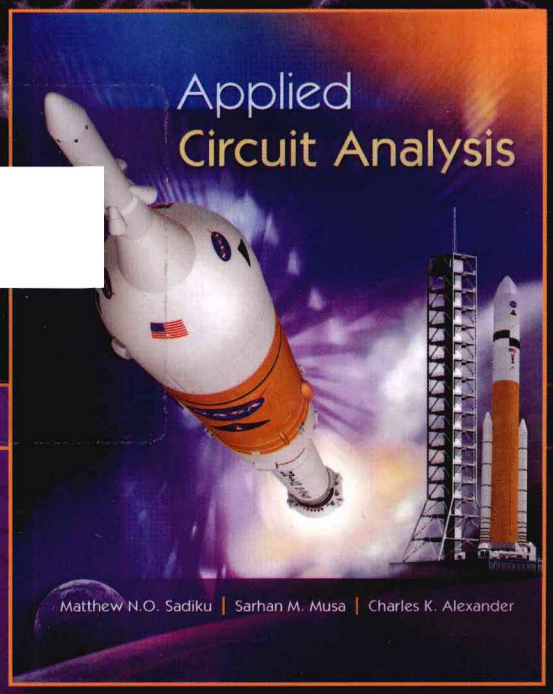
国外电子电气经典教材系列

应用电路分析

（英文版）

Applied Circuit Analysis

[美] Matthew N. O. Sadiku　Sarhan M. Musa　Charles K. Alexander　著



机械工业出版社
China Machine Press

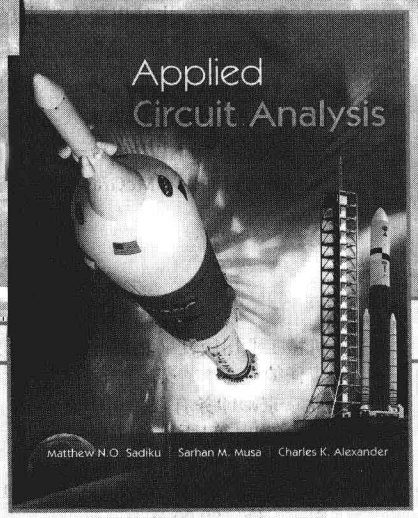
国外电子电气经典教材系列

应用电路分析

Applied Circuit Analysis

（英文版）

[美] Matthew N. O. Sadiku　Sarhan M. Musa　Charles K. Alexander　著



机械工业出版社
China Machine Press

图书在版编目（CIP）数据

应用电路分析（英文版）/（美）萨迪库（Sadiku，M. N. O.）等著. —北京：机械工业出版社，2013.3
（国外电子电气经典教材系列）
书名原文：Applied Circuit Analysis

ISBN 978-7-111-41781-1

I. 应… II. 萨… III. 电路分析－高等学校－教材－英文 IV. TM133

中国版本图书馆CIP数据核字（2013）第046497号

机械工业出版社（北京市西城区百万庄大街22号 邮政编码 100037）
责任编辑：李 荣
北京京师印务有限公司印刷
2013年4月第1版第1次印刷
186mm×240mm · 44印张
标准书号：ISBN 978-7-111-41781-1
定 价：89.00元

凡购本书，如有缺页、倒页、脱页，由本社发行部调换
客服热线：（010）88378991 88361066 投稿热线：（010）88379604
购书热线：（010）68326294 88379649 68995259 读者信箱：hzjsj@hzbook.com

出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，信息学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭示了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的信息产业发展迅猛，对专业人才的需求日益迫切。这对我国教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短的现状下，美国等发达国家在其信息科学发展的几十年间积淀和发展的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀教材将对我国教育事业的发展起到积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章公司较早意识到“出版要为教育服务”。自 1998 年开始，我们就将工作重点放在了遴选、移译国外优秀教材上。经过多年的不懈努力，我们与 Pearson，McGraw-Hill，John Wiley & Sons，Elsevier，Cambridge 等世界著名出版公司建立了良好的合作关系，从他们现有的数百种教材中甄选出《Digital Design: Principles and Practices，4E（数字设计原理与实践，原书第 4 版）》(John F.Wakerly 著）、《Fundamentals of Digital Logic with Verilog Design（数字逻辑基础与 Verilog 设计 ）》(Stephen Brown 著）、《Electromagnetic Field Theory Fundamentals，2E（电磁场与电磁波，原书第 2 版）》(Bhag Singh Guru 著）、《Fundamentals of Electric Circuits，5E(电路基础，原书第 5 版、英文版第 5 版)》(Charles K. Alexander 著）、《Digital Fundamentals: A Systems Approach（数字基础：系统方法）》(Thomas L. Floyd 著）、《Introductory Circuit Analysis ,12E（电路分析导论，原书第 12 版，本科教学版）》(Robert L.Boylestad 著）、《Foundations of MEMS，2E (微机电系统基础（原书第 2 版）》(Chang Liu 著）等大师名家的经典教材，以“国外电子电气经典教材系列”为总称出版，供读者学习、研究及珍藏。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证。随着电子电气专业学科建设的不断完善和教材改革的逐渐深化，教育界对国外电子电气教材的需求和应用都将步入一个新的阶段，我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下：

华章网站：www.hzbook.com

电子邮件：hzjsj@hzbook.com

联系电话：(010) 88379604

联系地址：北京市西城区百万庄南街 1 号

邮政编码：100037

华章教育

华章科技图书出版中心

Preface

This book is intended to present circuit analysis to engineering technology students in a manner that is clearer, more interesting, and easier to understand than other texts. This objective is achieved in the following ways:

- A course in circuit analysis is perhaps the first exposure students have to electrical engineering technology. We have included several features to help students feel at home with the subject. Each chapter opens with a historical profile or career talk. This is followed by an introduction that links the chapter with the previous chapters and states the chapter objectives. The chapter ends with a summary of key points and formulas.
- All principles are presented in a lucid, logical, step-by-step manner. As much as possible, we avoid wordiness and too much detail that could hide concepts and impede overall understanding of the material.
- Important formulas are boxed as a means of helping students sort out what is essential from what is not. Also, to ensure that students clearly get the gist of the matter, key terms are defined and highlighted.
- Thoroughly worked examples are liberally given at the end of every section. The examples are regarded as a part of the text and are clearly explained without asking the reader to fill in missing steps. Thoroughly worked examples give students a good understanding of the solution and the confidence to solve problems themselves. Some of the problems are solved in two or three ways to facilitate an understanding and comparison of different approaches.
- To give students practice opportunity, each illustrative example is immediately followed by a practice problem with the answer. The students can follow the example step-by-step to solve the practice problem without flipping pages or looking at end of the book for answers. The practice problem is also intended to test if students understand the preceding example. It will reinforce their grasp of the material before they move on to the next section.
- The last section in each chapter is devoted to application aspects of the concepts covered in the chapter. The material covered in the chapter is applied to at least one practical problem or device. This helps the students see how the concepts are applied to real-life situations.
- Ten review questions in multiple-choice form are provided at the end of each chapter, with answers. The review questions are intended to cover the little "tricks" that the examples and end-of-chapter problems may not cover. They serve as a self-test device and help students determine how well they have mastered the chapter.

- In recognition of the requirements by the ABET (Accreditation Board for Engineering and Technology) on integrating computer tools, the use of PSpice® and NI Multisim™ is encouraged in a student-friendly manner. Appendix C serves as a tutorial on PSpice for Windows, while Appendix D provides an introduction to Multisim. The latest versions of these software packages are used in the book. We also encourage the use of a TI-89 Titanium calculator and MATLAB® for number crunching.

Organization

This book was written for a two-semester or three-quarter course in linear circuit analysis. The book may also be used for a one-semester course by a proper selection of chapters and sections by the instructor. It is broadly divided into two parts. Part 1, consisting of Chapters 1 to 10, is devoted to dc circuits. Part 2, which contains Chapter 11 to 19, deals with ac circuits. The material in two parts is more than sufficient for a two-semester course, so the instructor must select which chapters or sections to cover. Sections preceded with the dagger sign may be skipped, explained briefly, or assigned as homework.

Prerequisites

As with most introductory circuit courses, the main prerequisite for a course using the text is physics. Although familiarity with complex numbers is helpful in the later part of the book, it is not required.

Online Resources

A website to accompany this text is available at www.mhhe.com/sadiku. The site includes a password-protected solutions manual, worked solutions in PSpice and Multisim, and an image library for instructors. Instructors can also obtain access to COSMOS for this text. COSMOS is a Complete Online Solutions Manual Organization System instructors can use to create exams and assignments, create custom content, and edit supplied problems and solutions.

McGraw-Hill Create™

Craft your teaching resources to match the way you teach! With McGraw-Hill Create, www.mcgrawhillcreate.com, you can easily rearrange chapters, combine material from other content sources, and quickly upload content you have written, such as your course syllabus or teaching notes. Find the content you need in Create by searching through thousands of leading McGraw-Hill textbooks. Arrange your book to fit your teaching style. Create even allows you to personalize your book's appearance by selecting the cover and adding your name, school, and course information. Order a Create book and you'll receive a complimentary print review copy in 3 to 5 business days or a complimentary electronic review copy (eComp) via e-mail in minutes. Go

to www.mcgrawhillcreate.com today and register to experience how McGraw-Hill Create empowers you to teach *your* students *your* way.

Electronic Textbook Option

This text is offered through CourseSmart for both instructors and students. CourseSmart is an online resource where students can purchase the complete text online at almost half the cost of a traditional text. Purchasing the eTextbook allows students to take advantage of CourseSmart's web tools for learning, which include full text search, notes and highlighting, and email tools for sharing notes between classmates. To learn more about CourseSmart options, contact your sales representative or visit www.CourseSmart.com.

Acknowledgments

Special thanks are due to Robert Prather and Dr. Warsame Ali for their help with Multisim. We appreciate the support received from Dr. Kendall Harris, dean of the college of engineering at Prairie View A&M University. We would like to thank Dr. John Attia for his support and understanding. We extend our appreciation to Dr. Karl J. Huehne for thoroughly going through the text and the solutions of the problems making sure they are accurate. The insights and cooperation received from the McGraw-Hill team (Raghu Srinivasan, Darlene Schueller, Lora Neyens, Curt Reynolds, Lisa Bruflodt, Margarite Reynolds, LouAnn Wilson, Ruma Khurana, and Dheeraj Chahal) is very much appreciated.

We would like to thank the following reviewers for their comments:

Ryan Beasley, *Texas A&M University*
Michael E. Brumbach, *York Technical College*
Thomas Cleaver, *University of Louisville*
Walter O. Craig III, *Southern University*
Chad Davis, *University of Oklahoma*
Mark Dvorak, *Minnesota State University–Mankato*
Karl Huehne, *Indiana University–Purdue University Indianapolis*
Rajiv Kapadia, *Minnesota State University–Mankato*
Mequanint Moges, *University of Houston*
Jerry Newman, *University of Memphis*
Brian Norton, *Oklahoma State University*
Norali Pernalete, *California State Polytechnic University–Pomona*
John Ray, *Louisiana Tech University*
Barry Sherlock, *University of North Carolina–Charlotte*
Ralph Tanner, *Western Michigan University*
Wei Zhan, *Texas A&M University*

M. N. O. Sadiku, S. M. Musa and C. K. Alexander

Table of Contents

Notes to Students

This may be one of your first courses in electrical engineering technology. Although electrical engineering technology is an exciting and challenging discipline, the course may intimate you. This book was written to prevent that. A good textbook and a good professor are an advantage-but you are the one who does the learning. If you keep the following ideas in mind, you will do very well in this course:

- This course is the foundation on which most other courses in the electrical engineering technology curriculum rest. For this reason, put in as much effort as you can. Study the course regularly.
- Problem solving is an essential part of learning process. Solve as many problems as you can. Begin by solving the practice problems following each example and then proceed to the end-of-chapter problems. The best way to learn is to solve a lot of problems. An asterisk in front of a problem indicates a challenging problem.
- Spice, a computer circuit analysis program, is used throughout the textbook. PSpice, the personal computer version of Spice, is the popular standard circuit analysis program at most universities. PSpice for Windows is described in Appendix C. Make an effort to learn PSpice, because you can check any circuit problem with PSpice and be sure you are handing in a correct problem solution.
- Multisim is another tool that helps you simulate what would otherwise be a real electronics workbench, complete with drawings, parts, and instruments. A quick introduction to Multisim is provided in Appendix D.
- MATLAB is a software package that is very useful in circuit analysis and other courses you will be taking. A brief tutorial on MATLAB is given in Appendix E to get you started. The best way to learn MATLAB is to start with it once you know a few commands.
- Each chapter ends with a section on how the material covered in the chapter can be applied to real-life situations. The concepts in this section may be new and advanced to you. No doubt, you will learn more of the details in other courses. We are mainly interested in gaining a general familiarity with these ideas.
- Attempt the review questions at the end of each chapter. They will help you discover some "tricks" not revealed in class or in the textbook.

A short review of finding determinants is covered in Appendix A, complex numbers in Appendix B, PSpice for Windows in Appendix C, Multisim in Appendix D, MATLAB in Appendix E, and the TI-89 Titanium calculator in Appendix F. Answers to odd-numbered problems are given in Appendix G.

Have fun!

PART ONE

DC Circuits

chapter

1

Basic Concepts

Technology feeds on itself. Technology makes more technology possible.

—Alvin Toffler

Historical Profiles

Alessandro Volta Alessandro Volta (1745–1827), an Italian physicist, invented the electric battery, which provided the first continuous flow of electricity, and the capacitor.

Born into a noble family in Como, Italy, Volta started performing electrical experiments at age 18. The invention of the battery by Volta in 1796 revolutionized the use of electricity. The publication of his work in 1800 marked the beginning of electric circuit theory. Volta received many honors during his lifetime, and the unit of voltage or potential difference, the *volt,* was named in his honor.

Alessandro Volta
© The Huntington Library, Burndy Library, San Marino, California

Andre-Marie Ampere Andre-Marie Ampere (1775–1836), a French mathematician and physicist, laid the foundation of electrodynamics (now called electromagnetism). It was during the 1820s that he defined electric current and developed a method to measure it.

Born in Lyons, France, Ampere mastered Latin rapidly because he was intensely interested in mathematics, and many of the best mathematical works at that time were in Latin. He was a brilliant scientist and a prolific writer. He invented the electromagnet and the ammeter and formulated the laws of electromagnetics. The unit of electric current, the *ampere,* was named after him.

Andre-Marie Ampere
© Pixtal/age Fotostock RF

1.1 Introduction

电路理论是电气工程技术的基础。电气工程技术的许多分支，如电源、电机、反馈和控制系统、电子学、计算机、通信以及电子仪器等都是在电路理论的基础上建立起来的。对于开始学习电气工程技术专业的学生来说，电路理论是起点，也是一门最重要的课程。电路理论对于其他理工科专业的学生也是很有意义的，因为电路通常是研究能量系统的非常有效的模型，而其中又包括了应用数学、物理学和拓扑学等诸多内容。

在电气工程技术中，通常要研究从一点到另一点的通信或者能量传递。为此，需要将若干电子器件相互连接起来实现这一功能。这种由电子器件相互连接构成的总体称为电路（electric circuit），电路中的每个组成部分称为元件（element）。

电路是由电子元件相互连接构成的总体。

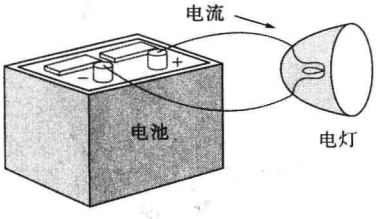


图1.1 一个简单的电路

图1.1给出了一个简单的电路，它由三个基本元件组成：电池、灯泡和连接导线。这样一个简单的电路可以用于手电筒、探照灯等多种应用。

图1.2给出了一个复杂的电路。该电路是无线电发射器的原理图。虽然看起来很复杂，但是利用本书介绍的方法，就可以对其进行分析。本课程的目标之一即使学生学习用于描述诸如此类电路的各种分析方法和计算机软件应用方法。

在大量电子系统中利用各种电路可以完成各类艰巨的任务。本书的目的不是研究各种电路的不同应用，而是专注于电路分析之中，并据此来研究电路特性。例如，电路在给定输入信号作用下是如何响应的？电路中相互连接的元件与器件是如何相互作用的？

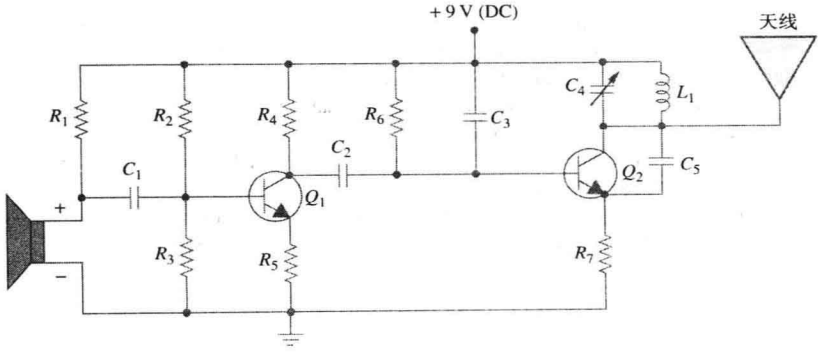


图1.2 无线电发射器电路图

在开始学习之前，首先对电荷、电流、电压、电路元件、功率和能量等电路中的一些基本概念进行定义。而定义这些概念之前，必须先建立本书所采用的计量单位制。

1.2 International Systems of Units

As engineering technologists, we deal with measurable quantities. Our measurement, however, must be communicated in a standard language that all professionals can understand irrespective of the country in which the measurement is conducted. Such an international measurement language is the International System (SI) of Units, adopted by the General Conference on Weights and Measures in 1960. In this system, there are seven principal units from which the units of all other physical quantities can be derived. Table 1.1 shows the six units and one derived unit that are relevant to this text.

Although the SI units have been officially adopted by Institute of Electrical and Electronics Engineers (IEEE) and are used throughout this text, certain English units (non-SI units) are commonly used in practice in the United States. This is because the United States has only recognized the SI system and not officially mandated it. For example, distances are still specified in feet and miles, while electric motors are rated in horsepower. Thus, you will occasionally need to convert non-SI units to SI units using Table 1.2.

Example 1.1

Convert 42 inches to meters.

Solution:

From Table 1.2, 1 inch = 0.0254 meter. Hence

$$42 \text{ inches} = 42 \times 0.0254 \text{ meter} = 1.0668 \text{ meters}$$

Practice Problem 1.1

Convert 36 miles to kilometers.

Answer: 57.924 kilometers

TABLE 1.1

Six basic SI units and one derived unit relevant to this text.

Physical quality	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Charge	coulomb	C

TABLE 1.2

Conversion factors.

To convert from	To	Multiply by
Length		
inches(in)	meters (m)	0.0254
feet (ft)	meters (m)	0.3048
yards (yd)	meters (m)	0.9144
miles (mi)	kilometers (km)	1.609
mils (mil)	millimeters (mm)	0.0254
Volume		
gallons (gal)(U.S.)	liters (L)	3.785
cubic feet (ft^3)	cubic meter (m^3)	0.0283
Mass/weight		
pounds (lb)	kilogram (kg)	0.4536
Time		
hours (h)	seconds (s)	3600
Force		
pounds (lb)	newtons (N)	4.448
Power		
horsepower (hp)	watts (W)	746
Energy		
foot-pounds (ft-lb)	joules (J)	1.356
kilowatt-hours (kWh)	joules (J)	3.6×10^6

Example 1.2

An electric motor is rated at 900 watts. Express this in horsepower.

Solution:

From Table 1.2, 1 horsepower = 746 watts. Therefore, 1 watt = 1/746 horsepower. Thus,

$$900 \text{ watts} = 900 \times 1/746 = 1.206 \text{ horsepower}$$

Practice Problem 1.2

A force of 50 newtons is applied to a certain object. Express the force in pounds.

Answer: 11.241 pounds

1.3 Scientific and Engineering Notation

In science and engineering technology, we often encounter very small and very large numbers. These very small or large numbers can be expressed using of one of the following widely used notations:

- Scientific notation.
- Engineering notation.

Scientific notation uses the power of 10. In scientific notation, a number is usually expressed as $X.YZ \times 10^n$.

In scientific notation, we express a number in powers of 10 with a single nonzero digit to the left of decimal point.