

Preface

Classical Electromagnetic Theory and its modern extension known as Computational Electromagnetics (CEM), are the foundation of electrical and electronic engineering and play a key role in the development and design of today's state-of-the-art technology. The rapid evolution and growing sophistication of technology demand ever higher processing speed and device miniaturisation, resulting in major electromagnetic modelling and simulation challenges. During the last four decades, Computational Electromagnetics has continuously evolved in response to these challenges, empowered by the concurrent rise of digital computer technology. Today, CEM is capable of modelling and simulating macro- to nano-devices from low to optical frequencies, whereas the conventional circuit-based theory has limitations at high frequencies and in nano-domain. For accurate design and wide-ranging coverage of applications at different frequencies and sizes, different principles, models and approaches are needed.

We have invited a number of prominent researchers in Computational Electromagnetics to contribute authoritative chapters on the most effective and successful numerical modelling methods for solving electromagnetic problems governed by Maxwell's equations. This book thus covers a comprehensive range of principles and applications, and illustrates past, present and future trends in the field of CEM. The project evolved from a special session titled 'Computational Electromagnetics—Retrospective and Outlook' we organised in honour of Professor Wolfgang J.R. Hoefer at the 2012 Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC), Singapore. The purpose of that session was to celebrate Professor Hoefer's career of 50 years in electromagnetics research.

The book consists of 12 chapters. They cover not only fundamentals and basic principles, but also the modelling of typical structures ranging from nano-scale to large and complex structures, and include hybrid, modified and novel numerical approaches. Multi-scale, multi-physics and nano-device modelling are covered as well, demonstrating the incorporation of quantum and multi-physics effects into Maxwell's equation. Finally, the acceleration of simulation speed through parallel implementation on graphics processing units (GPUs) is discussed. We hope that

these emerging topics in computational electromagnetics will provide some insight into new trends and directions to the reader.

Chapter 1 retraces the 50 years of pioneering research of Professor Wolfgang J.R. Hoefer in the fields of microwaves, electromagnetic fields and computational electromagnetics from an autobiographical perspective. It begins with early work on microwave ferrites at the RWTH Aachen (Germany) and the University of Grenoble (France) during the 1960s. His many activities and the contributions of his research teams during his tenure as a Faculty member at the Universities of Ottawa and Victoria (Canada), and recently at the A-STAR Institute of High Performance Computing (Singapore), form the subject of this personal account.

In Chap. 2, the pioneering work of Professor Hoefer on the transmission line matrix (TLM) method is highlighted. The relation of the TLM method to Christian Huygens' model of light propagation is discussed, and it is shown how the TLM method can be derived from Huygens' model by applying network theory. Furthermore, it is shown how the TLM approach can be embedded in a general discrete-time circuit concept. Examples taken from the field of electromagnetic compatibility (EMC) illustrate the approach.

Chapter 3 presents composite right/left-handed (CRLH) transmission line theory and its importance in the field of computational electromagnetics. In addition, a research history and examples of multilayer (ML) CRLH transmission lines are summarised, and the performance of the latest low temperature co-fired ceramics (LTCC) technology is highlighted. It is also shown that by using this technique, the size of the architecture can be reduced significantly.

Chapter 4 is devoted to the fundamental alternating directional implicit finite difference time domain (FADI-FDTD) approach and its applications to dispersive media. It is also shown how the efficiency of the approach can be further improved. The approach is studied by means of different dispersive models, such as the Debye, Lorentz, Drude and complex conjugate pole-residue pair models.

In Chap. 5, the transient behaviour and radiation performance of printed-circuit antennas for super-wideband (SWB) monitoring applications are investigated by using a time domain solver. Examples of microstrip and co-planar antennas are given for a wide range of operating frequencies (3–30 GHz), and radiation characteristics are studied for different polarisations. The co-planar antenna shows better performance than the microstrip antenna, and therefore the co-planar concept is extended to cover a wider range of applications from 3 to 60 GHz.

Chapter 6 presents a review of recent advances in time domain numerical techniques which allow Maxwell's equation to be solved using non-Cartesian discretisation. Such techniques, also called conformal time domain methods, can be advantageous for geometries comprising curved surfaces and multi-scale features. Two different concepts are studied; the first is a finite-volume time domain (FVTD) method with tetrahedral meshes, while the second highlights meshless methods. These approaches promise to play a significant role in the simulation of multi-scale, multi-physics and conformal problems.

In Chap. 7, a mortar element method is presented. It potentially overcomes the constraints associated with the conventional boundary element methods due to

conformity requirements. It allows local mesh refinement and facilitates scalable parallel computational implementation to achieve shorter computation time and better efficiency when simulating complex structures.

Chapter 8 highlights time domain approaches for modelling and simulation of devices from nano-electronics to nano-photonics. For the simulation of such a wide range of scenarios, various principles and models are incorporated into Maxwell's equations. For example, the Schrödinger equation is incorporated into Maxwell's equations to model nano-electronic and nano-plasmonic devices, and the Lorentz-Drude (LD) dispersive model is incorporated to simulate passive photonics/plasmonic devices, whereas a solid-state model is incorporated to model active nano-photonics/plasmonic devices. LD and solid-state models are hybridised for the simulation of active plasmonic devices. A graphics processing unit (GPU) is used to enhance the simulation speed; some of the described approaches are implemented on GPU and included as examples.

In Chap. 9, some challenging aspects of finite difference methods, such as boundary modelling and higher order convergence, are addressed. Some solutions for dealing with these challenges are proposed, and a perspective of the work that remains to be done is presented.

In Chap. 10, the FDTD and S-MRTD (scaling multi-resolution time-domain) methods are hybridised to exploit the advantages of both techniques. The stability criterion and the dispersion analysis of the hybrid approach are presented. To simulate open structures, a suitable perfectly matched layer (PML) is developed as well.

Chapter 11 presents parametric modelling of electromagnetic (EM) behaviour using neural networks. In addition, the introduction of artificial neural network (ANN) techniques for parametric modelling, training and automatic model generation are also highlighted. This setup can provide fast estimation of EM behaviour during EM optimisation, sensitivity analysis and statistical design, and design optimisation of high-frequency components and EM structures.

In Chap. 12, the theory, design and implementation of the TLM-based simulation tool MEFiSTo-2D classic plus is presented. The performance of MEFiSTo-2D on heterogeneous hardware (GPU + CPU) is discussed. Different aspects of the tool, such as modelling of boundaries, computation of fields, excitation, time steps, scattering parameters, non-linear devices, parallelisation of the tool and implementation on hardware accelerators are highlighted.

The global impact of Professor Hoefer's work is highlighted by the diversity of our contributors' affiliations and nationalities, representing all five continents. Most of the authors, including the Editors, have been directly associated with him for shorter or longer periods during the past 50 years, either as students, research associates, colleagues or collaborators. The total number of students and professionals whose lives and careers he has touched, exceeds by far our list of contributors, and it would be impossible to include contributions or testimony from all of them. However, the following list of distinctions and awards Professor Hoefer has received from his professional peers, illustrates his accomplishments and contributions as a researcher, teacher, mentor, editor and scientific leader:

- Life Fellow of the IEEE (2006)
- Fellow of the IEEE (1991) *for contributions to the modeling and design of passive microwave and millimeter-wave circuits*
- Fellow of the Electromagnetics Academy, MIT, USA (1989)
- Fellow of the British Columbia Advanced Systems Institute (1992)
- Fellow of the Royal Society of Canada (2003)
- Fellow of the German Academy of Science and Engineering (2008)
- Fellow of the Canadian Academy of Engineering (2009)
- Peter B. Johns Prize (1990) *for best paper published in the International Journal of Numerical Modelling*
- Mainstay Award, Applied Computational Electromagnetics Society (2002) *for outstanding promotion and support of the annual ACES conference*
- Distinguished Microwave Lecturer, IEEE MTT Society (2005–2007)
- Distinguished Educator Award, IEEE MTT Society (2006) *for outstanding achievements as an educator, mentor and role model of microwave engineers and engineering students*
- Honorary Doctorate ‘Doktor-Ingenieur h.c.’, Technische Universität München, Germany, (2007) *for extraordinary achievements in the area of electromagnetic field theory*
- A.G.L. McNaughton Gold Medal, IEEE Canada (2009) *in recognition of pioneering research in microwave engineering, computational electromagnetics, and working with industry to develop practical time domain simulators*
- Microwave Pioneer Award, IEEE MTT Society (2011) *for pioneering contributions to time domain computational methods in microwave engineering, in particular the transmission line matrix (TLM) and finite difference time domain (FDTD) methods*
- Most Inspiring Mentor Award, Agency for Science, Technology and Research (A*STAR), Singapore (2012) *in recognition of inspirational and dedicated scientists who have played fundamental roles in nurturing other scientists or scholars*

Professor Hoefer is the author and co-author of over 400 refereed publications in scientific journals and conference proceedings, two books, and six book chapters. Currently, he is Professor Emeritus at the University of Victoria, BC, Canada. He has been an ardent protagonists and pioneer of Computational Electromagnetics since its early beginnings and has made seminal contributions to the field over half a century. We therefore dedicate this book to him.

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