 2019) on the *in situ* assessment of RF electromagnetic fields generated by key communication and broadcasting technologies such as LTE-FDD, LTE-TDD, WiMAX, and DVB-T2. The research was conducted along two complementary directions: (i) the proposal and optimization of methodologies for measuring and evaluating exposure levels associated with these RF technologies; and (ii) the application of these methodologies in extensive *in situ* studies, involving a large number of measurements performed in both outdoor and indoor environments. An additional original study, presented in the final part of this chapter, provides a comprehensive comparative analysis of RF exposure levels recorded by eight fixed broadband monitoring systems installed in seven countries (Romania, Turkey, Spain – two systems, Switzerland, Colombia, Uruguay, and El Salvador). In total, more than 400 active monitoring stations were examined, each covering at least the frequency bands allocated to GSM-900, GSM-1800, and UMTS-2100 mobile communication systems. The results of these studies confirm the general international trend that exposure levels associated with such RF technologies are typically well below the safety limits established by regulatory bodies.

The final chapter outlines the author's strategic directions for academic development, structured along three complementary axes: didactic, professional, and research. At the research level, the focus is on developing research in electromagnetic field exposure assessment, advancing dedicated instrumentation, and strengthening interdisciplinary collaborations.

Throughout my research activity, I have not focused exclusively on the assessment of human exposure to electromagnetic fields. The skills acquired in virtual instrumentation, the solid expertise gained in measuring both electrical and non-electrical quantities, together with my strong interest in electromagnetic compatibility – particularly in EMC testing and measurements – have enabled me to propose and develop solutions within a wide range of research projects (over 30 national and international). In addition, I coordinated two research grants in the field of electromagnetic pollution, awarded through national CNCSIS competitions, and, as a postdoctoral researcher (2011 – 2013), I implemented the project *Evaluation of human exposure to electromagnetic fields in urban areas*, within the PERFORM-ERA project, co-funded by the European Social Fund.

The visibility of my academic activity is supported by 8 textbooks and specialized academic books, 3 book chapters published with renowned academic publishers, 92 scientific papers (44 as first author), and 1 granted patent. These papers include 11 articles in Web of Science journals with impact factor, 10 in journals indexed in other internationally recognized databases, and 50 in the proceedings of international conferences. Overall, 38 of these articles are indexed in the Web of Science database and 64 in Scopus. The visibility of my research is further demonstrated by 224 citations (excluding self-citations) in indexed journals and conference proceedings, as well as by the Hirsch index values reported in the main databases: 14 in Google Scholar, 8 in Web of Science, and 11 in Scopus.

Beginning in April 2020, I assumed the coordination of the Department of Electrical Measurements and Materials at the "Gheorghe Asachi" Technical University of Iasi, in the position of Department Director. Starting in the same year, I also served as co-chair of the International Workshop on Electromagnetic Compatibility and Engineering in Medicine and Biology, a landmark event organized by our faculty. Since 2024, I serve as Director of the Research Center "Metrology, Measurement Systems and Innovative Materials" (METROS), recognized by CNCSIS as a Center of Excellence, and in the same year I was elected to the Board of Directors of the Romanian Association for Electromagnetic Compatibility (ACER) for the 2024 – 2027 mandate, an honorable position within the national EMC community.