

Electromagnetic Field Theory Fundamentals

Guru and Hiziroğlu have produced an accessible and user-friendly text on electromagnetics that will appeal to both students and lecturers teaching this course. This lively book includes many worked examples and problems in every chapter, as well as chapter summaries and background revision material where appropriate. The book introduces undergraduate students to the basic concepts of electrostatic and magnetostatic fields, before moving on to cover Maxwell's equations, propagation, transmission, and radiation. Sections on the finite element and finite difference method, and a detailed appendix on the Smith chart, are additional enhancements.

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Frontmatter
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SECOND EDITION

**Bhag Singh Guru and
Hüseyin R. Hiziroğlu**

Kettering University



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Preface

Electromagnetic field theory has been and will continue to be one of the most important fundamental courses of the electrical engineering curriculum. It is one of the best-established general theories that provides explanations and solutions to intricate electrical engineering problems when other theories are no longer applicable.

This book is intended as a basic text for a two-semester sequence for undergraduate students desiring a fundamental comprehension of electromagnetic fields. The text can also be used for a one-semester course as long as the topics omitted neither result in any loss of continuity of the subject matter nor hamper the student’s preparation for the courses that follows. This text may also serve as a reference for students preparing for an advanced course in electromagnetic fields.

The first edition of this book appeared in 1998 and was well accepted by both the students and the faculty. Among the numerous comments we received from the students, the one that transcends the others is that the book is written in simple, everyday language so that anyone can easily understand even the most sophisticated concepts of electromagnetic fields. We attribute such a favorable comment to the fact that the book was written from first-hand experience of class-room teaching. The development of this second edition also follows the same time-tested approach.

A thorough understanding of vector analysis is required to comprehend electromagnetic theory in a logical manner. Without much exaggeration, we can say that vector analysis is the backbone of the mathematical formulation of electromagnetic field theory. Therefore, a complete grasp of vector analysis is crucial to the comprehension of electromagnetic fields. In order to ensure that every reader begins with essentially the same level of understanding of vectors, we have devoted an entire chapter, Chapter 2, to the study of vector analysis. A great deal of emphasis is placed upon the coordinate transformations and various theorems.

In the development and application of electromagnetic field theory, the student is expected to recall from his/her memory various mathematical relationships. To help those who fail to recall some of the required mathematical formulas, we have included enough information

in Appendix C on trigonometric identities, series, and integral calculus, etc.

A quick glance at the table of contents reveals that the text may be divided into two parts. The first part, which can be covered during the first semester for a two-semester sequence, introduces the students to static fields such as electrostatic fields (Chapter 3), magnetostatic fields (Chapter 5), and fields due to steady currents (Chapter 4). Because most of the applications of static fields involve both electric and magnetic fields, we decided to present such applications in one chapter (Chapter 6). We are also of the opinion that once the students grasp the basics of static fields, they can study the applications with a minimum of guidance. If time permits, the development of Maxwell's equations in both the time domain and the frequency (phasor) domain can be included in the first part of the course. This material is presented in Chapter 7, where the emphasis is laid upon the coexistence of time-varying electric and magnetic fields and the concept of average power density. Also included in this chapter are some of the applications of the time-varying fields in the area of electrical machines and transformers.

The rest of the book provides the subject matter for the second semester in a two-semester sequence, which deals with the propagation, transmission, and radiation of electromagnetic fields in a medium under various constraints. A chapter-by-chapter explanation follows.

The development of wave equation and its solution that provides an inkling of wave propagation are discussed in Chapter 8. Also explained in this chapter are the reflection and transmission of the waves at normal and oblique incidences. The wave may have perpendicular or parallel polarization. The wave incidence may involve an interface between the two conductors, the two dielectrics, a conductor and a dielectric, or a dielectric and a perfect conductor.

The transmission of energy along the transmission lines is covered in Chapter 9. Instead of postulating a distributed equivalent circuit for a transmission line, we used field theory to justify the use of such a model. The wave equations in terms of the voltages and the currents along the length of transmission line are then developed and their solutions are provided. In order to minimize reflections on the transmission line, impedance matching with the stubs is explained. Lattice diagrams are used to explain the transient behavior of transmission lines. Although the Smith chart provides a visual picture of what is happening along a transmission line, we still feel that it is basically a transmission-line calculator. We can now use pocket calculators and computers to obtain exact information on the line. For this reason, we have placed the Smith chart and its applications in Appendix A.

The propagation of guided waves within the rectangular cross-section of a waveguide is covered in Chapter 10. The conditions for the existence of transverse electric (TE) and transverse magnetic (TM) modes

are emphasized. Power flow in a rectangular waveguide under various conditions is also analyzed. Also explained in this chapter are the necessary conditions for the existence of fields inside a cavity and the use of a cavity as a frequency meter.

The radiation of electromagnetic waves is the subject matter of Chapter 11. The wave equations in terms of potential functions are developed and their solutions are sought for various types of antennas. The concepts of near-zone and radiation fields are explained. Also discussed in this chapter are the directive gain and directivity of a transmitting antenna, receiving antenna and Friis equation, the radar operation and the Doppler effect.

Chapter 12 covers the computer-aided analysis of electromagnetic fields. Some of the commonly used methods discussed in this chapter are the finite-difference method, the finite-element method, and the method of moments. Computer programs based upon these methods are included in Appendix B.

Our aim was to write a detailed student-oriented book. The success of first edition attests that we have succeeded in our mission. The first edition has already been translated into two foreign languages: Chinese and Korean. We hope that this second edition will also be accepted both by the students and faculty with the same zeal and zest as the first. Our goal has been and still is to present the material in such a way that a student can comprehend it with a minimum of help from instructors. To this end, we have carefully placed numerous worked examples with full details in each chapter. These examples, clearly delineated from the textual matter, not only enhance appreciation of a concept or a physical law but also bridge the perceived gap, real or otherwise, between a formal theoretical development and its applications. We opine that examples are necessary for immediate reinforcement and further clarification of a topic. Near the end of each chapter, we have included some easy questions under the heading of “Exercises” whose answers depend upon the direct applications of the concepts covered in each section. We believe that these exercises will help to impart motivation, nurture confidence, and heighten the understanding of the material presented in each chapter. In addition, there are problems at the end of each chapter that are designed to offer a wide range of challenges to the student. The exercises and the problems are an important part of the text and form an integral part of the study of electromagnetic fields. We suggest that the student should use basic laws and intuitive reasoning to obtain answers to these exercises and problems. The practice of such problem-solving techniques instills not only confidence but also empowers a student to tackle more difficult, albeit real-life, problems. Each chapter ends with a summary as well as a set of review questions. Some of the important equations are included in the summary for an easy reference. The review questions are tailored to ensure that a student has taken to heart

the basics of the material presented in that chapter. Once again, we have endeavored very hard to make this book as student friendly as possible and we welcome any suggestions in this regard.

Our experience points out that the students tend to view the theoretical development as an abstraction and place emphasis on some equations, treating them as “formulas”. Soon frustrations set in as the students find that the so-called formulas are different, not only for different media but also for different configurations. The array of equations needed to compute just one field quantity intimidates them to the extent that they lose interest in the material. It then just another “difficult” course that they must pass to satisfy the requirements of a degree in electrical engineering. We believe that it is the instructor’s responsibility to

- explain the aim of each development,
- justify the assumptions imperative to the development at hand,
- emphasize its limitations,
- highlight the influence of the medium,
- illustrate the impact of geometry on an equation, and
- point to some of its applications.

To attain these goals, instructors must use their own experiences in the subject and also emphasize other areas of application. They must also stress any new developments in the field while they are discussing the fundamentals. For example, while explaining the magnetic force between two current-carrying conductors, an instructor can discuss magnetically levitated vehicles. Likewise, an instructor can shed light upon the design of a microwave oven while discussing a cavity resonator.

When the subject matter is explained properly and the related equations are developed from the basic laws, the student then learns to

- appreciate the theoretical development,
- forsake intimidation,
- regain motivation and confidence, and
- grasp the power of reasoning to develop new ideas.

Whatever we have presented in this second edition, we have done so according to our own convictions and understanding of the subject matter. It is quite possible that while stating and explaining our points of view, we may have said something that may conflict with your views, for which we seek your candid opinion and constructive criticism. If your point of view helps sway our minds, we will surely include it in a revised edition of this book. For this reason, your input is highly valuable to us.

Acknowledgments

We are deeply grateful for all the help we received from Dr. A. Haq Qureshi during the development of the first edition of this book. His mastery of the subject and the yearning for its clear and accurate presentation had direct impact upon the success of the first edition. We are much beholden to reviewers of both editions for their invaluable suggestions and constructive criticisms. We are most appreciative of the following persons and their establishments for providing us various photographs that are reproduced in this book: Ellen Modock (Keithley Instruments, Cleveland, Ohio), Bernard Surtz (Andrew Corporation, Orlando Park, Illinois), Bruce Whitney (Detroit Edition, Detroit, Michigan), Homer Bartlett (Microstar Inc. Florida), and Jeremiah Chambers (Space Machine & Engineering Corp., Florida).

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