Chapter 1
Introduction

The subject of computation in electricity and magnetism has so advanced in the past 40 years, since the advent of digital computers and thanks to the development of numerical methods, that today it urges and deserves adequate collocation also in curricula for electrical engineering. However, the time allotted to the subject in general is not very large in undergraduate studies, where more emphasis is still usually attributed to circuits and systems than to fields. Moreover, field models are generally not very popular among students, who are by far more familiar with circuit models. Even if one considers the quasi-static case, however, not only is electromagnetism fundamental for people dealing with electric and magnetic devices, but it provides the basis for, e.g. semiconductor device design, bioengineering applications and so forth.

In the authors' opinion, therefore, time has come to present field models in electricity and magnetism, in the frame of an introductory textbook to be used by senior undergraduate or graduate students in the area of electrical and computer engineering. Elementary electromagnetism, basic vector analysis and fundamentals of numerical analysis are assumed to be known subjects.

Having this in mind, the authors have collected the experience they have accumulated in teaching electromagnetic theory at various levels and in different countries; they intend to offer a book on applied electricity and magnetism, describing the problems of calculating electromagnetic fields and the integral parameters connected with them in sufficiently clear and short form.

The aim is that of writing a textbook containing the necessary background, i.e. laws explaining electromagnetic phenomena, mathematical operators and equations as well as methods for electromagnetic field calculation. The latter include both analytical and numerical methods applied to the analysis as well as to the synthesis of electromagnetic devices.

Classical analytical methods are first presented and closed-form solutions to some problems are obtained by making the simplifying assumptions required. Numerical methods are then discussed and it is shown how they are able to provide a solution to practically any complicated problem. Special emphasis, among the numerical schemes, is attributed to the finite element method because it is largely and commonly used for field simulation. A peculiar feature of the book is the fact that the accent

is always put on field vectors rather than potentials, because the former represent the quantity of main physical interest; consequently, the differential formulation of Maxwell's equations is preferred with respect to the integral one. An effort is accordingly made to develop both analytical and numerical methods for solving the electromagnetic problem in terms of field components directly.

Chapter 2 starts with a basic introduction to the world of vector fields. The reader is guided through definitions, properties, theorems and equations in simply connected domains, both bounded and unbounded. Scalar and vector potentials associated to fields are presented as well. Then electric, magnetic and conduction fields under steady conditions are considered separately.

Chapter 3 presents the most common analytical methods for solving boundary-value problems which are applicable to simple domains.

For more complicated domains, numerical methods are required. Accordingly, Chapter 4 deals with the finite-element method which has become the most general and powerful method to solve field problems in these domains.

A general introduction to time-varying electromagnetic fields is presented in Chapter 5, where Maxwell's equations are presented and solved in some fundamental cases.

Finally, in Chapters 6 and 7 the authors move from direct to inverse problems, which in the past decade have increasingly attracted the attention not just of researchers but also of practitioners in the field of electricity and magnetism. Nowadays, in fact, the association of powerful low-price and high-speed computers with available advanced numerical methods makes it possible to try solutions for inverse problems of various kind, with the ultimate target of offering engineers the possibility of implementing the so-called automated optimal design. In these two chapters, after giving definitions and a general presentation of the background, strategies to solve inverse problems are presented and some case studies are solved.

Throughout the book theoretical concepts are illustrated by practical examples, following a problem-solving approach and never forgetting that the engineering task is just that of formulating and solving electromagnetic problems in a computational fashion. It has been decided, in particular, to solve a single test problem by different methods so that, from the comparison, limitations and advantages of each approach are made clear.

The book is mainly recommended and addressed to undergraduate and graduate students of electrical and computer engineering; however, it could also be helpful for students preparing their Ph.D. projects, as well as for researchers and engineers working in the broad area of electromagnetism. Finally the book, although written by the authors who had in mind their own students in Italy and Poland, is intended hopefully to be valid for a wider international audience.

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