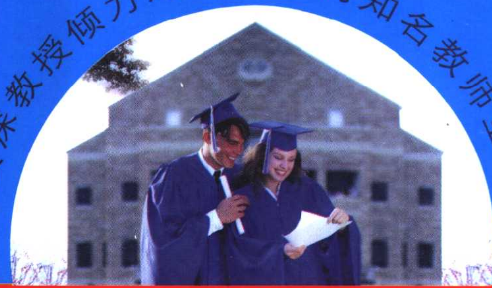
国外资深教授倾力之作　国内知名教师全力推荐

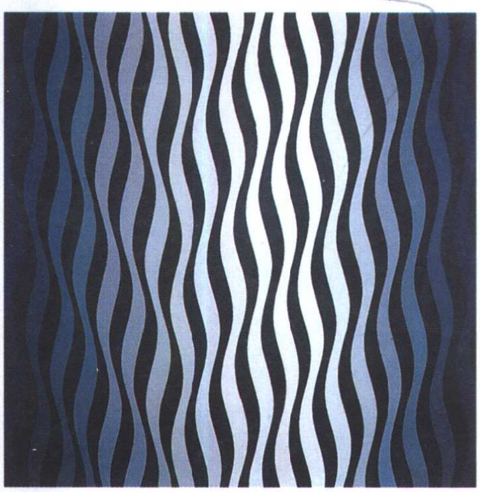


国外高校电子信息类优秀教材

工程电磁学

Engineering Electromagnetics

（英文影印版）



Kenneth R. Demarest 著

科学出版社
www.sciencep.com

Pearson Education

国外高校电子信息类优秀教材(英文影印版)

工程电磁学

Engineering Electromagnetics

Kenneth R. Demarest 著

科学出版社
北京

内 容 简 介

本书为国外高校电子信息类优秀教材(英文影印版)之一。

本书基于物理方法,讲述了电磁学的理论和基本公式,包括:矢量分析,电磁源、电磁力和电磁场,自由空间中的电场,介质中的电场,电容和电能,自由空间中的磁场,介质中的磁场,磁感应系数、磁能和磁力,时分电磁场,传输线,平面波,波导,辐射和天线。书中还介绍了如何将它们应用于工程实践。

本书可作为电子工程、通信专业本科生教材,也可作为工程技术人员的参考书。

图字:01-2002-5986

图书在版编目(CIP)数据

工程电磁学/(美)德马雷斯特(Demarest, K. R.)著.—影印本.—北京:科学出版社,2003

(国外高校电子信息类优秀教材)

ISBN 7-03-011148-6

Ⅰ.工… Ⅱ.德… Ⅲ.电磁学-高等学校-教材-英文 Ⅳ.O441

中国版本图书馆 CIP 数据核字(2003)第 005584 号

责任编辑:巴建芬 李 宇/封面设计:黄华斌 陈 敬/责任印制:刘秀平

科学出版社 出版
北京东黄城根北街16号
邮政编码:100717
http://www.sciencep.com

源海印刷有限责任公司 印刷
科学出版社发行 各地新华书店经销

*

2003年3月第 一 版 开本:787×1092 1/16
2003年3月第一次印刷 印张:43 1/4
印数:1—3 000 字数:1 001 000

定价:48.00元

(如有印装质量问题,我社负责调换〈环伟〉)

国外高校电子信息类优秀教材(英文影印版)

丛 书 编 委 会

(按姓氏笔画排序)

Preface

I. Why I wrote this text

This book is about my favorite academic subject: electromagnetics.

The genesis of this book goes back to a student get-together I attended during the third year of my teaching career. I struck up a conversation with a good student who had taken an introductory electromagnetics course from me the previous semester. When I asked him what he remembered from the course, he very politely told me that he really couldn't remember much, except that it involved a lot of mathematics and theory. Worst of all, he seemed unaware of any way in which the material in that course would apply to his career as an electrical engineer. Apparently, he had gotten the message that, outside of "niche" areas like antennas, electromagnetics had little to do with the practice of electrical engineering.

This conversation caused me to do some serious soul searching about the way I had been teaching electromagnetics. In the end, I concluded that this student had been largely correct. While I had very accurately presented the laws of electromagnetics, I made no particular effort to integrate the material into the larger context of electrical engineering. My class in electomagnetics was probably not too different from the one taught across campus in the physics department. Given this, many of my students were convinced that electromagnetics was relevant to their careers in electrical engineering only because they needed to pass the course in order to obtain a degree.

In reviewing a selection of electromagnetics textbooks intended for electrical engineers, I realized that the problem was more than just my own teaching style. Upon closer examination, I concluded that most of these textbooks could be divided into two classes. Textbooks in the first class tended to integrate electromagnetics nicely into engineering practice, but were often technically weak. On the other hand, textbooks in the second class typically gave solid, mathematically oriented discussions of electromagnetic theory, but little or no physical insight or engineering application.

As my teaching skills matured, I gradually found ways to convince my students that electromagnetic theory connects with all aspects of electrical engineering, while still approaching the material with the rigor needed for solving real problems. For instance, I found that students are more apt to see the relevance of electromagnetics when I remind them that the job of an electrical engineer is to constrain electric and magnetic fields so that they perform a desired task. This way of thinking is just as applicable for computer circuit designers as it is for antenna and microwave engineers.

I also found that topics that motivated the past generation of students to think seriously about electromagnetics no longer have the same resonance with the current generation. Topics like antennas and radar, while still extremely important in engineering practice, don't touch these students lives as much as computers and consumer electronics do. Fortunately, there are a whole range of new topics that work just as well as the old ones. As an example, students quickly take notice when it is pointed out to them that the motherboard of their PC, while a digital system, is in many ways a microwave network. Even better is to show them how electrical interference between digital networks is a major safety and economic issue that can only be solved using electromagnetic techniques.

This textbook represents my vision of how to present electromagnetics to undergraduate students - one that emphasizes the physical processes and applications of electromagnetics in engineering, while at the same time presenting the material with the rigor necessary to approach real problems in engineering practice.

II. Features of This Text

Once I started writing, I discovered that a project of this magnitude appears to take on a life of its own. Although my goals for the text remained fixed, the features of the book went through a metamorphosis as the years of writing and testing in the classroom unfolded. What finally grew out of this process was a text that I feel is readable and understandable for the student, easy to integrate in the classroom, and, possibly most important, displays electromagnetics as a mainstream subject in electrical engineering.

1. This text presents electromagnetics using what most would consider a modified "traditional" or "historical" approach. After a brief overview (see point 3), static electric and magnetic fields are presented separately, followed by the time-varying case. This approach provides the greatest insight into the physical relevance of electromagnetics and allows students to grapple with electric and magnetic fields separately, before tackling the more difficult time-varying case.

2. Whenever possible, concepts and results are presented both mathematically and in plain English. My experience has shown that instructors usually prefer purely mathematical developments, but students like (and often need) word descriptions to give meaning to these developments. In addition, these physical descriptions help develop the student's engineering intuition. This is important for the students transition into engineering practice, where the problems don't look like textbook problems.
3. Chapter 3, "Sources, Forces, and Fields" provides a broad overview of the experiments and theories that led up to the definitive equations of electromagnetics—Maxwell's equations. This chapter is designed to show the basic connections between electromagnetic sources and the fields and forces they produce. The physical laws are presented in their historical order, culminating in Maxwell's equations.
4. Chapters 4–6 and 7–9 present electric and magnetic fields in parallel fashion. Each sequence starts with fields in free space, followed by material effects, and finally energy relations. This parallel construction allows students to see clearly what is similar and dissimilar about low-frequency electric and magnetic fields.
5. Graphical solution techniques are presented for both low frequency electric and magnetic fields. These techniques are useful in gaining insight into many practical problems and are also fun.
6. Unlike most traditional texts, this text presents transmission lines *before* plane waves. I have done this for two reasons. The first is that students find it easier to make the transition into propagating waves by first considering scalar voltage and current waves. Once these scalar waves are mastered, the jump into the more general case of space waves is easier. The second reason is that this choice makes it easier to introduce network-analyzer based laboratory experiments in conjunction with the last 4 chapters (transmission lines, plane waves, waveguides, and antennas and radiation).
7. Chapter 11, "Transmission Lines," covers both time-varying and frequency domain analysis. Thévenin equivalent concepts are used throughout this chapter to clearly show the student how electromagnetic and circuit theory are complementary. A great effort was made to make the time-domain section relevant to students whose primary interests are digital and computer circuits. Advanced topics in this section include microstrip transmission lines, reactive and nonlinear loads, and rise-time calculations.
8. This text covers a number of topics associated with electric and magnetic shielding, electromagnetic compatibility (EMC), and electromagnetic interference (EMI). These topics are discussed in both the static and dynamic sections of the text. My experience has shown that students very quickly see the relation between these topics and consumer electronics.
9. Chapter 13, "Waveguides," discusses both copper-based and dielectric based waveguides. This chapter includes a sizable discussion of optical fibers and systems.
10. In addition to a fundamental discussion of radiation and antenna principles, Chapter 14, "Antennas and Radiation," also presents a broad overview of the major classes of antennas encountered in engineering practice.

III. How to Use This Text

This textbook is intended for junior level electrical engineering students and can be used in either a one- or two-semester format. The following table gives suggested schedules for one- and two-semester courses.

Chapter	Title	2-Semester Lecture Hours	1-Semester Lecture Hours
1	Introduction	1	1
2	Vector Analysis	2	2
3	Electromagnetic Sources, Forces, and Fields	4	2
4	Electrostatic Fields in Free Space	5	5
5	Electrostatic Fields in Material Media	9	5
6	Capacitance and Electric Energy	3	3
7	Magnetostatic Fields in Free Space	4	4
8	Magnetostatic Fields in Material Media	5	3
9	Magnetic Inductance, Energy, and Forces	5	4
10	Time-Varying Electromagnetic Fields	4	4
11	Transmission Lines	14	6
12	Plane Waves	10	3
13	Waveguides	8	
14	Radiation and Antennas	10	
	Totals	**84**	**42**

These schedules assume that students have had some previous experience with vector calculus, presumably from their calculus sequence. When this is the case, I have found that two lectures on the material in chapter 2 is a sufficient review, and students typically refer back to chapter 2 throughout the course to review various aspects of this material. For curricula where vector calculus has not yet been encountered, a longer exposure to chapter 2 would provide students with all the necessary background.

For a two-semester course sequence, I have found that there is ample time to cover nearly all the material in this text. For a one-semester course, the suggested schedule provides a more concentrated coverage of the electrostatic and magnetostatic topics, while still allowing time for 13 lectures on the most important time-varying topics.

IV. Acknowledgments

In writing this book, I have drawn from every instructor and textbook that I have encountered throughout my career as a student and a professor. Without them, I could not possibly have written this textbook. Even though the writing style that emerged is uniquely my own, I am indebted to all of them.

My greatest thanks go the students at the University of Kansas who endured the many drafts of this text in class. I was genuinely surprised by the enthusiasm they displayed for being a part of this writing process. Their comments were very insightful, and I made many changes in the manuscript in response to their comments. Although

space does not allow me to recognize all the students who made significant comments, I could not rest without recognizing Mr. Scott Filion, who provided me with unbelievably detailed and helpful comments on the first half of the book.

I want to thank the reviewers who reviewed the manuscript of this text at various stages: Dr. Paul O. Berrett (Professor Emeritus) - Brigham Young University, Paul R. Melsaac - Cornell University, John R. Cogdell - University of Texas at Austin, Dr. Stuart A. Long - University of Houston, Walter J. Gajda, Jr. - University of Missouri - Rolla, Dennis P. Nyquist - Michigan State University, Kai Chang - Texas A & M University, Warren L. Stutzman - Virginia Polytechnic Institute and State University, Markus Zahn - Massachusetts Institute of Technology, Dr. David Rogers - North Dakota State University, Bruce Mc Leod - Montana State University, Jeffrey P. Mills - Illinois Institute of Technology, Robert York - University of California, Santa Barbara, Robert C. Owens - Santa Clara University, Vladimir Mitin - Wayne State University, Steven Scott Gearhart - University of Wisconsin - Madison. Their many comments caused me to rethink many aspects of the book and point me in the right direction. I appreciated their honesty and directness in telling me exactly what they did and did not like about the various manuscripts.

I also want to thank a number of colleagues and friends at the University of Kansas who assisted me in various ways during the writing of this text. Included in these are: Professors James Roberts, James Rowland and K. Sam Shanmugan, who gave me encouragement throughout this project, and Ms. Donnis Graham, who assisted in the final manuscript revisions. I would also like to thank Professor Ruth Miller at Kansas State University for several helpful discussions about teaching philosophies and electromagnetics.

Finally, I am most thankful to my wife Susan and my children, Eric and Rebecca, for standing by me during the over seven years it took to complete this text. Their concern and compassion for me during this time was greatly appreciated, and I could not have endured the process without them. I only hope I can follow through with my promise that life in the Demarest house will be easier now that this text is finally finished!

Kenneth Demarest
University of Kansas

Contents

1

Background and Motivation

1-1 Introduction

Electromagnetics is both the oldest and most basic of all the branches of electrical engineering. Stated simply, electromagnetics deals with four questions: What is electricity, how does it behave, what can it do, and how can we control it? So fundamental are the questions that it addresses that it is not an exaggeration to say that electromagnetics is at the heart of *everything* that is done with electricity. As a result, an understanding of electromagnetics is essential in order to fully understand the operation of many (if not most) electrical devices and effects.

At its most basic level, electromagnetics concerns itself with the forces that charged particles exert upon each other. These forces are important for two reasons. The first is that they determine how electric charges and currents distribute themselves in electrical devices. The second is that it is such forces that make electricity useful to us, since they make other things move and allow us to detect the presence of charges and currents. Indeed, applications such as telecommunications, electrical machines, and computers would not be possible were it not for electromagnetic forces.

Although there are many applications where electromagnetic forces are our primary interest (as in the case of electric motors), we are usually more interested in how those forces cause the charges and currents in circuits and devices to distribute themselves. For instance, in the case of electrical computing, electronic memory is accomplished by moving packets of charge into discrete locations in semiconductor chips and later sensing their presence (or absence). Similar processes are used in a large number of applications whereby information is stored or transmitted by controlling the flow of charges throughout a system or device. Examples include radio, television, radar, and sound reproduction, among many others.

Possibly the most useful and remarkable property of electricity is its ability to produce effects between two devices or circuits when there is no material connection between them. This is unlike mechanical systems, which must always have some sort of mechanical linkage in order for there to be any effect.[1] Electricity is capable of producing measurable effects over very large distances, even through great distances in vacuum. This allows us to routinely use electricity in such applications as wireless communications, radar, and remote sensing, as well as many others. The key to devising these applications is an understanding of the physical quantities that are responsible for the interactions involved: electric and magnetic fields. Once these concepts are understood, the range of applications in electrical devices and systems is limited only by our imagination, our knowledge of the properties of materials, and our manufacturing ability.

1-2 A Little History

Electrical systems and devices are so common in our lives that it is difficult to envision an age when electricity and magnetism were simply mysterious curiosities. But up until the early 1800s, that is exactly what they were. How these phenomena were discovered, understood, and harnessed is one of the greatest feats in the history of science and engineering.

"Electromagnetics" is a word that was coined in the late 1800s to denote a newly discovered phenomenon that was the combination of what previously had been thought to be completely separate phenomena: electricity and magnetism. Electric effects were the first to be discovered. History records that the ancient Greeks discovered that when an amber rod was rubbed with fur, the amber would attract bits of dust, straw, and other small objects. Nearly 2,000 years passed before William Gilbert realized in the early 1600s that this same effect could be observed when rubbing a variety of substances together. It was he who coined the term "electric," using the Greek word for amber, *elektron*. About the same time, Niccolo Cabeo also discovered that the electric effect could result in both attractive and repulsive forces between electrified (i.e., charged) objects.

The first indications that electricity can move from one place to another came from experiments conducted by Stephen Gray in 1729. He found that when two objects were connected by a tube, both could be electrified when only one was rubbed. This discovery led J.T. Desaguliers in 1739 to the discovery of a class of materials he called *conductors* that pass electricity easily.

[1] Although mechanical systems are, in theory, coupled by gravity, this coupling is so weak as to render it essentially useless in most applications.

As interesting as these discoveries were, they did not explain how these electric effects occurred. This started to change in the mid-1700s when a number of investigators began to suspect that the forces between charges could be described as an inverse-square law that was similar to the universal gravitational law proposed by Sir Isaac Newton in the late 1600s. Although Benjamin Franklin, Joseph Priestley, John Robison, and Henry Cavendish all made significant contributions to the discovery of this law, it was Charles Augustin de Coulomb who attracted the most attention, so we now call the law *Coulomb's law of force.* The discovery of Coulomb's law was the first step towards finding a comprehensive theory of electromagnetics.

Like the electric properties of amber, the magnetic properties of a mineral called lodestone were also known to the ancients, who knew that the mineral could attract iron and would point towards north when allowed to float on water. As time progressed, several other materials were found to possess similar characteristics. Also, it was discovered that artificial magnets could be made from naturally occurring ones. The first quantitative theories of magnetism were advanced in the 18th century. In 1750, John Michell theorized that permanent magnets have north and south poles that attract or repel each other according to an inverse-square law that is similar to Coulomb's law of force.

The pace of discovery of both the electric and magnetic effects quickened with the onset of the 19th century. In the year 1800, Volta developed the first chemical battery, which consisted of strips of dissimilar metals immersed in a weak acid electrolyte. This invention enabled the flow of steady currents and fostered numerous experiments involving chemical effects, heating, and material studies. One of the most important series of experiments was performed by George Simon Ohm in 1826; Ohm showed that when a constant voltage is applied to a conductor, the resulting current is proportional to the conductor's cross-sectional area and inversely proportional to its length. This is *Ohm's law*, which is one of the most important laws of circuit theory.

The first evidence that electric and magnetic phenomena are related came from Hans Christian Oersted, who, in 1819, discovered that a steady current could move a compass needle, just as a permanent magnet can. This was closely followed by André-Marie Ampère's discovery that electric currents exert attractive and repulsive forces on each other. Ampère discovered that the force exerted by current segments varies inversely with the square of the distance between them and is perpendicular to the line that connects them. We call this law *Ampère's law of force*, which is the magnetic analog of Coulomb's law of force.

Another important experimental connection between electric and magnetic effects was discovered by Michael Faraday in 1831. He conducted an experiment whereby two insulated wires were wrapped around an iron core. Faraday found that when the current in one winding was switched, a voltage was induced in the other. This discovery of transformer action led Faraday to a series of experiments in which he was able to conclude that a voltage is produced in a circuit whenever a time-varying magnetic field is present—either because the current is time varying or because the circuit or source are in motion. We call this *Faraday's law of induction* (often simply called *Faraday's law*).

With the discovery of Faraday's law, the stage was set for the development of a complete theory of electromagnetism. This was accomplished by James Clerk