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ELEMENTS OF ENGINEERING ELECTROMAGNETICS

FIFTH EDITION

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ELEMENTS OF ENGINEERING ELECTROMAGNETICS

FIFTH EDITION

Om Shri Ganeshaya Namaha

In deep appreciation of
the profound influence on my professional career
by the late Edward C. Jordan (1910–1991),
renowned author of the famous text book,
"Electromagnetic Waves and Radiating Systems,"
first published in 1950 by Prentice Hall,
and revered head of my department
for 25 years (1954–1979).

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Preface

Electromagnetics textbooks and this edition

The introductory textbooks on engineering electromagnetics can be classified broadly into three categories:

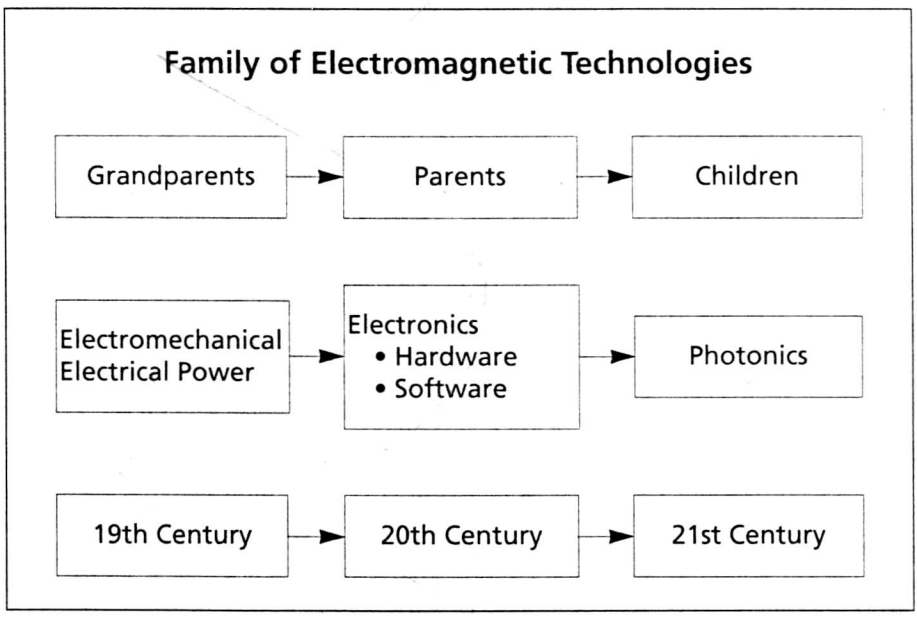
1. One-semester textbooks based on the traditional approach, covering essentially electrostatics and magnetostatics and culminating in Maxwell's equations with some discussion of their applications.
2. Two-semester textbooks with the first half or more covering electrostatics and magnetostatics as in category 1 and the remainder devoted to topics associated with electromagnetic waves.
3. One- or two-semester textbooks that have deviated from the traditional approach with the degree and nature of deviation depending on the author.

The bulk of the textbooks fall into categories 1 and 2, and only a small minority, including this book, belong to category 3. The deviation from the traditional approach originated with the first edition, a one-semester text with the basic material built up on time-varying fields and their engineering applications so as to enhance its utility for the one-semester student of engineering electromagnetics, while enabling the student to take further (elective) courses in electromagnetics to learn many of the same field concepts and mathematical tools provided by the traditional treatment. In preparing the second edition, a major revision of the first edition was undertaken by expanding the text for one- or two-semester usage to provide flexibility, while preserving the basic philosophy of the first edition, arising from the assertion that as a prerequisite to the first EE course in fields, most schools have an engineering physics course in which the students are exposed to the historical treatment of electricity and magnetism. Subsequent editions have further enhanced the usage by incorporating changes and adding material to satisfy the prerequisite needs pertinent to emerging technologies. For example, the substantial changes leading to the fourth edition have been prompted by the increasing need for coverage of material at the introductory level for application beyond the microwave region into the optical regime

of the electromagnetic spectrum with the advent of the era of photonics overlapping with that of electronics.

Electromagnetic technologies

In preparing this fifth edition, I have carried the deviation from the traditional approach even further as we are nearing the end of the twentieth century and approaching the dawn of the twenty-first century. To put this in proper perspective, reference is made to the article by Anthony DeMaria,[1] which describes how in the family tree of major technologies that are based on Maxwell's equations, nineteenth century electrically and magnetically based technologies (electromechanics) may be viewed as the grandparents, twentieth century electronics hardware and software as the parents, and the subgroups of the twenty-first century photonics technology as the children, as illustrated in the following diagram (© 1991 IEEE):



Thus, in this edition, I have reorganized the material of the fourth edition and added topics to associate chapters or parts of chapters with the blocks in the family of electromagnetic technologies. To do this, I have divided the book into two parts. Part I, entitled "Fundamental Elements," comprises the first five chapters:

1. Vectors and Fields
2. Fields and materials
3. Maxwell's Equations in Integral form and Boundary Conditions

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[1]Anthony J. DeMaria, "Maxwell's Children Light the Way," *IEEE Circuits and Devices Magazine*, vol. 7, No. 2, March 1991, pp. 36–43.

4. Maxwell's Equations in Differential Form, Potential Functions, and Energy Storage
5. Uniform Plane Waves and Power Flow in an Electromagnetic Field

These chapters are the same as Chapters 1, 2, 3, 4, and 6, respectively, of the fourth edition. Note that the chapter on uniform plane waves is considered to be fundamental (instead of an application of Maxwell's equations) and immediately follows the chapters on Maxwell's equations. Part II, entitled "Applied Elements," comprises the remaining seven chapters:

6. Field and Line Essentials for Digital Electronics
7. Transmission Lines for Communications
8. Topics in Electric- and Magnetic-Field Systems
9. Guided Wave Principles for Electronics and Optoelectronics
10. Several Topics for Electronics and Photonics
11. Principles of Radiation and Antennas
12. Topics in Numerical Electromagnetics

These chapters constitute a reorganization of the material of Chapters 5, 7, 8, 9, 10, and 11 of the fourth edition with a few additional topics included to provide the coverage to achieve the stated goal, as evident from the titles of the chapters.

Thread of development of material

Thus, some of the salient features of the thread of development of the material, evident from a reading of the table of contents, are the following:

1. Introduces basic concepts of vectors and fields for static as well as time-varying cases at the outset and vector calculus concepts later as needed.
2. Discusses materials following the presentation of electric- and magnetic-field concepts prior to the study of Maxwell's equations.
3. Introduces collectively Maxwell's equations for time-varying fields, first in integral form and then in differential form.
4. Considers boundary conditions following Maxwell's equations in integral form, and potential functions and associated equations following Maxwell's equations in differential form.
5. Obtains uniform plane wave solutions by considering the infinite plane current sheet source first in free space and then in a material medium.
6. Provides continuous coverage of field and line topics essential for digital electronics, beginning with p–n junction and circuit elements and progressing through transmission-line time-domain analysis leading to interconnections between logic gates and culminating in crosstalk on transmission lines.
7. Presents the sinusoidal steady-state analysis of transmission lines comprising the topics of standing waves, resonance, power transfer, and matching with emphasis on computer and graphical solutions.
8. Introduces quasistatic approximations of Maxwell's equations as the basis for electric- and magnetic-field systems, important for the study of electromechanics, and considers other topics pertinent to electromechanical systems.

9. Develops principles of guided waves for both electronics and optoelectronics by confining the treatment to one-dimensional waveguides comprising parallel-plate metallic waveguides followed by dielectric slab waveguides.
10. Devotes a chapter to several topics pertinent to electronics and photonics, including two-dimensional metallic waveguides and optical fibers, pulse broadening due to dispersion, interference and diffraction, and wave propagation in an anisotropic medium.
11. Introduces radiation by obtaining the complete field solution to the Hertzian dipole field through the magnetic vector potential, and then develops the basic concepts of antennas.
12. Devotes a chapter to numerical methods comprising the finite-difference method, the method of moments, the finite-element method, and the finite-difference time-domain method, including their formulation and application to the solution of electromagnetic field problems.

While the entire book can be used for a two-semester course sequence, this edition incorporates flexibility to facilitate its adoption for a one-semester course of content depending on the background preparation for the course and the needs of the curriculum, as in the case of the second, third, and fourth editions. Specifically, this edition addresses the needs of a first course required for electrical engineering students as well as computer engineering students, and more useful than the traditional treatment, followed by one or more required or elective courses for electrical engineering students, that build up on the first course. Chapters 3 through 6 constitute the core material for this course, with Chapter 2 serving as a review or an enhancement of what the students already learn in the sophomore physics course on electricity and magnetism.

Teaching and learning aids

As in the previous editions, a number of teaching and learning aids are employed: (1) examples distributed throughout the text, (2) discussions of practical applications of field concepts and phenomena interspersed among presentations of basic subject matter, (3) descriptions of brief experimental demonstrations suitable for presentation in the classroom, (4) summary of material and review questions (**Q**) for each chapter, (5) inclusion of drill problems (**D**) at the end of each section, (6) marginal notes, and (7) keywords (**K**) at the end of each section. I have omitted the PC program listings in BASIC but retained the details pertinent to the computations and the results. New to this edition are review problems (**R**) at the end of each chapter, following the homework problems (**P**). For the book, there are a total of 105 Examples, 162 **D** Problems, 426 **P** Problems, 415 **Q** Questions, and 80 **R** Problems. Answers are provided for 40 % of the **P** Problems.

Acknowledgment

I wish to express my appreciation to the many colleagues at the University of Illinois at Urbana–Champaign who have taught from the previous editions of the book during the period from 1977 to 1998. Listed in alphabetical order are J. Bernhard, M.T. Birand, D.J. Brady, A. Cangellaris, K.Y. Cheng, W.C. Chew, S.L. Chuang, D.H. Cooper, K. Coperich, C. Daft, T.A. DeTemple, M. Feng, S.J. Franke, S. Fridman, L.A. Frizzell, S.D. Gedney, R. Gilbert, S. Gnanalingam, Y. Gu, K.C. Hsieh, S. Iyer, J. Joseph, K. Kim, P.W. Klock, J. Kolodzey, E. Kudeki,

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About the dedication

The first part of the dedication offering Salutations to Lord Ganesha was inspired in part by my visit in January 1999 to the Bandung Institute of Technology, Bandung, Indonesia, where the Image of Ganesha adorns the entrance to the Institute on Jalan Ganesha. With reference to the second part of the dedication pertaining to the profound influence on my professional career by the late E.C. Jordan, I also wish to express my appreciation for the opportunities provided to me by my department heads G.W. Swenson, Jr., E.W. Ernst, T.N. Trick, and S.M. Kang, following his tenure.

N. Narayana Rao

Urbana, Illinois
February 1999

About the Author

Nannapaneni Narayana Rao was born in Kakumanu, Guntur District, Andhra Pradesh, India. Prior to coming to the United States in 1958, he received a B. Sc. degree in physics from the University of Madras in 1952 and a Diploma in Electronics from the Madras Institute of Technology in 1955. In the United States, he attended the University of Washington, receiving M.S. and Ph.D. degrees in Electrical Engineering in 1960 and 1965, respectively. In 1965, he joined the faculty of the Department of Electrical Engineering, now the Department of Electrical and Computer Engineering, of the University of Illinois at Urbana–Champaign, where he carried out research in the general area of ionospheric propagation and authored the undergraduate textbook *Basic Electromagnetics with Applications* (Prentice Hall, 1972), prior to the four previous editions of this book (1977, 1987, 1991, and 1994).

Professor Rao has received numerous awards and honors for his teaching and curricular activities. These include the first Award in Engineering in 1983 from the Telugu Association of North America, an association of Telugu-speaking people of origin in the State of Andhra Pradesh, India, with the citation, "Dedicated teacher and outstanding contributor to electromagnetics"; a plaque of highest appreciation from the Faculty of Technology, University of Indonesia in Jakarta, for curriculum development in 1985–1986; the Campus Undergraduate Instructional Awards in 1982 and 1988, the Everitt Award for Teaching Excellence from the College of Engineering in 1987, the Campus Award for Teaching Excellence and the first Oakley Award for Innovation in Instruction in 1989, and the Halliburton Award for Engineering Education Leadership from the College of Engineering in 1991, all at the University of Illinois at Urbana–Champaign; election to the Fellow grade of the Institute of Electrical and Electronics Engineers (IEEE) in 1989 for contributions to electrical engineering education and ionospheric propagation; the AT&T Foundation Award for Excellence in Instruction of Engineering Students from the Illinois–Indiana Section of the American Society for Engineering Education

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(ASEE) in 1991; the ASEE Centennial Certificate in 1993 for exceptional contribution to the ASEE and the profession of engineering; and the IEEE Technical Field Award in Undergraduate Teaching in 1994 with the citation, "For inspirational teaching of undergraduate students and the development of innovative instructional materials for teaching courses in electromagnetics."

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PART ONE

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