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电子电气专业理论教材 | 工程师必备参考指南

工程电磁场

（第9版）

Engineering Electromagnetics

(Ninth Edition)

[美] 威廉姆·H. 哈特（William H. Hayt, Jr.）
约翰·A.巴克（John A. Buck） 著

袁建生 选译

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内容简介

本书系统论述了工程电磁场的理论及其分析方法，首先介绍了电磁场中所用到的数学基础——矢量分析，然后分五章介绍静电场，包括电场的定义（库仑定律）、场与源的关系即电场强度与电荷的关系（高斯定理）、电场能量与电场做功（电位的定义）、静电场的两种材料（导体与介质）、电场范畴的元件（电容）。其后关于恒定磁场的论述也包含这五个方面的内容，只不过仅划分成两章，包括磁场的定义（毕奥-萨伐尔定律）、场与源的关系（安培环路定律）、磁场能与磁场力、磁材料、磁场范畴的元件（电感与互感）。磁场中还包含一部分内容：磁路。在介绍了非时变、各自独立的电场与磁场之后，讨论时变电磁场，即电场与磁场相互耦合、相互为源，先介绍变化的磁场产生电场的现象与定量关系（法拉第电磁感应定律），然后介绍变化的电场产生磁场的现象（位移电流与全电流定律），在此基础上结合两种现象与矢量函数的特性等，给出描述时变电磁场特性的麦克斯韦方程组；并进一步介绍可表征麦克斯韦方程组的位函数及其满足的方程。在介绍完电磁场的基本特性后，插入一章介于电磁场与电路原理知识之间的内容——传输线。后面四章内容都属于高频时变电磁场的场特性分析与应用特性。

本书适合作为高校电气与电子信息类专业本科生与研究生的基本教材。

William H. Hayt, Jr.　John A. Buck
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ABOUT THE AUTHORS

William H. Hayt, Jr. (deceased) received his B.S. and M.S. degrees at Purdue University and his Ph.D. from the University of Illinois. After spending four years in industry, Professor Hayt joined the faculty of Purdue University, where he served as professor and head of the School of Electrical Engineering, and as professor emeritus after retiring in 1986. Professor Hayt's professional society memberships included Eta Kappa Nu, Tau Beta Pi, Sigma Xi, Sigma Delta Chi, Fellow of IEEE, ASEE, and NAEB. While at Purdue, he received numerous teaching awards, including the university's Best Teacher Award. He is also listed in Purdue's Book of Great Teachers, a permanent wall display in the Purdue Memorial Union, dedicated on April 23, 1999. The book bears the names of the inaugural group of 225 faculty members, past and present, who have devoted their lives to excellence in teaching and scholarship. They were chosen by their students and their peers as Purdue's finest educators.

A native of Los Angeles, California, **John A. Buck** received his B.S. in Engineering from UCLA in 1975, and the M.S. and Ph.D. degrees in Electrical Engineering from the University of California at Berkeley in 1977 and 1982. In 1982, he joined the faculty of the School of Electrical and Computer Engineering at Georgia Tech, and is now Professor Emeritus. His research areas and publications have centered within the fields of ultrafast switching, nonlinear optics, and optical fiber communications. He is the author of the graduate text *Fundamentals of Optical Fibers* (Wiley Interscience), which is in its second edition. Dr. Buck is the recipient of four institute teaching awards and the IEEE Third Millenium Medal.

序

William H. Hayt, Jr. 教授生前曾任教于美国普渡大学，其一生获得诸多荣誉，堪称教学名师之典范。在学习本教材之前，请读者一定要阅读作者简介，相信这一定会激发您对 William H. Hayt. Jr. 教授的敬仰和对电磁场学习的兴趣。第二作者 John A. Buck 为乔治亚理工学院电气与计算机工程系荣誉退休教授。William H. Hayt. Jr. 编写的第一版距今已 60 多年。自该书的第六版起主要由 John A. Buck 教授修订。该版本称为国际版，在美国之外的国家发行使用。第九版与第八版相比改动不大。

本教材与我国电子与电气工程专业的本科教材内容基本一致，满足我国高校相关教学大纲要求。其基本概念讲述清晰、详尽，注重物理概念，淡化公式推导，图文并茂，章节划分细致，每个基本概念和问题分为一小节；每章后面都配有约 30 道习题。

本书文笔流畅、可读性强、易理解，学生可以使用该教材进行自主学习，是电磁场或电磁场与电磁波课程的理想教材或参考书。

本书在内容编排上有独到之处。例如，在静电场部分，将能量与电位的引入结合在一起（第 4 章的题目为"能量与电位"），突出了电位是电场对单位电荷做功的物理属性，而不是像国内教材强调电位梯度等于电场强度的数学关系；在磁场部分，相对于静电场部分的总共 5 章编排，该部分仅以两章出现，一章的题目为"恒定磁场"，另一章的题目为"磁场力、材料和电感"，这种编排的综合性与静电场内容编排的分散性形成了明显反差，且在叙述中多处是通过与静电场类比的形式直接给出结果或结论。

相对于我国相应教材，本书静电场中电容的计算内容较丰富；磁场中介绍了磁路概念，特别介绍了铁磁材料的非线性与磁滞回线概念，铁磁材料的非线性现象确实是需要学生牢记的一种现象和一定要掌握的基本概念；另外就是利用一章介绍了传输线问题（第 10 章）。传输线分析内容属于电磁场课程还是电路课程内容并无明确定论，但从场的根本属性和空间分布看，传输线内容应该归在电路课程中。无论归为哪个课程内容，传输线概念是学生应具备的电工基础知识。

在使用本教材时应注意三点：

① 其时变电磁场部分仅一章（第 9 章：时变场与麦克斯韦方程组），内容偏少、偏简单、过于数学化，没有准静态场的概念，没有涡流、趋肤效应与邻近效应等较重要的实用性内容，这不利于以低频电磁场为基础的电气工程类学生的知识构成。

② 5.1 ~ 5.3 节的电流与电阻内容插在静电场内容中容易使学生混淆不同类型的场，混淆静电场是分析介质中的电场，而电流场是分析导体内的电场。静电场中导体内场强为零，电容属于

静电场的概念,而电流场中导体内场强不为零,电阻属于电流场的概念,两种场研究的问题截然不同。

③ 边值问题的内容比较薄弱,在电位与磁矢量位的泊松方程相关内容中,没有给出位函数应满足的交界面条件和边界条件,也没有给出多媒质中通过解边值问题得到场分布的内容和例题。这不利于学生建立电磁场数值计算所需的电磁场基本概念。

本书配有学习网站(网址为 www.mhhe.com/hayt/buck9e),网站提供了丰富的学习资源和内容,包括小测验问答题,一些场图、动画、互动等内容,书中页面空白处的 WWW 图标指明了网站对应的内容,每当学到图标处建议查阅网站上的相应内容。另外,每章后面的习题采用三级难度分类标识给出了每道题的难易程度(见题号后的竖条),便于不同水平的学生选择习题。

本人对该书的部分词语进行了翻译和注释,并写了一些导读,不当之处请批评指正!

袁建生
清华大学电机与应用电子技术系
2019 年 3 月

PREFACE

The printing of this book occurs one year short of 60 years since its first edition, which was at that time under the sole authorship of William H. Hayt, Jr. In a sense, I grew up with the book, having used the second edition in a basic electromagnetics course as a college junior. The reputation of the subject matter precedes itself. The prospect of taking the first course in electromagnetics was then, as now, a matter of dread to many if not most. One professor of mine at Berkeley put it succinctly through the rather negative observation that electromagetics is "a test of your ability to bend your mind". But on entering the course and first opening the book, I was surprised and relieved to find the friendly writing style and the measured approach to the subject. This for me made it a very readable book, out of which I was able to learn with little help from my instructor. I referred to the book often while in graduate school, taught from the fourth and fifth editions as a faculty member, and then became coauthor for the sixth edition on the retirement (and subsequent untimely death) of Bill Hayt. To this day, the memories of my time as a beginner are vivid, and in preparing the sixth and subsequent editions, I have tried to maintain the accessible style that I found so encouraging and useful then.

Over the 60-year span, the subject matter has not changed, but emphases have. In universities, the trend continues toward reducing electrical engineering core course allocations to electromagnetics. This is a matter of economy, rather than any belief in diminished relevance. Quite the contrary: A knowledge of electromagnetic field theory is in the present day more important than ever for the electrical engineer. Examples that demonstrate this include the continuing expansion of high-speed wireless and optical fiber communication. Additionally, the need continues for ever-smaller and denser microcircuitry, in which a command of field theory is essential for successful designs. The more traditional applications of electrical power generation and distribution remain as important as ever.

I have made efforts to further improve the presentation in this new edition. Most changes occur in the earlier chapters, in which much of the wording has been shortened, and several explanations were improved. Additional introductory material has been added in several places to provide perspective. In addition, all chapters are now subsectioned, to improve the organization and to make topics easier to locate.

Some 100 new end-of-chapter problems have been added throughout, all of which replaced older problems that I considered well-worn. I have retained the previous system in which the approximate level of difficulty is indicated beside each problem on a three-level scale. The lowest level is considered a fairly straightforward problem, requiring little work assuming the material is understood; a level 2 problem is conceptually more difficult, and/or may require more work to solve; a level 3 problem is considered either difficult conceptually, or may require extra effort (including possibly the help of a computer) to solve.

As in the previous edition, the transmission lines chapter (10) is stand-alone, and can be read or covered in any part of a course, including the beginning. In it, transmission lines are treated entirely within the context of circuit theory; wave phenomena are introduced and used exclusively in the form of voltages and currents. Inductance and capacitance concepts are treated as known parameters, and so there is no reliance on any other chapter. Field concepts and parameter computation in transmission lines appear in the early part of the waveguides chapter (13), where they play additional roles of helping to introduce waveguiding concepts. The chapters on electromagnetic waves, 11 and 12, retain their independence of transmission line theory in that one can progress from Chapter 9 directly to Chapter 11. By doing this, wave phenomena are introduced from first principles but within the context of the uniform plane wave. Chapter 11 refers to Chapter 10 in places where the latter may give additional perspective, along with a little more detail. Nevertheless, all necessary material to learn plane waves without previously studying transmission line waves is found in Chapter 11, should the student or instructor wish to proceed in that order.

The antennas chapter covers radiation concepts, building on the retarded potential discussion in Chapter 9. The discussion focuses on the dipole antenna, individually and in simple arrays. The last section covers elementary transmit-receive systems, again using the dipole as a vehicle.

The book is designed optimally for a two-semester course. As is evident, statics concepts are emphasized and occur first in the presentation, but again Chapter 10 (transmission lines) can be read first. In a single course that emphasizes dynamics, the transmission lines chapter can be covered initially as mentioned or at any point in the course. One way to cover the statics material more rapidly is by deemphasizing materials properties (assuming these are covered in other courses) and some of the advanced topics. This involves omitting Chapter 1 (assigned to be read as a review), and omitting Sections 2.5, 2.6, 4.7, 4.8, 5.5–5.7, 6.3, 6.4, 6.7, 7.6, 7.7, 8.5, 8.6, 8.8, 8.9, and 9.5.

A supplement to this edition is web-based material consisting of articles on special topics in addition to animated demonstrations and interactive programs developed by Natalya Nikolova of McMaster University and Vikram Jandhyala of the University of Washington. Their excellent contributions are geared to the text, and icons appear in the margins whenever an exercise that pertains to the narrative exists. In addition, quizzes are provided to aid in further study.

The theme of the text is the same as it has been since the first edition of 1958. An inductive approach is used that is consistent with the historical development. In it, the experimental laws are presented as individual concepts that are later unified in Maxwell's equations. After the first chapter on vector analysis, additional mathematical tools are introduced in the text on an as-needed basis. Throughout every edition, as well as this one, the primary goal has been to enable students to learn independently. Numerous examples, drill problems (usually having multiple parts), end-of-chapter problems, and material on the web site, are provided to facilitate this.

Answers to the drill problems are given below each problem. Answers to odd-numbered end-of-chapter problems are found in Appendix F. A solutions manual and a set of PowerPoint slides, containing pertinent figures and equations, are available to instructors. These, along with all other material mentioned previously, can be accessed on the website:

www.mhhe.com/haytbuck

I would like to acknowledge the valuable input of several people who helped to make this a better edition. They include:

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I also acknowledge the feedback and many comments from students, too numerous to name, including several who have contacted me from afar. I continue to be open and grateful for this feedback and can be reached at john.buck@ece.gatech.edu. Many suggestions were made that I considered constructive and actionable. I regret that not all could be incorporated because of time restrictions. Creating this book was a team effort, involving several outstanding people at McGraw-Hill. These include my editors, Raghu Srinivasan and Tomm Scaife, whose vision and encouragement were invaluable. Jenilynn McAtee and Lora Neyens deftly coordinated the production phase with excellent ideas and enthusiasm, and Tina Bower, who was my guide and conscience from the beginning, providing valuable insights, and jarring me into action when necessary. I am, as usual in these projects, grateful to a patient and supportive family.

John A. Buck
Marietta, Georgia
May, 2017

On the cover: Three-dimensional field map for an electric dipole.

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