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Electronic Circuit Analysis and Design

Second Edition

电子电路分析与设计

第 2 版

Donald A. Neamen

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ELECTRONIC CIRCUIT ANALYSIS AND DESIGN

SECOND EDITION

DONALD A. NEAMEN
University of New Mexico

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——信息技术学科和电气工程学科系列

出 版 说 明

郑大钟

清华大学信息科学与技术学院

当前，在我国的高等学校中，教学内容和课程体系的改革已经成为教学改革中的一个非常突出的问题，而为数不少的课程教材中普遍存在的“课程体系老化，内容落伍时代，本研层次不清”的现象又是其中的急需改变的一个重要方面。同时，随着科教兴国方针的贯彻落实，要求我们进一步转变观念扩大视野，使教学过程适应以信息技术为先导的技术革命和我国社会主义市场经济体制的需要，加快教学过程的国际化进程。在这方面，系统地研究和借鉴国外知名大学的相关教材，将会对推进我们的课程改革和推进我国大学教学的国际化进程，乃至对我们一些重点大学建设国际一流大学的努力，都将具有重要的借鉴推动作用。正是基于这种背景，我们决定在国内推出信息技术学科和电气工程学科国外知名大学原版系列教材。

本系列教材的组编将遵循如下的几点基本原则。(1)书目的范围限于信息技术学科和电气工程学科所属专业的技术基础课和主要的专业课。(2)教材的范围选自于具有较大影响且为国外知名大学所采用的教材。(3)教材属于在近5年内所出版的新书或新版书。(4)教材适合于作为我国大学相应课程的教材或主要教学参考书。(5)每本列选的教材都须经过国内相应领域的资深专家审看和推荐。(6)教材的形式直接以英文原版形式印刷出版。

本系列教材将按分期分批的方式组织出版。为了便于使用本系列教材的相关教师和学生从学科和教学的角度对其在体系和内容上的特点和特色有所了解，在每本教材中都附有我们所约请的相关领域资深教授撰写的影印版序言。此外，出于多样化的考虑，对于某些基本类型的课程，我们还同时列选了多于一本的不同体系、不同风格和不同层次的教材，以供不同要求和不同学时的同类课程的选用。

本系列教材的读者对象为信息技术学科和电气工程学科所属各专业的本科生，同时兼顾其他工程学科专业的本科生或研究生。本系列教材，既可采用作为相应课程的教材或教学参考书，也可提供作为工作于各个技术领域的工程师和技术人员的自学读物。

组编这套国外知名大学原版系列教材是一个尝试。不管是书目确定的合理性，教材选择的恰当性，还是评论看法的确切性，都有待于通过使用和实践来检验。感谢使用本系列教材的广大教师和学生的支持。期望广大读者提出意见和建议。

"Electronic Circuit Analysis and Design"(第2版)

影印版序

"Electronic Circuit Analysis and Design"(第2版)一书包括半导体器件及其基本应用、模拟电子技术和数字电子技术三个部分,共十七章。其中第一部分有九章,主要阐述半导体材料、二极管及其电路、双极型晶体管及基本放大电路、单极型晶体管及基本放大电路、频率响应、输出级和功率放大电路、理想运放及由它组成的基本运算电路;第二部分有六章,主要围绕集成运算放大电路阐明其偏置电路及有源负载、差分及多级放大电路、反馈及稳定性、运算放大电路分析、运算放大电路中非理想因素的影响、集成电路的应用及设计;第三部分结合主要门电路、触发器、存储器等阐明MOS管和双极型管集成数字电路的结构特点及电气特性。

该书与目前国内出版的同类教材相比具有其明显的特色。它的第一部分包含了国内同类教材的半导体器件和模拟电路的基础部分,可以作为对大学本科非电类学生的基本要求;第二、三部分所讲述的内容比国内同类教材中类似部分更加深入非富,因而可以作为同类课程的参考书。

该书虽然篇幅较大(约1200页),但各章结构合理,层次清楚,思路清晰,叙述详细,文字流畅,因而易于阅读。更具特色的是,书中插入大量例题,一般在叙述一个重要问题之后,均有例题及其评述或讨论,有些还给出设计举例、自测题等。因此便于自学,使读者像面对一个循循善诱的老师一样,在启发引导下,由浅入深,循序渐进。

全书每一章的最后一节均为"SUMMARY",并有"CHECKPOINT"和"REVIEW QUESTIONS",以说明读者学完本章后应达到的目的和本章所讨论的基本问题。教学基本要求明确。

各章后面的习题均分为三部分,第一部分"PROBLEMS"是按"节"出题,习题所涉及的知识主要针对本节内容;第二部分"COMPUTER SIMULATION"是计算机仿真习题,以训练读者对电子电路CAD软件的应用能力;第三部分"DESIGN PROBLEMS"是提高题,训练读者对所学知识的综合应用能力。习题要求层次分明。

本书还配有光盘,以方便学生使用电子电路分析软件,加深对本课程内容的理解。

本书正好弥补国内同类教材叙述不够详尽,内容较为浓缩,例题和习题较少的缺憾。因此,无论对于教师还是对于学生,本书均具有很好的参考价值。

华成英
清华大学自动化系
2000年11月

ABOUT THE AUTHOR

Donald Neamen is a professor and associate chairman for the Department of Electrical and Computer Engineering at The University of New Mexico. He received his Ph.D. from The University of New Mexico and then became an electronics engineer at the Solid State Sciences Laboratory at Hanscom Air Force Base. In 1976, he became an Assistant Professor in the EECE department at The University of New Mexico, where he teaches the semiconductor physics and devices course and electronics courses.

In 1980, Professor Neamen received the Outstanding Teacher Award for The University of New Mexico. In 1983 and 1985, he was recognized as Outstanding Teacher in the College of Engineering by Tau Beta Pi. In 1990 and 1994 to 1999, he received the Faculty Recognition Award, presented by graduating EECE students. He was also honored with the Teaching Excellence Award in the College of Engineering for 1994.

In addition to his teaching, Professor Neamen has worked in industry with Martin Marietta, Sandia National Laboratories, and Raytheon Company. He has published many papers and is the author of *Semiconductor Physics and Devices: Basic Principles*, 2nd ed.

PREFACE

PHILOSOPHY AND GOALS

Electronic Circuit Analysis and Design is intended as a core text in electronics for undergraduate electrical and computer engineering students. The purpose of the second edition of the book is to provide a foundation for analyzing and designing both analog and digital electronic circuits.

A majority of electronic circuits today are designed as integrated circuits (ICs), in which the entire circuit is fabricated on a single piece of semiconductor material. The integrated circuit may contain over a million semiconductor devices and other elements, and may perform many complex functions. The microprocessor is an example of such a circuit. The ultimate objective is to understand the operation, characteristics, and limitations of these integrated circuits.

Initially, discrete transistor circuits are analyzed and designed. The complexity of the circuits studied is then increased. Eventually the reader should be able to analyze and design the basic elements of integrated circuits, such as 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 are 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.

COMPUTER-AIDED ANALYSIS AND DESIGN (PSPICE)

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 the personal computer is PSpice. A comprehensive appendix on the PSpice circuit modeling program is included in this text. Example programs are also given in Appendix B. Instructors may introduce PSpice at any point in the course.

Electronics Workbench (EWB) simulates over 100 circuits taken from the figures, examples, and problems marked by the icon  . These circuit files are on the CD-ROM that accompanies this text. Current users of EWB have access to all 100 files. Readers unfamiliar with EWB can use the free demonstration to use 20 unlocked files. If you wish to purchase the Electronics Workbench program, it is provided on the CD and can be unlocked for $79 by contacting Interactive Image Technologies, the maker of Electronics Workbench.

It is our belief that the use of computer analysis must be handled with care in an introductory electronics course. The objective in this introductory course is to learn the fundamental aspects of device models, circuit configurations, and basic circuit properties. We believe this learning is enhanced by going through the hand analysis and calculations. In this course, then, the computer analysis can be used as a check of the hand analysis results.

In several places in the text, PSpice results are included and are correlated with the hand analysis results. The PSpice capture schematics are included, as well as the computer simulation results. Specific computer simulation problems are included at the end of most chapters. However, at the instructor's discretion, PSpice can be used for any exercise or problem, to verify the hand analysis.

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 it is not a substitute for a thorough understanding of the basic concepts of circuit analysis.

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. These problems are designated with an RD or a D. The RD is for redesign and generally refers to a circuit that has already been designed. The redesign problems are generally less complicated and may lead to a unique solution. Meeting an explicit set of design criteria is a first step in the design process. The D is for design problems that generally do not have unique solutions. A separate section in the end-of-chapter problems contains open-ended design problems.

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 I, consisting of the first eight chapters, covers semiconductor devices and basic circuit applications. Chapter 1 introduces semiconductor material and the diode, which leads to the application of diodes in circuits, given in Chapter 2. Chapter 3 covers

the bipolar junction transistor, with basic linear amplifier applications given in Chapter 4. Chapter 5 discusses the field-effect transistor (FET), with strong emphasis on the metal-oxide-semiconductor FET (MOSFET), and Chapter 6 covers basic FET linear amplifier circuits. Although the bipolar transistor is discussed before the FET, these chapters are written to stand alone, so the FET and its circuits can be covered before the bipolar transistor. The frequency response of transistors and transistor circuits is covered in Chapter 7. Finally, Chapter 8 addresses special applications, including power amplifiers.

Although many of the circuit configurations for bipolar transistors and FETs are very similar, we feel that the emphasis in Part I should be on analysis and design techniques. We therefore feel that mixing the two types of transistors in the same chapter would introduce unnecessary confusion. In Part II, however, both bipolar and FET circuits are evaluated in the same chapters.

Part I in essence presents the basic components of electronics. Part II covers more advanced topics in analog electronics, and Part III considers digital electronic circuits. Again, these two parts are written to stand alone, so the order of study of advanced analog and digital electronics can be interchanged, although it may be somewhat disconcerting to both students and instructors to jump from Chapter 6 to Chapter 16.

Chapters 9 through 15 are included in Part II, which addresses more advanced analog electronics. In this part, the emphasis is placed on the operational amplifier. The ideal operational amplifier and ideal op-amp circuits are covered in Chapter 9. Chapter 10 analyzes constant-current source biasing circuits and introduces the active load, both of which are used extensively in integrated circuits (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 III, consisting of Chapters 16 and 17, covers the basics of digital electronics, including both FET and bipolar logic gates. Chapter 16 analyzes MOS digital electronic circuits. Since MOSFETs are used extensively in digital electronics, they are covered before bipolar circuits. Chapter 17 presents bipolar digital circuits, including emitter-coupled logic and classic transistor–transistor logic circuits.

Six appendixes are included at the end of the text. Appendix A contains physical constants and conversion factors. Appendix B is a discussion of PSpice, including analysis types. Several examples are presented in which the PSpice circuit schematic is given as well as the output response. This will allow the reader to get started with PSpice. Several available texts provide a complete discussion of SPICE and PSpice.

Manufacturers' data sheets for several devices and circuits are included in Appendix C. References are listed in Appendix E, and answers to selected end-of-chapter problems are given in Appendix F.

FEATURES OF THE SECOND EDITION

- A preview section introduces each chapter. This preview links the chapter to previous chapters and states the chapter's goals, i.e., what the reader should gain from 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.
- Exercise or drill problems are included throughout the chapter. These problems are generally placed immediately after an example problem, rather than at the end of a long section, so that readers can immediately test their understanding of the material just covered. Answers are given for each drill problem so readers do not have to search for an answer at the end of the book. These problems will reinforce readers' grasp of the material before they move on to the next section.
- Problem Solving Techniques are given throughout each chapter to assist the reader in analyzing circuits. Although there may 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 Summary section follows the text of each chapter. This section summarizes the overall results derived in the chapter and reviews the basic concepts developed.
- 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. Approximately 300 new problems have been included in the second edition. Design oriented problems are included as well as problems with varying degrees of difficulty. Again, RD indicates redesign-type problems, D indicates design-type problems, and an asterisk (*) indicates more difficult problems. Separate computer simulation problems and open-ended design problems are also included.
- An Electronics Workbench CD-ROM is included with the second edition of the text. The CD-ROM contains a copy of Electronics Workbench software and approximately 100 circuit simulations from the text.
- Answers to selected problems are given in an appendix. Knowing the answer to a problem can aid and reinforce the problem solving.
- Manufacturers' data sheets for selected devices and circuits are given in another appendix. These data sheets should allow the reader to

relate the basic concepts and circuit characteristics studied to real circuit characteristics and limitations.

SUPPLEMENTS

The book is supported by the following supplements:

- A CD-ROM containing a copy of Electronics Workbench software and circuit simulations is provided with each book.
- Solutions Manual, available to instructors in paper and electronic form.
- Transparency masters of important figures.
- A Web site containing PowerPoint slides of 200 important figures, a solutions manual, links to Electronics Workbench and other important sites, and text updates. The URL for the Web site is http://www.mhhe.com/neamen.

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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 Professors Cox, Hawkins, and McNeil at the University of New Mexico who have taught from the first edition and who have made excellent suggestions for improvement.

The University of New Mexico has my appreciation for providing an atmosphere conducive to writing this book.

I want to thank the many people at McGraw-Hill for their tremendous support. To Tom Casson, publisher, and Catherine Fields, sponsoring editor, I am grateful for their encouragement and support. A special thanks to Kelley Butcher, senior developmental editor at McGraw-Hill. Her attention to the plethora of details, her unwavering support, and her tremendous enthusiasm throughout the entire project are especially recognized and appreciated. I also appreciate the efforts of Karen Nelson, project manager, who guided the work through its final phase toward publication. This effort included gently, but firmly, pushing me through proofreading.

Four special groups of people deserve my thanks. These are the 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 the examples, exercises, and problems to minimize any errors I may have introduced. The fourth group consists of those individuals who have reviewed the first edition and the manuscript for the second edition. The efforts and suggestions made by all of these individuals have made this a better book. These people are recognized for their valuable contributions.

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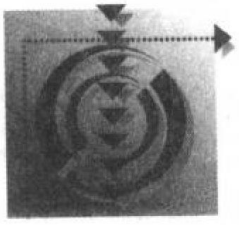
Donald A. Neamen

Industry Insight



RICHARD J. VALENTINE
Principal Staff Engineer
Motorola, Inc.

"Discrete semiconductor devices form the basis of most electronic circuits. Even complex integrated devices like microcomputer chips are designed from individual diodes and transistors. Understanding how these individual devices function is essential before an engineer can start a circuit design, whether it is a modest home computer power supply or a 5-million-transistor microprocessor integrated circuit. Future electronic designs will incorporate more semiconductor devices to achieve higher efficiency levels. Discrete power semiconductor and microcontroller devices allow motors to perform smarter with less power consumption, which is significant when you realize that half of the world's electric energy supply is consumed just by electric motors.

Each type of semiconductor device has unique properties that are optimized for different circuit requirements. Learning these properties enables the circuit designer to select the correct units quickly. The time spent learning how each discrete semiconductor device type operates and interacts with other components is always rewarded. For example, our engineering team was given a task of designing a motor control unit for electric vehicles. We quickly determined the best power transistor and rectifier types, based on our education in semiconductor technology. After building and testing the electric vehicle motor controller, we focused on areas of improvement for the semiconductor device design, again based on our knowledge of semiconductor theory.

Any career in electronics will involve the use, and probably the design, of semiconductor devices. Mastering the material presented in the following chapters is important for both the technician, who will be testing diodes, transistors, and microchips, and the engineer, who will be designing these semiconductor devices into electronic equipment."

BRIEF TABLE OF CONTENTS

PART III

DIGITAL ELECTRONICS 1001

C O N T E N T S