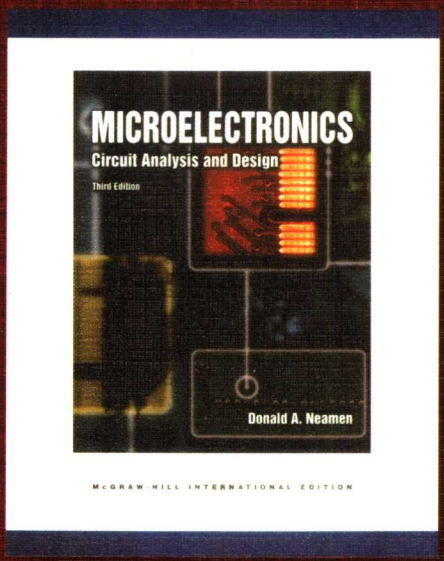
Mc Graw Hill Education

清华版双语教学用书



电子电路分析与设计（第3版）
——数字电子技术

Microelectronics
Circuit Analysis and Design
(Third Edition)

Donald A. Neamen

清华大学出版社

Mc Graw Hill

清华版双语教学用书

电子电路分析与设计（第3版）

——数字电子技术

Microelectronics

Circuit Analysis and Design

(Third Edition)

Donald A. Neamen

清华大学出版社
北京

Donald A. Neamen
EISBN: 0-07-125443-9

北京市版权局著作权合同登记号 图字：01-2006-7231

图书在版编目（CIP）数据

电子电路分析与设计＝Microelectronics Circuit Analysis and Design. 数字电子技术：第3版：英文/（美）尼曼（Neamen, D. A.）著. —影印本. —北京：清华大学出版社，2007.11
（清华版双语教学用书）
ISBN 978-7-302-15684-0

Ⅰ. 电… Ⅱ. 尼… Ⅲ. ①电子电路－电路设计－双语教学－教材－英文 ②电子电路－电路分析－双语教学－教材－英文 ③数字电路－电子技术－双语教学－教材－英文Ⅳ. TN710 TN79

中国版本图书馆 CIP 数据核字（2007）第 106275 号

责任编辑： 王一玲
责任印制： 孟凡玉
出版发行： 清华大学出版社
http://www.tup.com.cn
c-service@tup.tsinghua.edu.cn
社 总 机： 010-62770175
投稿咨询： 010-62772015
地　　址： 北京清华大学学研大厦 A 座
邮　　编： 100084
邮购热线： 010-62786544
客户服务： 010-62776969
印 刷 者： 北京嘉实印刷有限公司
装 订 者： 三河市新茂装订有限公司
经　　销： 全国新华书店
开　　本： 200×260　**印张：** 12.5
版　　次： 2007 年 11 月第 1 版　2007 年 11 月第1 次印刷
印　　数： 1～3000
定　　价： 25.00 元

Microelectronics Circuit Analysis and Design, Third Edition
影印版序

清华大学出版社曾经于2000年引进Donald A. Neamen教授的《电子电路分析与设计》(Electronic Circuit Analysis and Design)(第2版),受到了国内广大高校师生的欢迎。最近,本书推出了第3版,应清华大学出版社之邀,本人再次推荐本书。

Microelectronics Circuit Analysis and Design(第3版)与第2版在总体结构、章节安排、体例、内容编排和叙述方法上基本相同。

全书包括半导体器件及其基本应用、模拟电子学和数字电子学三个部分,共17章。第一部分包括第1～8章,主要阐述半导体材料和二极管、二极管电路、场效应管及其放大电路、晶体三极管及其放大电路、频率响应、输出级和功率放大电路等。第二部分包括第9～15章,主要阐述理想运放及其基本应用、集成电路的偏置电路和有源负载、差分及多级放大电路、反馈及稳定性、运算放大电路、运算放大电路中非理性因素的影响、集成电路的应用和设计等。第三部分包括第16和17章,主要阐述NMOS、CMOS、BiCMOS、ECL逻辑电路的组成,不同类型门电路的工作原理和电气特性,触发器、时序逻辑电路、存储器的构成和逻辑功能,并介绍模数转换器和数模转换器的基本组成和工作原理。

一、本书第3版与第2版的主要区别

1. 上述三个部分的前面增加了“序言”,以概述有关的基本知识、基本概念和基本方法。“序言1”是电子学序言,介绍电子技术发展简史、有源元件和无源元件、电子电路方框图、分立和集成电路、模拟信号和数字信号等基本知识。“序言2”是电子设计序言,介绍设计流程、系统设计和电子设计的方法和步骤。“序言3”是数字电子学序言,介绍逻辑代数与逻辑门、逻辑电平、噪声容限、传输时间和开关时间等数字电路的有关概念和方法。

2. 各章均增加了“设计应用”一节,设计题目均为结合本章基本内容的实际问题。例如,利用二极管、MOSFET管和BJT管设计电子温度计,利用二极管和稳压管设计直流电源,利用FET和BJT设计实用放大器,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。

3. 在第一部分中,虽然章节内容基本没变,但将场效应管及其放大电路置于晶体三极管及其放大电路之前,适应了集成电路的发展和当前芯片应用的现状。此外,在全书中有关场效应管的例题习题也略有增加。

4. 在第三部分中,增加了模数转换器和数模转换器部分,讲述了有关基本概念、常见电路和转换原理,使数字电子学部分更加全面。

二、本书的基本特点

1. 内容丰富,视野开阔,知识面较宽,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基本要求，因而可作为电子技术基础及同类课程的参考书或教材。

2. 本书虽然篇幅较多（1300 多页），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。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。

3. 全书每一章的最后一节均为“Summary”，并有“Checkpoint”和“Review Questions”，以说明学完本章后应达到的目的和本章所讨论的基本问题。各章后面的习题均分为三部分，第一部分“Problems”按节出题，习题所涉及的知识主要针对本节基本内容，以满足教学基本要求；第二部分“Computer Analysis Problems”是计算机仿真习题，以训练对 EDA 软件的应用能力；第三部分“Design Problems”是提高题，以训练对所学知识的综合应用能力。三种习题的教学目的层次分明。

4. 设计举例单独设节，强调理论联系实际，且叙述具有示范性，和各章的“Design Problems”相互呼应，以提高电子电路的设计能力。

综上所述，与国内出版的同类教材相比，本书具有明显的特色。它正好弥补国内同类教材因篇幅所限叙述不够详尽、内容较为浓缩、例题和习题较少、设计举例不多的缺憾。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。

另外，为了更好地适应国内教学的需要，并根据国内电子技术类课程教学的特点，将本书分成三册出版。这样可以更加方便读者选用。第一册为《半导体器件及其基本应用》，包括原版书的第 1～8 章；第 2 册为《模拟电子技术》，包括原版书的第 9～15 章；第 3 册为《数字电子技术》，包括原版书的第 16 和 17 章。

华成英

2007 年 3 月于清华园

注：华成英系清华大学自动化系教授，首届国家级精品课程“电子技术基础”课程负责人，国家教学名师。

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 third edition of the book is to provide a foundation for analyzing and designing both analog and digital electronic circuits.

The majority of electronic circuit design today involves using integrated circuits (ICs). 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 an example of such a circuit. The ultimate goal of this text is to understand the operation, characteristics, and limitations of the basic circuits that form 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 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.

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 personal computers 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.

The text emphasizes hand analysis and design. However, in several places in the text, PSpice results are included and are correlated with the hand analysis results. The PSpice capture schematic diagrams 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 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 in this text. The end-of-chapter design problems are designated with a D. Many of these design examples and problems have a set of specifications that lead to a unique solution. Engineering design in its truest sense does not lead to a unique solution. Although the type of design problem given in the text may not be design in its strictest form, the author believes that this is a first step in learning the design process. A separate section, Design Application, found 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 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. Six appendices are included at the end of the text.

Part 1. Chapter 1 introduces the semiconductor material and pn junction, which leads to the 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 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

Possible Order of Initial 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

of discussing MOSFETs before bipolars as given in the text, or discussing bipolars before MOSFETs in the more traditional manner as shown in the following table.

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.

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. This jump may be somewhat disconcerting to students, but it is possible.

Appendices. Six appendices are included at the end of the text. Appendix A contains physical constants and conversion factors. Appendix B is a discussion of PSpice, including examples of various types of analyses. Several examples are presented in which the PSpice circuit schematic diagram is given as well as the output response. This will allow the reader to get started with PSpice.

Manufacturers' data sheets for several devices and circuits are included in Appendix C. Standard resistor and capacitor values are given in Appendix D, and references and other reading sources are listed in Appendix E. Finally, answers to selected end-of-chapter problems are given in Appendix F.

FEATURES OF THE THIRD EDITION

- 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 third 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 F. 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 C. 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 a wide variety of supplements both online and in addition to the text. The book's website contains resources for both instructors and students. The student portion of the site contains two new features: algorithmic problems and Profiles. The algorithmic problems allow students to practice step-by-step problem-solving using a recursive computational procedure to create an infinite number of problems. The Profiles give students insight into the real world of electrical engineering by presenting interviews with engineers working at a number of different businesses, from Fairchild Semiconductor to Apple. A number of useful links also appear on the site.

The secure and convenient instructor portion of the site contains PowerPoints with all figures from the text, the full solutions, and a laboratory manual. In addition, instructors can access a demo for COSMOS, McGraw-Hill's new tool for professors.

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, Dr. Vadiee, and Dr. Ed Graham of the University of New Mexico who have taught from the second edition and who have made excellent suggestions for improvement.

I want to thank the many people at McGraw-Hill for their tremendous support. To Suzanne Jeans, publisher, Michael Hackett, sponsoring editor, and Rebecca Olson, 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 Peggy Lucas and Sheila Frank, project managers, who both guided the work through its final phase toward publication. This effort included gently, but firmly, pushing me through proofreading.

Five 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 through the original examples, exercises, and problems to minimize any errors I may have introduced. The fourth group consists of those individuals who reviewed the first edition prior to the second edition, and the fifth group consists of those individuals who reviewed the second edition prior to the third edition. These people are recognized for their valuable contributions.

REVIEWERS FOR THE FIRST EDITION

Timothy F. Darling
University of California—Santa Barbara
Daniel J. Moore
Rose Hulman Institute of Technology
R.G. Deshmukh
Florida Institute of Technology
Khalid Najafi
University of Michigan—Ann Arbor
Godi Fischer
University of Rhode Island
Bruce Johnson
University of Nevada—Reno
Dennis Polla
University of Minnesota
Donnie K. Reinhard
Michigan State University
Raymond S. Winton
Mississippi State University
Wesley G. Lawson
University of Maryland
Eugene D. Fabricius
California Polytechnic State University—San Luis Obispo
Glen C. Gerhard
University of Arizona
David J. Dumin
Clemson University
James C. Gottling
Ohio State University
Daniel W. Hart
Valparaiso University
William Wilson
Rice University
Anura P. Jayasumana
Colorado State University
Charles E. Smith
University of Mississippi
Robert J. Krueger
University of Wisconsin—Milwaukee
Philip C. Munro
Youngstown State University
Thomas Wong
Illinois Institute of Technology

Focus Group Participants

Donnie K. Reinhard
Michigan State University
Richard Hester
Texas Instruments
Peter E. Engler
New Jersey Institute of Technology
Mahmood Navi
California Polytechnic State University—San Luis Obispo
Stuart M. Wentworth
Auburn University
Farid Tranjan
University of North Carolina—Charlotte
Arthur F. Witulski
University of Arizona
Michael Hassul
California State University—Long Beach
Glen C. Gerhard
University of Arizona
Daniel J. Moore
Rose Hulman Institute of Technology
Ronald S. Gyurcsik
North Carolina State University

Accuracy Checkers

Daniel J. Moore
Rose Hulman Institute of Technology
William Davis
Virginia Polytechnic Institute and State University
Paul Weston
University of Illinois—Urbana—Champaign
Hongyan Diao
University of Houston
Calvin L. Finn
University of Idaho
Tony King
University of Houston
George Aliftiras
Virginia Polytechnic Institute and State University
Howard Hao Wu
University of Houston
Montanez Wade
Tennessee State University
William Schneider
University of Houston

Carl Erickson
Messiah College
William Kuhn
Virginia Polytechnic Institute and State University
Maritza Kozicki
Sam Stone

Reviewers for the Second Edition

Kay D. Baker
Utah State University
Paul Benkeser
Georgia Institute of Technology
John Brews
University of Arizona
Steven M. Durbin
Florida State University
Martin Feldman
Louisiana State University
Jack Lee
University of Texas at Austin
Daniel J. Moore
Rose Hulman Institute of Technology
Farid Najm
University of Illinois—Urbana—Champaign
Mehmet Ozturk
North Carolina State University
Donald Parker
Texas A&M University
Andrew Rys
Kansas State University
Mahmoud Wagdy
California State University—Long Beach

Reviewers for the Third Edition

Richard H. Cockrum
California State University, Pomona
Marc Cahay
University of Cincinatti
Sannasi Ramanan
Rochester Institute of Technology
Stephen M. Goodnick
Arizona State University
Juin J. Liou
University of Central Florida
Mark J. Wharton
Pennslyvania State University
Ron Roscoe
Massachusetts Institute of Technology
John Scalzo
Louisiana State University
Rongqing Hui
University of Kansas
Richard Kwor
University of Colorado, Colorado Springs
Weizhong Wang
University of Wisconsin, Milwaukee
Norman R. Cox
University of Missouri, Rolla
Doran Baker
Utah State University

Please forward any comments, suggestions, or corrections concerning the book to me in care of McGraw-Hill, 111 Huntington Ave., 6th Floor, Boston, MA 02155.

Donald A. Neamen

Brief Table of Contents

PROLOGUE I

PROLOGUE TO ELECTRONICS

PART 1

SEMICONDUCTOR DEVICES AND BASIC APPLICATIONS

Chapter 1
Semiconductor Materials and Diodes

Chapter 2
Diode Circuits

Chapter 3
The Field-Effect Transistor

Chapter 4
Basic FET Amplifiers

Chapter 5
The Bipolar Junction Transistor

Chapter 6
Basic BJT Amplifiers

Chapter 7
Frequency Response

Chapter 8
Output Stages and Power Amplifiers

PROLOGUE II

PROLOGUE TO ELECTRONIC DESIGN

PART 2

ANALOG ELECTRONICS

Chapter 9
Ideal Operational Amplifiers and Op-Amp Circuits

Chapter 10
Integrated Circuit Biasing and Active Loads

Chapter 11
Differential and Multistage Amplifiers

Chapter 12
Feedback and Stability

Chapter 13
Operational Amplifier Circuits

Chapter 14
Nonideal Effects in Operational Amplifier Circuits

Chapter 15
Applications and Design of Integrated Circuits

PROLOGUE III

PROLOGUE TO DIGITAL ELECTRONICS 1

PART 3

DIGITAL ELECTRONICS 5

Chapter 16
MOSFET Digital Circuits 7

Chapter 17
Bipolar Digital Circuits 117

Appendix
Answers to Selected Problems 176

Contents

PROLOGUE III

PROLOGUE TO DIGITAL ELECTRONICS 1

Preview 1
Logic Functions and Logic Gates 1
Logic Levels 3
Noise Margin 3
Propagation Delay Times and Switching Times 4
Summary 4

PART 3

DIGITAL ELECTRONICS 5

Chapter 16 **MOSFET Digital Circuits 7**

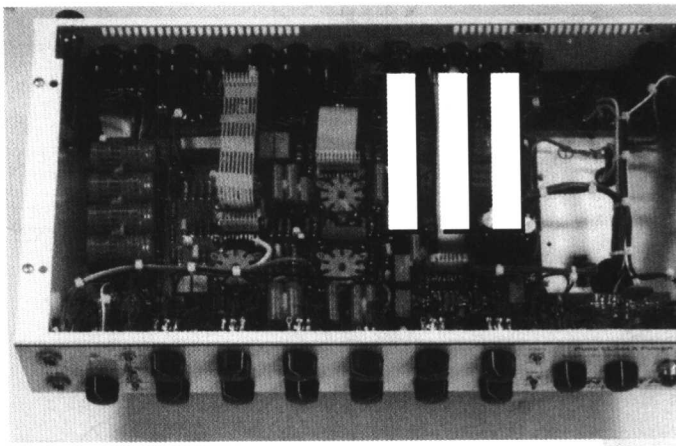
Preview 7
16.1 NMOS Inverters 8
16.2 NMOS Logic Circuits 25
16.3 CMOS Inverter 30
16.4 CMOS Logic Circuits 44
16.5 Clocked CMOS Logic Circuits 52
16.6 Transmission Gates 55
16.7 Sequential Logic Circuits 63
16.8 Memories: Classifications and Architectures 69
16.9 RAM Memory Cells 73
16.10 Read-Only Memory 82
16.11 Data Converters 87
16.12 Design Application: A Static CMOS Logic Gate 93
16.13 Summary 95
Problems 99

Chapter 17 **Bipolar Digital Circuits 117**

Preview 117
17.1 Emitter-Coupled Logic (ECL) 118
17.2 Modified ECL Circuit Configurations 129
17.3 Transistor–Transistor Logic 139
17.4 Schottky Transistor–Transistor Logic 151
17.5 BiCMOS Digital Circuits 158
17.6 Design Application: A Static ECL Gate 160
17.7 Summary 162
Problems 163

Appendix **Answers to Selected Problems 176**

Prologue to Digital Electronics



Courtesy of Mesa Boogie, Inc.

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 is 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.

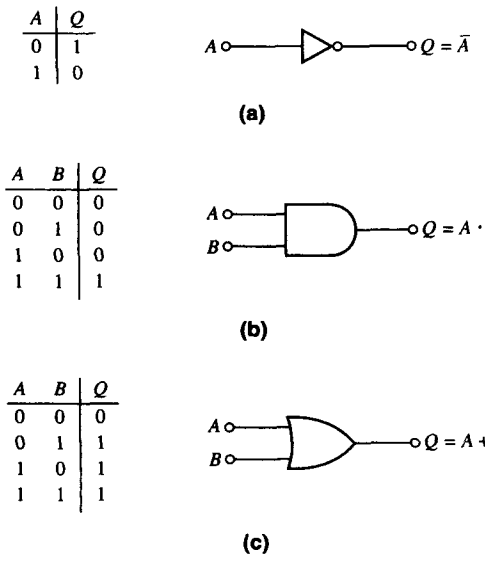


Figure PR3.1 Truth tables, logic gate symbols, and Boolean expressions: (a) NOT function, (b) AND function, and (c) OR function

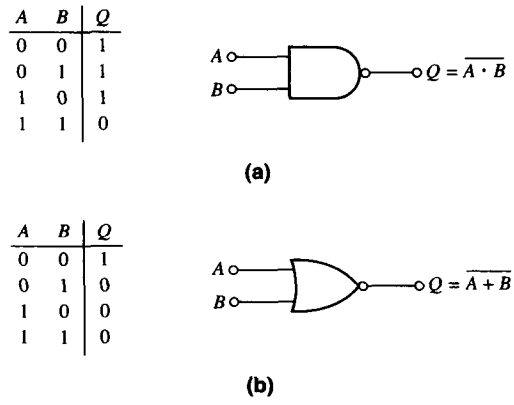


Figure PR3.2 Truth tables, logic gate symbols, and Boolean expressions: (a) NAND function and (b) NOR function

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 gate symbols. The truth tables, logic gate symbols, and Boolean expressions for these operations are shown in Figure PR3.3. In the exclusive-OR operation, the output becomes a logic 1 when either $A = 1$ or $B = 1$, but not when both are a logic 1. The output of the exclusive-NOR is the complement of the exclusive-OR function.

In the following sections of this prologue, we briefly describe the basic logic functions and logic gates with two input variables, although more than two are

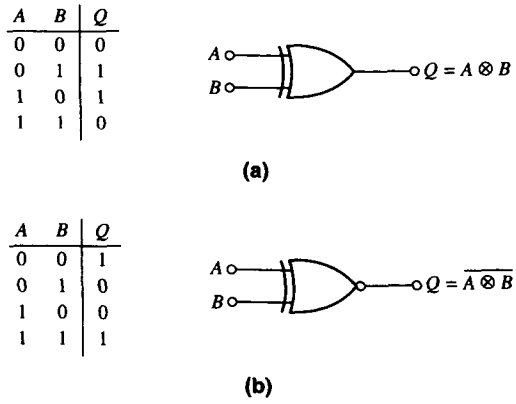


Figure PR3.3 Truth tables, logic gate symbols, and Boolean expressions: (a) exclusive-OR function and (b) exclusive-NOR function