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电子电气
科技丛书

MICROELECTRONICS: CIRCUIT ANALYSIS AND DESIGN (FOURTH EDITION)

影印版

电子电路分析与设计（第四版）——数字电子技术

[美] 尼曼（Donald A. Neamen） 著

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北京

Donald A. Neamen
Microelectronics: Circuit Analysis and Design, Fourth Edition
ISBN: 978-0-07-338064-3

图书在版编目(CIP)数据

电子电路分析与设计: 第四版 = Microelectronics: Circuit Analysis and Design(Fourth Edition). 数字电子技术: 英文/(美)尼曼(Donald A. Neamen)著. —北京: 清华大学出版社,2018
(新视野电子电气科技丛书)
ISBN 978-7-302-50085-8

Ⅰ. ①电… Ⅱ. ①尼… Ⅲ. ①电子电路-电路设计-英文 ②电子电路-电路分析-英文 ③数字电路-电子技术-英文 Ⅳ. ①TN702

中国版本图书馆 CIP 数据核字(2018)第 103196 号

责任编辑: 王 芳
封面设计: 傅瑞学
责任校对: 白 蕾
责任印制: 刘海龙

出版发行: 清华大学出版社
网 址: http://www.tup.com.cn, http://www.wqbook.com
地 址: 北京清华大学学研大厦 A 座 邮 编: 100084
社 总 机: 010-62770175 邮 购: 010-62786544
投稿与读者服务: 010-62776969, c-service@tup.tsinghua.edu.cn
质量反馈: 010-62772015, zhiliang@tup.tsinghua.edu.cn
印 装 者: 清华大学印刷厂
经 销: 全国新华书店
开 本: 203mm × 260mm 印 张: 13.5 字 数: 324 千字
版 次: 2018 年 9 月第 1 版 印 次: 2018 年 9 月第1次印刷
定 价: 59.00 元

产品编号: 078042-01

第四版序

Donald A. Neamen 教授主编的《电子电路分析与设计》第四版和读者见面了，该书自清华大学出版社于 2000 年引进以来，颇受国内广大高校师生的欢迎。新版不但秉承了前几版“为模拟和数字电子电路的分析和设计提供基础教程”的宗旨，而且在诸多方面进行了改进、补充和重新编排，使之具有更加鲜明的特色，突出了科学性、基础性、系统性和适用性。

一、本书的结构和内容

本书第四版与第三版在总体结构上基本相同；全书包括三个部分，共 17 章。

第 1 ~ 8 章为第一部分，主要阐述分立元件模拟电子电路的分析和设计方法。内容包括半导体材料、二极管基本原理及其基本应用电路、场效应管工作原理及其线性放大电路、双极型三极管工作原理及其线性放大电路和应用、频率响应、输出级和功率放大电路等。

第 9 ~ 15 章为第二部分，主要阐述更复杂的模拟电子电路的分析和设计，即运算放大器及构成集成放大电路的基本模块，以及运放的应用等。包括理想运放及其基本应用、集成电路的恒流源偏置电路和有源负载、差分放大电路、反馈及放大电路的稳定性、构成运算放大器的各种电路的分析和设计、模拟集成电路中非理想因素的影响以及有源滤波电路和振荡电路等。

第 16 章和第 17 章为第三部分，主要阐述数字电子电路的分析和设计。第 16 章的内容是 CMOS 数字电路的分析和设计，包括基本逻辑门电路、触发器、寄存器、基本 A/D 和 D/A 转换器等。第 17 章的内容是双极型数字电路的分析与设计，包括射极耦合逻辑电路(ECL)和三极管-三极管逻辑电路(TTL)。

二、本书内容编排的特点

(1) 每章均以内容简介开篇，对前一章和新一章的内容起承上启下的作用；预览部分以列表形式呈现，使读者一目了然。每章以小结和复习题结尾，仍以列表形式回顾本章建立的基本概念和方法，提出学过本章后应达到的水平和应具有的能力，并可通过习题完成自我评估，以便更好地进入下一章的学习。开头和结尾相互呼应，教学目标性很强。

(2) 各章每一大节开始均给出本节的学习目标，结尾大都有理解测试题，做到一节一测试。同时，各章节配有充分的例题，每一道例题后面均紧跟一道与例题相似的练习题，随时检查刚刚学过的内容；使学习过程循序渐进，一步一个脚印。这些例题包含了电子电路分析和设计的各个细节，所以不断加深读者对基本概念和基本方法的理解和应用。

(3) 每章的最后一节为设计应用，阐述一个与本章内容紧密相关的具体的电子电路设计，以期达到理论联系实际、学以致用的目的。例如，利用二极管、MOSFET 管和 BJT 管设计电子温度计，利用集成运放设计有源滤波器，利用 CMOS 和 ECL 电路的基本结构设计门电路，等等；使读者逐渐掌握电子电路自上而下的设计方法。

三、本书的主要特色

本书加强了教学的严密性，修改了部分电路参数和元件参数，使之更适于现代电子学的发展。与国内众多同类教材相比，以下特色更为显著。

1. 突出鲜明的教学目的

本书在每一章、甚至每一节都给出了明确的学习目标，使读者“心中有数”，了解学习后应掌握的基本元件，基本概念、电路和方法以及应当达到的能力。

2. 满足灵活的教学安排

本书具有很强的适应性，各个重要部分在叙述上既相互独立，又相互联系，使得教学安排能够灵活多变。在全局上，既可以先讲数字电子电路，又可以先讲模拟电子电路；在模拟电子电路部分，既可以先讲集成运放及其应用，又可以先讲分立元件放大电路及其应用；在分立元件放大电路部分，既可以先讲场效应管及其放大电路，又可以先讲双极型三极管及其放大电路；在数字电子电路部分，既可以先讲单极型逻辑电路，又可以先讲双极型逻辑电路。

3. 强调电子设计的重要性

电子技术课程具有很强的工程性，作者认为“设计是工程的核心。好的设计源于相当丰富的分析经验”。因此，本书在对电子电路进行分析时特别强调它们不同的特性，以期读者能够建立一种可以“在设计过程中应用的直觉”。这种将分析和设计紧密结合的方法，使得学生将分析中获得的感悟立刻用于设计之中，从而逐步掌握电子电路的设计方法。

4. 提高习题的丰富性

本书在各种习题的丰富性上做了大量工作，共新增 250 多道练习题和理解测试题，580 多道章后习题；其中包含 50 多道开放设计题，60 多道计算机仿真题；并提供习题答案，读者可以在每一章、每一节甚至每一个例题后进行自我测试，一步一步地达到学习目标。

5. 明确 EDA（Electronic Design Automation）应用的目的

电子电路计算机辅助分析和设计的方法已日臻成熟，EDA 软件的应用已成为电子技术类课程不可或缺的组成部分。本书特别强调人工分析与设计，以便读者透彻地理解基本的电路概念。但是，对于某些复杂电路和问题，作者则大量使用较为流行的 PSpice 软件进行分析；并在不少章节同时给出人工分析结果和 PSpice 分析结果；使得读者不但深入掌握电子电路的基本概念，而且理解 EDA 工具的应用场合和使用方法。

总之，本书在各个章节中，分析与设计紧密结合，启发引导，循序渐进，叙述详尽；在总体内容上，充分体现知识的系统和完整性；各种习题丰富多彩，自我测评细致入微。本书内容涵盖了我国高等院校模拟电子技术和数字电子技术课程大部分教学要求，内容丰富，视野开阔；虽然篇幅较大，但层次清楚、思路清晰、文字流畅、易于阅读；因而不但可以作为电子技术基础及同类课程的教材，还可以作为相关课程的参考书。

华成英

2018 年 4 月于清华园

Preface

PHILOSOPHY AND GOALS

Microelectronics: Circuit Analysis and Design is intended as a core text in electronics for undergraduate electrical and computer engineering students. The purpose of the fourth edition of the book is to continue to provide a foundation for analyzing and designing both analog and digital electronic circuits. A goal is to make this book very readable and student-friendly.

Most electronic circuit design today involves integrated circuits (ICs), in which the entire circuit is fabricated on a single piece of semiconductor material. The IC can contain millions of semiconductor devices and other elements and can perform complex functions. The microprocessor is a classic example of such a circuit. The ultimate goal of this text is to clearly present the operation, characteristics, and limitations of the basic circuits that form these complex integrated circuits. Although most engineers will use existing ICs in specialized design applications, they must be aware of the fundamental circuit's characteristics in order to understand the operation and limitations of the IC.

Initially, discrete transistor circuits are analyzed and designed. The complexity of circuits being studied increases throughout the text so that, eventually, the reader should be able to analyze and design the basic elements of integrated circuits, such as linear amplifiers and digital logic gates.

This text is an introduction to the complex subject of electronic circuits. Therefore, more advanced material is not included. Specific technologies, such as gallium arsenide, which is used in special applications, are also not included, although reference may be made to a few specialized applications. Finally, the layout and fabrication of ICs are not covered, since these topics alone can warrant entire texts.

DESIGN EMPHASIS

Design is the heart of engineering. Good design evolves out of considerable experience with analysis. In this text, we point out various characteristics and properties of circuits as we go through the analysis. The objective is to develop an intuition that can be applied to the design process.

Many design examples, design exercise problems, and end-of-chapter design problems are included in this text. The end-of-chapter design problems are designated with a "D". Many of these examples and problems have a set of specifications that lead to a unique solution. Although engineering design in its truest sense does not lead to a unique solution, these initial design examples and problems are a first step, the author believes, in learning the design process. A separate section, Design Problems, found in the end-of-chapter problems, contains open-ended design problems.

COMPUTER-AIDED ANALYSIS AND DESIGN

Computer analysis and computer-aided-design (CAD) are significant factors in electronics. One of the most prevalent electronic circuit simulation programs is Simulation Program with Integrated Circuit Emphasis (SPICE), developed at the University of California. A version of SPICE tailored for personal computers is PSpice, which is used in this text.

The text emphasizes hand analysis and design in order to concentrate on basic circuit concepts. However, in several places in the text, PSpice results are included and are correlated with the hand analysis results. Obviously, at the instructor's discretion, computer simulation may be incorporated at any point in the text. A separate section, Computer Simulation Problems, is found in the end-of-chapter problems.

In some chapters, particularly the chapters on frequency response and feedback, computer analysis is used more heavily. Even in these situations, however, computer analysis is considered only after the fundamental properties of the circuit have been covered. The computer is a tool that can aid in the analysis and design of electronic circuits, but is not a substitute for a thorough understanding of the basic concepts of circuit analysis.

PREREQUISITES

This book is intended for junior undergraduates in electrical and computer engineering. The prerequisites for understanding the material include dc analysis and steady-state sinusoidal analysis of electric circuits and the transient analysis of RC circuits. Various network concepts, such as Thevenin's and Norton's theorems, are used extensively. Some background in Laplace transform techniques may also be useful. Prior knowledge of semiconductor device physics is not required.

ORGANIZATION

The book is divided into three parts. Part 1, consisting of the first eight chapters, covers semiconductor materials, the basic diode operation and diode circuits, and basic transistor operations and transistor circuits. Part 2 addresses more advanced analog electronics, such as operational amplifier circuits, biasing techniques used in integrated circuits, and other analog circuits applications. Part 3 covers digital electronics including CMOS integrated circuits. Five appendices are included at the end of the text.

Content

Part 1. Chapter 1 introduces the semiconductor material and pn junction, which leads to diode circuits and applications given in Chapter 2. Chapter 3 covers the field-effect transistor, with strong emphasis on the metal-oxide-semiconductor FET (MOSFET), and Chapter 4 presents basic FET linear amplifiers. Chapter 5 discusses the bipolar junction transistor, with basic bipolar linear amplifier applications given in Chapter 6.

The frequency response of transistors and transistor circuits is covered in a separate Chapter 7. The emphasis in Chapters 3 through 6 was on the analysis and

design techniques, so mixing the two transistor types within a given chapter would introduce unnecessary confusion. However, starting with Chapter 7, both MOSFET circuits and bipolar circuits are discussed within the same chapter. Finally, Chapter 8, covering output stages and power amplifiers, completes Part 1 of the text.

Part 2. Chapters 9 through 15 are included in Part 2, which addresses more advanced analog electronics. In this portion of the text, the emphasis is placed on the operational amplifier and on circuits that form the basic building blocks of integrated circuits (ICs). The ideal operational amplifier and ideal op-amp circuits are covered in Chapter 9. Chapter 10 presents constant-current source biasing circuits and introduces the active load, both of which are used extensively in ICs. The differential amplifier, the heart of the op-amp, is discussed in Chapter 11, and feedback is considered in Chapter 12. Chapter 13 presents the analysis and design of various circuits that form operational amplifiers. Nonideal effects in analog ICs are addressed in Chapter 14, and applications, such as active filters and oscillators, are covered in Chapter 15.

Part 3. Chapters 16 and 17 form Part 3 of the text, and cover the basics of digital electronics. The analysis and design of MOS digital electronics is discussed in Chapter 16. The emphasis in this chapter is on CMOS circuits, which form the basis of most present-day digital circuits. Basic digital logic gate circuits are initially covered, then shift registers, flip-flops, and then basic A/D and D/A converters are presented. Chapter 17 introduces bipolar digital electronics, including emitter-coupled logic and classical transistor-transistor logic circuits.

Appendices. Five appendices are included at the end of the text. Appendix A contains physical constants and conversion factors. Manufacturers' data sheets for several devices and circuits are included in Appendix B. Standard resistor and capacitor values are given in Appendix C, and references and other reading sources are listed in Appendix D. Finally, answers to selected end-of chapter problems are given in Appendix E.

Order of Presentation

The book is written with a certain degree of flexibility so that instructors can design their own order of presentation of topics.

1. *Op-Amp Circuits:* For those instructors who wish to present ideal op-amp circuits as a first topic in electronics, Chapter 9 is written such that sections 9.1 through 9.5.5 can be studied as a first chapter in electronics.

Chapter Presentation
Ideal Op-Amp Circuits:
1. Chapter 9, Sections 9.1–9.5.5.
2. Chapters 1, 2, etc.

2. *MOSFETs versus Bipolars:* The chapters covering MOSFETs (3 and 4) and the chapters covering bipolars (5 and 6) are written independently of each other. Instructors, therefore, have the option of discussing MOSFETs before bipolars, as

given in the text, or discussing bipolars before MOSFETs in the more traditional manner.

Chapter Presentation

Text		Traditional	
Chapter	**Topic**	**Chapter**	**Topic**
1	pn Junctions	1	pn Junctions
2	Diode Circuits	2	Diode Circuits
3	MOS Transistors	5	Bipolar Transistors
4	MOSFET Circuits	6	Bipolar Circuits
5	Bipolar Transistors	3	MOS Transistors
6	Bipolar Circuits	4	MOSFET Circuits
etc.		etc.	

3. *Digital versus Analog:* For those instructors who wish to present digital electronics before analog electronics, Part 3 is written to be independent of Part 2. Therefore, instructors may cover Chapters 1, 2, 3, and then jump to Chapter 16.

Chapter Presentation:

Chapter	**Topic**
1	pn Junctions
2	Diode Circuits
3	MOS Transistors
16	MOSFET Digital Circuits
5	Bipolar Transistors
17	Bipolar Digital Circuits
etc.	Analog Circuits

NEW TO THE FOURTH EDITION

- Addition of over 250 new Exercise and Test Your Understanding Problems.
- Addition of over 580 new end-of-chapter problems.
- Addition of over 50 new open-ended Design Problems in the end-of-chapter problems sections.
- Addition of over 65 new Computer Simulation Problems in the end-of-chapter problems sections.
- Voltage levels in circuits were updated to more closely match modern day electronics.
- MOSFET device parameters were updated to more closely match modern day electronics.
- Chapter 9 was rewritten such that ideal op-amp circuits can be studied as a first topic in electronics.
- Maintained the mathematical rigor necessary to more clearly understand basic circuit operation and characteristics.

RETAINED FEATURES OF THE TEXT

- A short introduction at the beginning of each chapter links the new chapter to the material presented in previous chapters. The objectives of the Chapter, i.e., what the reader should gain from the chapter, are presented in the Preview section and are listed in bullet form for easy reference.
- Each major section of a chapter begins with a restatement of the objective for this portion of the chapter.
- An extensive number of worked examples are used throughout the text to reinforce the theoretical concepts being developed. These examples contain all the details of the analysis or design, so the reader does not have to fill in missing steps.
- An Exercise Problem follows each example. The exercise problem is very similar to the worked example so that readers can immediately test their understanding of the material just covered. Answers are given for each exercise problem so readers do not have to search for an answer at the end of the book. These exercise problems will reinforce readers' grasp of the material before they move on to the next section.
- Test Your Understanding exercise problems are included at the end of most major sections of the chapter. These exercise problems are, in general, more comprehensive that those presented at the end of an example. These problems will also reinforce readers' grasp of the material before they move on to the next section. Answers to these exercise problems are also given.
- Problem Solving Techniques are given throughout each chapter to assist the reader in analyzing circuits. Although there can be more than one method of solving a problem, these Problem Solving Techniques are intended to help the reader get started in the analysis of a circuit.
- A Design Application is included as the last section of each chapter. A specific electronic design related to that chapter is presented. Over the course of the book, students will learn to build circuits for an electronic thermometer. Though not every Design Application deals with the thermometer, each application illustrates how students will use design in the real world.
- A Summary section follows the text of each chapter. This section summarizes the overall results derived in the chapter and reviews the basic concepts developed. The summary section is written in bullet form for easy reference.
- A Checkpoint section follows the Summary section. This section states the goals that should have been met and states the abilities the reader should have gained. The Checkpoints will help assess progress before moving to the next chapter.
- A list of review questions is included at the end of each chapter. These questions serve as a self-test to help the reader determine how well the concepts developed in the chapter have been mastered.
- A large number of problems are given at the end of each chapter, organized according to the subject of each section. Many new problems have been incorporated into the fourth edition. Design oriented problems are included as well as problems with varying degrees of difficulty. A "D" indicates design-type problems, and an asterisk (*) indicates more difficult problems. Separate computer simulation problems and open-ended design problems are also included.
- Answers to selected problems are given in Appendix E. Knowing the answer to a problem can aid and reinforce the problem solving ability.
- Manufacturers' data sheets for selected devices and circuits are given in Appendix B. These data sheets should allow the reader to relate the basic concepts and circuit characteristics studied to real circuit characteristics and limitations.

SUPPLEMENTS

The website for Microeletronics features tools for students and teachers. Professors can benefit from McGraw-Hill's COSMOS electronic solutions manual. COSMOS enables instructors to generate a limitless supply of problem material for assignment, as well as transfer and integrate their own problems into the software. For students, there are profiles of electrical engineers that give students insight into the real world of electrical engineering by presenting interviews with engineers working at a number of businesses, from Fairchild Semiconductor to Apple. In addition, the website boasts PowerPoint slides, an image library, the complete Instructor's Solution Manual (password protected), data sheets, laboratory manual, and links to other important websites. You can find the site at **www.mhhe.com/neamen.**

ELECTRONIC TEXTBOOK OPTIONS

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

I am indebted to the many students I have taught over the years who have helped in the evolution of this text. Their enthusiasm and constructive criticism have been invaluable, and their delight when they think they have found an error their professor may have made is priceless. I also want to acknowledge Professor Hawkins, Professor Fleddermann, and Dr. Ed Graham of the University of New Mexico who have taught from the third edition and who have made excellent suggestions for improvement.

I want to thank the many people at McGraw-Hill for their tremendous support. To Raghu Srinivasan, publisher, and Lora Neyens, development editor, I am grateful for their encouragement and support. I also want to thank Mr. John Griffith for his many constructive suggestions. I also appreciate the efforts of project managers who guided the work through its final phase toward publication. This effort included gently, but firmly, pushing me through proofreading.

Let me express my continued appreciation to those reviewers who read the original manuscript in its various phases, a focus group who spent an entire precious weekend discussing and evaluating the original project, and the accuracy checkers who worked through the original examples, exercises, and problems to minimize any errors I may have introduced. My thanks also go out to those individuals who have continued to review the book prior to new editions being published. Their contributions and suggestions for continued improvement are incredibly valuable.

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Brief Table of Contents

Contents

Prologue to Digital Electronics

PREVIEW

Several basic digital electronics concepts are common to the remaining chapters of this text. These principles, which are usually covered in an introductory course in computer logic design, are reviewed briefly in this prologue.

In a digital system, information is represented solely in discrete or quantized form. Normally, only two discrete states are used, denoted as logic 0 and logic 1. The algebra applicable to the binary system was invented by George Boole (1815–1864) and is known as Boolean algebra. We do not use Boolean algebra directly in this text; however, some familiarity with it is beneficial in the analysis and design of digital integrated circuits. We will be directly concerned with basic Boolean operations and the corresponding logic gates.

Several techniques have been developed to aid in the reduction of Boolean expressions to a minimum set of variables. One common technique is the Karnaugh map. Though not used directly in this text, this technique is helpful in designing digital systems.

LOGIC FUNCTIONS AND LOGIC GATES

The three basic logic or Boolean operations are: NOT, AND, and OR. These operations can be described using a truth table.

The truth table and logic gate symbol for the NOT function is shown in Figure PR3.1(a). The bar over the output variable indicates the NOT function, or the complement. Since only two states of a variable are permitted, if $A = 0$, then $\bar{A} = 1$. The small circle at the output of the logic gate indicates a logic inversion. As depicted by the figure, this logic gate is also called an inverter.

Figure PR3.1(b) shows the truth table, logic gate symbol, and Boolean expression for the AND function. A logic 1 is produced at the output only when both inputs are a logic 1; otherwise, the output is a logic 0.

The truth table, logic gate symbol, and Boolean expression for the OR operation are shown in Figure PR3.1 (c). In this case, a logic 1 output is produced if either $A = 1$ or $B = 1$, or if both inputs are a logic 1.

Two other commonly used logic functions are the NAND and NOR. The NAND function is the complement of the AND operation, and the NOR function is the complement of the OR operation. The truth tables and logic gate symbols for these functions are shown in Figure PR3.2. Again, the small circle at the output of each logic gate indicates a logic inversion.

Finally, two additional logic functions useful in digital design are the exclusive-OR function and the exclusive-NOR function. Although these logic functions can be derived from a combination of the basic functions, they have their own logic