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Energy in the heart of EM waves: modelling, measurements and management—Foreword

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Energy in the heart of EM waves: modelling, measurements and management—Foreword

L'énergie au cœur des ondes électromagnétiques : modélisation, mesures et gestion — Avant-propos

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Energy is more relevant than ever: modes of transmission, harvesting, conversion, storage as well as associated materials and systems are interdisciplinary issues in many sectors of activity (mobility, communication, etc.). Electromagnetic waves play an increasing role in the transmission, control and management of energy, both through fundamental aspects, technological developments and analysis tools.

Electromagnetics engineering related to waves involves appropriate numerical modeling and simulation tools for analysis and design. Experimental protocols are simultaneously required to measure electromagnetic fields according to energy levels, frequencies, etc., particularly in case of human exposure considerations and biomedical engineering. Also, management strategies including virtual prototyping and electromagnetic compatibility analysis (EMC) are currently widely adopted in the design of electrical and electronic systems over a wide range of frequencies from DC to hundreds of GHz.

The URSI-France 2023 workshop, organized under the auspices of the French Academy of Sciences, focused on "Energy in the heart of waves". It was jointly organized by SATIE (Information and Energy Technology, Systems and Applications) and GeePs (Group of electrical engineering—Paris). The workshop was held on the campus of CentraleSupélec, in Gif-sur-Yvette (France), from March 21 to March 22, 2023.

The following special issue is organized in 9 papers covering different aspects and challenges related to electromagnetic waves including: modelling, measurement and management.

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This special issue is introduced by an invited "review paper" from Prof. Stavros Koulouridis (University of Patras) dealing with wireless power transfer in biomedical engineering. It presents an analysis of implantable antenna systems using the scattering matrices formalism.

Electromagnetic fields interact with living matter driving an exhaustive research related to human exposure. **A first group of four papers** is related to public exposure to electromagnetic waves including in-situ measurement techniques and dedicated simulation tools. These contributions cover both public area in case of radio-communications systems (5G for example) and industrial workplaces in case of electromagnetic fields radiated by power systems (in the kHz range).

The first paper entitled "*A Simulation Method Suited for the Whole French Territory Electromagnetic Waves* Exposure" and authored by Nicolas Noé, Lydia Sefsouf, Jean-Benoit Dufour, Samuel Carré, Emmanuelle Conil, Nabila Bounoua and Jean-Benoit Agnani presents a dedicated simulation method for the numerical modeling of the whole French territory's exposure to Electromagnetic fields. The method accounts for EMF exposure everywhere (outdoors and inside buildings), while performing fast enough to fulfill operational constraints.

The second paper entitled "*Monitoring of the exposure to electromagnetic fields with autonomous probes installed outdoors in France*" is authored by Ourouk Jawad, Emmanuelle Conil, Jean-Benoît Agnani, Shanshan Wang and Joe Wiart. It draws statistical conclusions on the exposure of the population based on temporal analysis of exposure monitored by autonomous broadband probes. It shows that monitoring probes are able to detect the seasonality of the exposure and provide analysis of correlation between monitoring probes and radio environment.

The third paper entitled "*Extensive 5G measurement campaign to monitor EMF exposure in France*" is authored by Lydia Sefsouf, Emmanuelle Conil and Jean-Benoît Agnani. It focuses on the exposure evolution related to the deployment of 5G on the French national territory during the year 2021. More than 5000 measurements were part of a large exposure monitoring program at nearly 2000 sites.

The fourth paper entitled "*Electromagnetic compatibility of active cardiovascular implants to occupational magnetic field environments: impact of the field direction*" is authored by Lucien Hammen, Lionel Pichon, Yann Le Bihan, Mohamed Bensetti and Gérard Fleury. It presents a new testing method to assess the electromagnetic compatibility method of active implantable medical devices against occupational magnetic field sources. It is based on an experimental approach using a specific test bench able to generate a controlled magnetic field in all space directions up to the high occupational exposure limits between 50 Hz and 3 kHz.

Appropriate 3D modeling approaches and computational methods are required to understand the interaction between electromagnetic fields and the environment and also to design and optimize complex structures. **A second group of four papers** shows dedicated numerical methods and simulation tools for investigations in realistic environments.

The fifth paper entitled "*3D Computation of Lightning Leader Stepped Propagation Inside a Realistic Cloud*" is authored by Philippe Dessante. It studies the propagation of leaders in clouds or toward the ground and structures. It describes a modeling approach involving a macro model and a heuristic based on the electric potential's maximization to find a leader's direction in case of a real cloud space charge repartition.

The sixth paper entitled "*Multi-label classification with deep learning techniques applied to the B-Scan images of GPR*" is authored by Soukayna El Karakhi, Alain Reineix and Christophe Guiffaut. It is related to object detection with ground penetrating radar. It presents a multi-label classification model based on transfer learning and data augmentation dedicated to B-scan images.

The seventh paper entitled "Design and optimization of inductive power transfer systems by metamodeling techniques" is authored by Yao Pei, Lionel Pichon, Mohamed Bensetti and Yann Le Bihan. It addresses wireless power transfer for charging batteries of electric vehicles. It presents

a fast design and optimization methodology of a power transfer systems based of metamodeling techniques.

The eighth paper entitled "*Matching of an observed event and its virtual model in relation to smart theories, coupled models and supervision of complex procedures—A review*" is authored by Adel Razek. It aims to illustrate the nature of the observation–modeling (or real–virtual) link, the importance of the exact model in the matching involved in this link and the use of this link in the supervision of complex procedures via the digital twin concept.

We believe that this Special Issue will provide readers with a valuable opportunity to have an overview of the challenges and progress in the field of electromagnetics and waves. We hope that all contents of this Special Issue demonstrate useful and insightful knowledge to the community.

First, we thank the authors who decided to submit their work and contribute to this Special Issue. Second, we are indebted with anonymous expert reviewers, who devoted considerable time and efforts in the review of the submitted manuscripts, providing always valuable feedback to the authors. Finally, we would like to thank the scientific committee of the URSI-France 2023 workshop for its contribution to the development of the program and the *Comptes Rendus Physique* editorial committee for agreeing to publish this special issue.