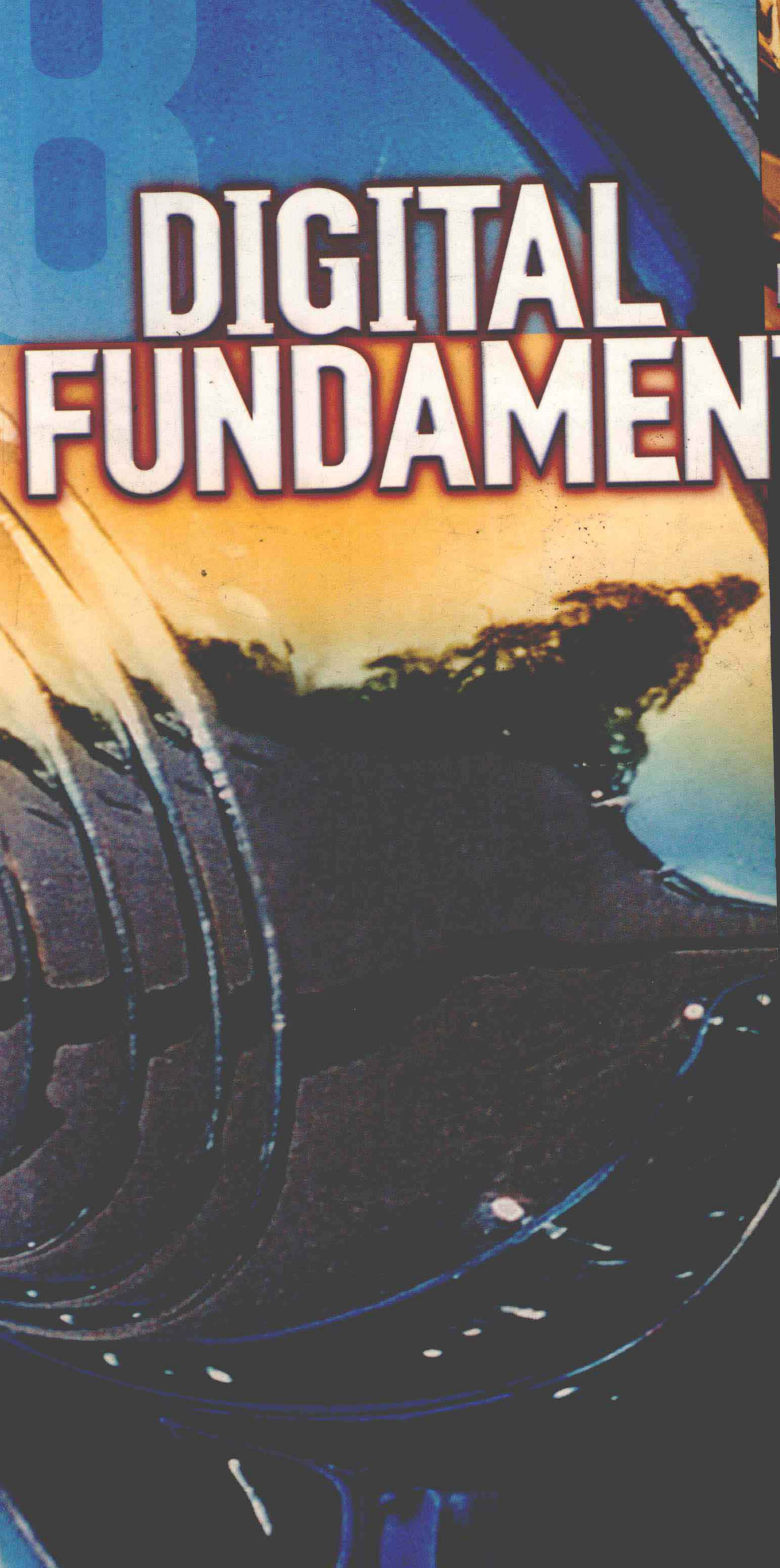
DIGITAL FUNDAMENTALS

Eighth Edition

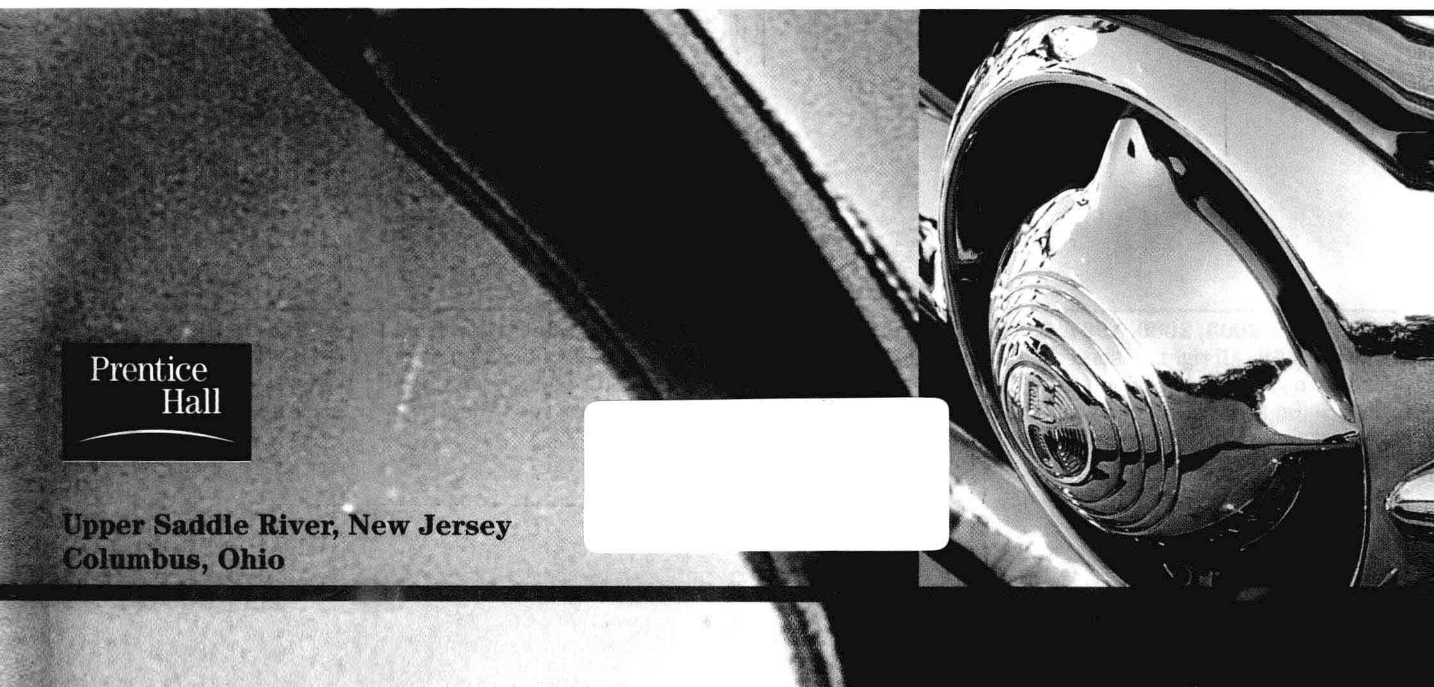


FLOYD

EIGHTH EDITION

DIGITAL FUNDAMENTALS

Thomas L. Floyd



Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

Library of Congress Cataloging-in-Publication Data

Floyd, Thomas L.
Digital fundamentals / Thomas L. Floyd.— 8th ed.
p. cm.
ISBN 0-13-094200-6 (alk. paper)
1. Digital electronics. 2. Logic circuits. I. Title.

TK7868.D5 F53 2003
621.39′5—dc21

2002019750

Editor in Chief: Stephen Helba
Acquisitions Editor: Dennis Williams
Development Editor: Kate Linsner
Production Editor: Rex Davidson
Design Coordinator: Karrie Converse-Jones
Text Designer: Seventeenth Street Studios
Cover Designer: Thomas Borah
Cover Photo: PhotoDisc
Production Manager: Pat Tonneman
Illustrations: Jane Lopez and Steve Botts

The book was set in Times Roman by The Clarinda Company and was printed and bound by Von Hoffmann Press, Inc. The cover was printed by Phoenix Color Corp.

Chapter opening photos and Troubleshooting photo by EyeWire, Inc.

Pearson Education Ltd.
Pearson Education Australia Pty. Limited
Pearson Education Singapore Pte. Ltd.
Pearson Education North Asia Ltd.
Pearson Education Canada, Ltd.
Pearson Educación de Mexico, S. A., de C. V.
Pearson Education—Japan
Pearson Education Malaysia Pte. Ltd.
Pearson Education, *Upper Saddle River, New Jersey*

Prentice Hall

10 9 8 7 6 5 4 3 2 1
ISBN: 0-13-094200-6

To Taylor, Jared, and Carly

Preface

This is the eighth edition of *Digital Fundamentals.* As with previous editions, it provides comprehensive coverage in a clear, straightforward, and well-illustrated format. Many topics have been strengthened or enhanced, and numerous improvements can be found throughout the book. This edition further reflects the shift from fixed-function logic devices to programmable logic devices (PLDs) by introducing programmable logic in Chapter 1 and continuing with a complete section in many chapters devoted to the topic of PLDs. As before, the programming of PLDs using the ABEL hardware description language is covered in two chapters. A new chapter on digital signal processing has been added. Also, a new text design and layout enhance the text's appearance and usability.

You will probably find more topics in this text than you can cover in a single course. This range of topics provides the flexibility to accommodate a variety of program requirements. For example, some of the design-oriented or system application topics may not be appropriate in some courses. Other programs may not cover PLDs or ABEL, while some may not have time to discuss microprocessors or digital signal processing. Also, there are programs that may not need to delve into the details of "inside-the-chip" circuitry. These and other topics can be omitted or covered lightly without affecting the coverage of the fundamental topics. A background in transistor circuits is not a prerequisite for this textbook.

New Features and Improvements

- Programmable logic devices (PLDs) are covered early in the text, beginning with an introduction in Chapter 1.
- CPLDs and FPGAs are introduced.
- An entire chapter is devoted to digital signal processing.
- EWB and Multisim circuit files on CD-ROM simulate many of the logic circuits that are illustrated in the text. These are indicated by the CD logo.
- Multisim files in addition to the EWB files are now included for the troubleshooting problems at the end of most chapters. These are indicated by the CD logo.
- Coverage of specific fixed-function logic devices and specific PLDs is set apart graphically in the text.
- Margin notes provide information in a very condensed form.
- Key terms are listed in each chapter opener. Within the chapter, the key terms are highlighted in boldface color. Each key term is defined at the end of the chapter, as well as at the end of the book in the comprehensive glossary along with other glossary terms.
- Error detection and correction codes are covered in Appendix B.
- Answer reminders are used to remind the student where to find the answers to the various exercises and problems throughout each chapter.

Additional Features

- Full-color format.
- Chapter 15 is designed as a "floating chapter" to provide optional coverage of IC technology ("inside-the-chip circuitry") at any point in your course.

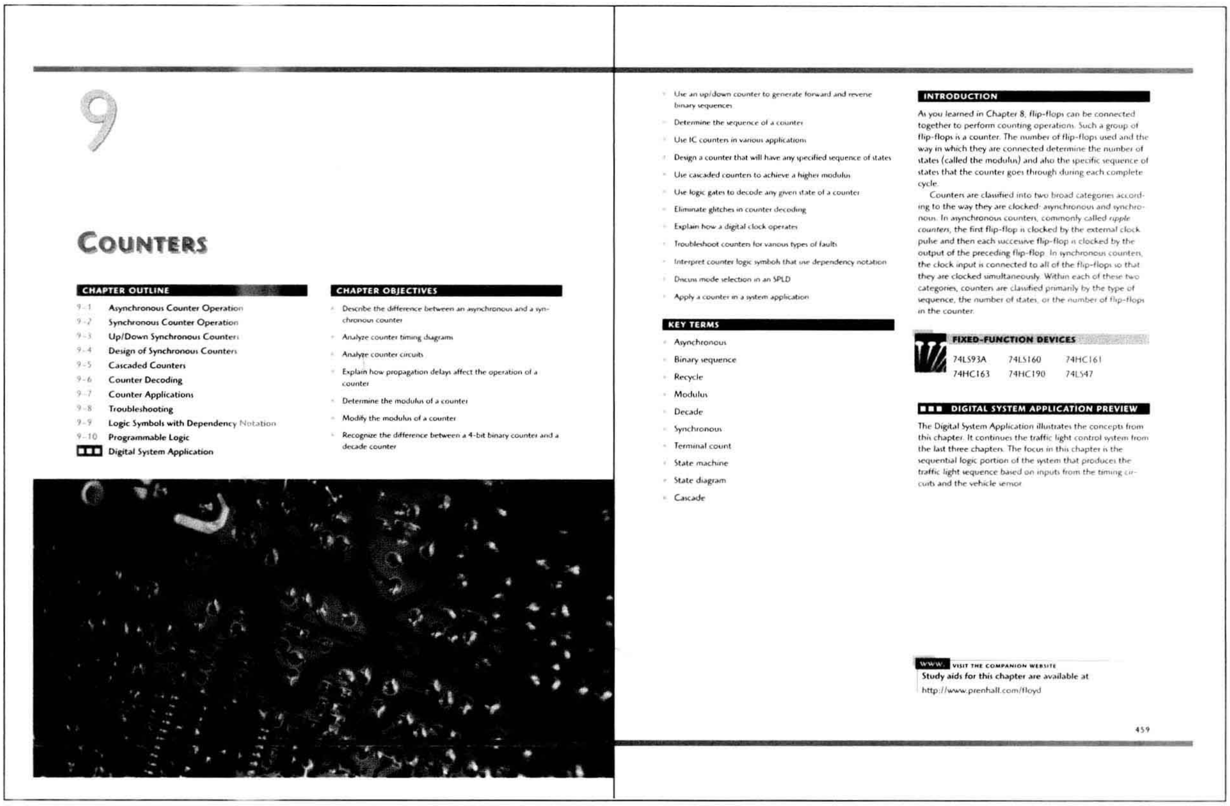
- Overview and objectives in each chapter opener.
- Introduction and objectives at the beginning of each section within a chapter.
- Review questions and exercises at the end of each section in a chapter.
- Related Problem in each worked example.
- Computer Notes interspersed throughout to provide interesting information about computer technology as it relates to the text coverage.
- Hands-On Tips interspersed throughout to provide useful and practical information.
- Digital System Application feature at the end of many chapters.
- Chapter summaries.
- Multiple choice self-test at the end of each chapter.
- Extensive sectionalized problem sets at the end of each chapter.
- Comprehensive glossary at the end of the book.
- A selection of device data sheets in Appendix A.

Accompanying Student Resources

- ***Experiments in Digital Fundamentals,*** Sixth Edition, a laboratory manual by David Buchla. Solutions are available in the Instructor's Resource Manual.
- ***Digital Experiments Emphasizing Troubleshooting,*** Sixth Edition, by Jerry V. Cox and Vincent P. Palagi. Solutions are available in the Instructor's Resource Manual.
- **Electronics Workbench®/Multisim® CD-ROM.** Packaged with each text, this software includes a set of EWB simulation circuits and a corresponding set of Multisim simulation circuits for logic circuits within the text and EWB/Multisim troubleshooting problems in the text. Also included on this CD is the Electronics Workbench Enhanced Textbook Edition of Multisim.
- **Texas Instruments Manufacturer's Data Sheets CD-ROM.**
- **EWB tutorials** online at *www.prenhall.com/floyd.*

Instructor Resources

- **PowerPoint® CD-ROM.** Contains slides featuring all figures from the text as well as lecture presentations for every chapter. This CD-ROM also includes innovative PowerPoint slides for the lab manual by Dave Buchla.
- **Companion Website (*www.prehall.com/floyd*).** For the instructor, this website offers the ability to post a syllabus online with Syllabus Manager. This is a great solution for classes taught online, self-paced, or in any computer-assisted manner.
- **Online Course Support.** Instructors whose programs are offered in a distance learning format can contact their local Prentice Hall sales representative for a list of product solutions.
- **Instructor's Resource Manual.** Includes worked-out solutions to chapter problems, solutions to Digital System Applications, a summary of EWB/Multisim simulation results, and solutions to the experiments in the laboratory manuals.
- **Prentice Hall Test Manager.** This is an electronic test bank.


9

COUNTERS

CHAPTER OUTLINE

9-1 Asynchronous Counter Operation
9-2 Synchronous Counter Operation
9-3 Up/Down Synchronous Counters
9-4 Design of Synchronous Counters
9-5 Cascaded Counters
9-6 Counter Decoding
9-7 Counter Applications
9-8 Troubleshooting
9-9 Logic Symbols with Dependency Notation
9-10 Programmable Logic
Digital System Application

CHAPTER OBJECTIVES

- Describe the difference between an asynchronous and a synchronous counter
- Analyze counter timing diagrams
- Analyze counter circuits
- Explain how propagation delays affect the operation of a counter
- Determine the modulus of a counter
- Modify the modulus of a counter
- Recognize the difference between a 4-bit binary counter and a decade counter
- Use an up/down counter to generate forward and reverse binary sequences
- Determine the sequence of a counter
- Use IC counters in various applications
- Design a counter that will have any specified sequence of states
- Use cascaded counters to achieve a higher modulus
- Use logic gates to decode any given state of a counter
- Eliminate glitches in counter decoding
- Explain how a digital clock operates
- Troubleshoot counters for various types of faults
- Interpret counter logic symbols that use dependency notation
- Discuss mode selection in an SPLD
- Apply a counter in a system application

KEY TERMS

- Asynchronous
- Binary sequence
- Recycle
- Modulus
- Decade
- Synchronous
- Terminal count
- State machine
- State diagram
- Cascade

INTRODUCTION

As you learned in Chapter 8, flip-flops can be connected together to perform counting operations. Such a group of flip-flops is a counter. The number of flip-flops used and the way in which they are connected determine the number of states (called the modulus) and also the specific sequence of states that the counter goes through during each complete cycle.

Counters are classified into two broad categories according to the way they are clocked: asynchronous and synchronous. In asynchronous counters, commonly called *ripple counters*, the first flip-flop is clocked by the external clock pulse and then each successive flip-flop is clocked by the output of the preceding flip-flop. In synchronous counters, the clock input is connected to all of the flip-flops so that they are clocked simultaneously. Within each of these two categories, counters are classified primarily by the type of sequence, the number of states, or the number of flip-flops in the counter.

FIXED-FUNCTION DEVICES

74LS93A 74LS160 74HC161
74HC163 74HC190 74LS47

DIGITAL SYSTEM APPLICATION PREVIEW

The Digital System Application illustrates the concepts from this chapter. It continues the traffic light control system from the last three chapters. The focus in this chapter is the sequential logic portion of the system that produces the traffic light sequence based on inputs from the timing circuits and the vehicle sensor.

WWW. VISIT THE COMPANION WEBSITE
Study aids for this chapter are available at
http://www.prenhall.com/floyd

459

FIGURE P–1

Chapter opener.

Illustration of Chapter Features

Chapter Opener Each chapter begins with a two-page spread, as shown in Figure P–1. The left page includes a list of the sections in the chapter and a list of chapter objectives. A typical right page includes a chapter introduction, a list of specific devices introduced in the chapter, a brief Digital System Application preview, a list of key terms, and a website reference for chapter study aids.

Section Opener Each of the sections in a chapter begins with a brief introduction that includes a general overview and section objectives. An illustration is shown in Figure P–2.

Section Review Each section ends with a review consisting of questions or exercises that emphasize the main concepts presented in the section. This feature is shown in Figure P–2. Answers to the Section Reviews are at the end of the chapter.

Worked Examples and Related Problems There is an abundance of worked-out examples that help illustrate and clarify basic concepts or specific procedures. Each example ends with a Related Problem that reinforces or expands on the example by requiring the student to work through a problem similar to the example. A typical worked example with a Related Problem is shown in Figure P–3.

Troubleshooting Section Many chapters include a troubleshooting section that relates to the topics covered in the chapter and that emphasizes troubleshooting techniques and the use of test instruments. A portion of a typical troubleshooting section is illustrated in Figure P–4.

Digital System Application Appearing at the end of many chapters, this feature presents a practical application of the concepts and devices covered in the chapter. This feature presents a "real-world" system in which analysis, troubleshooting, and design elements

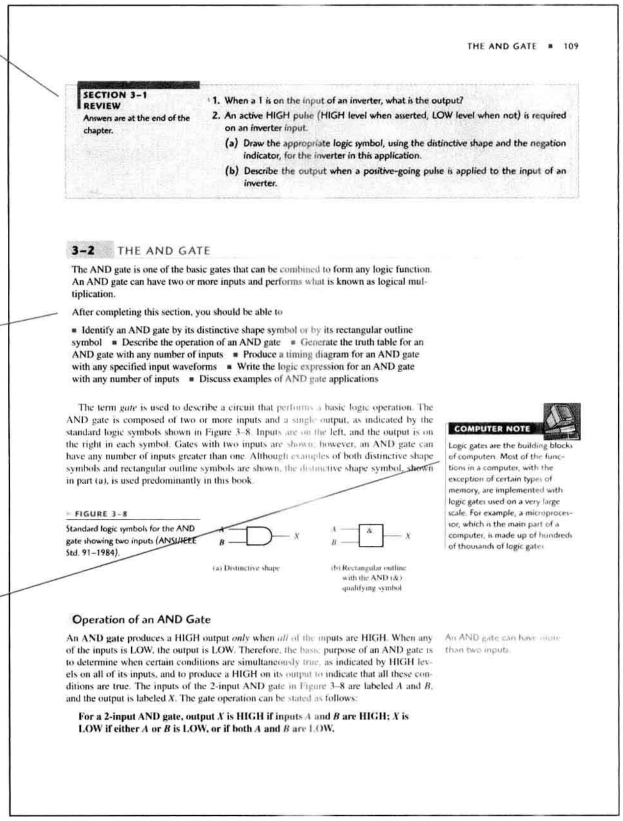
FIGURE P–2

Section opener and section review.

Review exercises end each section.

Introductory paragraph and a list of performance-based section objectives begin each section.

Computer Notes are found throughout the text (not part of section opener).



THE AND GATE ■ 109

SECTION 3–1 REVIEW
Answers are at the end of the chapter.

1. When a 1 is on the input of an inverter, what is the output?
2. An active HIGH pulse (HIGH level when asserted, LOW level when not) is required on an inverter input.
   (a) Draw the appropriate logic symbol, using the distinctive shape and the negation indicator, for the inverter in this application.
   (b) Describe the output when a positive-going pulse is applied to the input of an inverter.

3–2 THE AND GATE

The AND gate is one of the basic gates that can be combined to form any logic function. An AND gate can have two or more inputs and performs what is known as logical multiplication.

After completing this section, you should be able to

■ Identify an AND gate by its distinctive shape symbol or by its rectangular outline symbol ■ Describe the operation of an AND gate ■ Generate the truth table for an AND gate with any number of inputs ■ Produce a timing diagram for an AND gate with any specified input waveforms ■ Write the logic expression for an AND gate with any number of inputs ■ Discuss examples of AND gate applications

The term *gate* is used to describe a circuit that performs a basic logic operation. The AND gate is composed of two or more inputs and a single output, as indicated by the standard logic symbols shown in Figure 3–8. Inputs are on the left, and the output is on the right in each symbol. Gates with two inputs are shown; however, an AND gate can have any number of inputs greater than one. Although examples of both distinctive shape symbols and rectangular outline symbols are shown, the distinctive shape symbol, shown in part (a), is used predominantly in this book.

COMPUTER NOTE
Logic gates are the building blocks of computers. Most of the functions in a computer, with the exception of certain types of memory, are implemented with logic gates used on a very large scale. For example, a microprocessor, which is the main part of a computer, is made up of hundreds of thousands of logic gates.

FIGURE 3–8
Standard logic symbols for the AND gate showing two inputs (ANSI/IEEE Std. 91–1984).
(a) Distinctive shape (b) Rectangular outline with the AND (&) qualifying symbol

Operation of an AND Gate

An AND gate produces a HIGH output *only* when *all* of the inputs are HIGH. When any of the inputs is LOW, the output is LOW. Therefore, the basic purpose of an AND gate is to determine when certain conditions are simultaneously true, as indicated by HIGH levels on all of its inputs, and to produce a HIGH on its output to indicate that all these conditions are true. The inputs of the 2-input AND gate in Figure 3–8 are labeled *A* and *B*, and the output is labeled *X*. The gate operation can be stated as follows:

An AND gate can have more than two inputs.

For a 2-input AND gate, output *X* is HIGH if inputs *A* and *B* are HIGH; *X* is LOW if either *A* or *B* is LOW, or if both *A* and *B* are LOW.

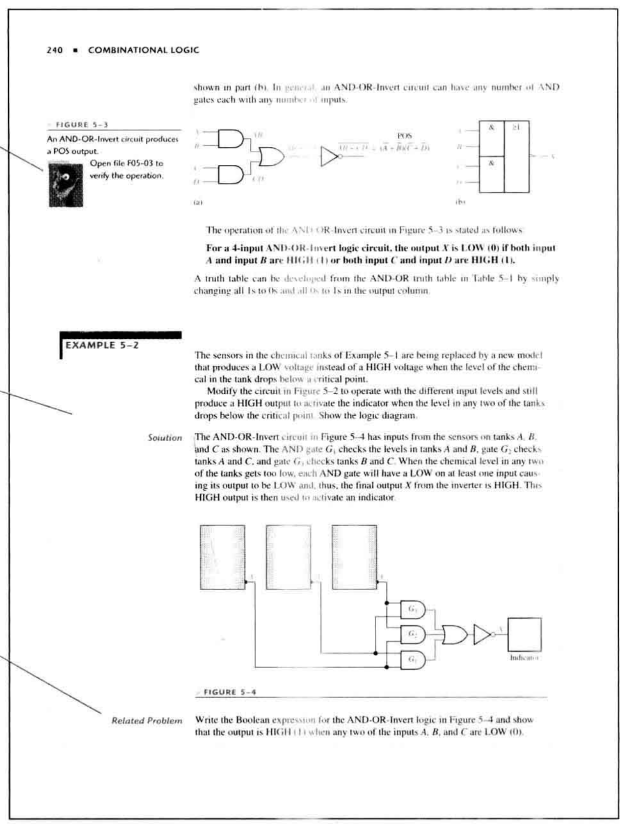
FIGURE P–3

An example and related problem.

A special icon indicates selected circuits that are on the EWB CD-ROM packaged with the text.

Examples are set off from text.

Each example contains a problem related to the example.



240 ■ COMBINATIONAL LOGIC

shown in part (b). In general, an AND-OR-Invert circuit can have any number of AND gates each with any number of inputs.

FIGURE 5–3
An AND-OR-Invert circuit produces a POS output.
Open file F05-03 to verify the operation.

The operation of the AND-OR-Invert circuit in Figure 5–3 is stated as follows:

For a 4-input AND-OR-Invert logic circuit, the output *X* is LOW (0) if both input *A* and input *B* are HIGH (1) or both input *C* and input *D* are HIGH (1).

A truth table can be developed from the AND-OR truth table in Table 5–1 by simply changing all 1s to 0s and all 0s to 1s in the output column.

EXAMPLE 5–2

The sensors in the chemical tanks of Example 5–1 are being replaced by a new model that produces a LOW voltage instead of a HIGH voltage when the level of the chemical in the tank drops below a critical point.

Modify the circuit in Figure 5–2 to operate with the different input levels and still produce a HIGH output to activate the indicator when the level in any two of the tanks drops below the critical point. Show the logic diagram.

Solution The AND-OR-Invert circuit in Figure 5–4 has inputs from the sensors on tanks *A*, *B*, and *C* as shown. The AND gate G_1 checks the levels in tanks *A* and *B*, gate G_2 checks tanks *A* and *C*, and gate G_3 checks tanks *B* and *C*. When the chemical level in any two of the tanks gets too low, each AND gate will have a LOW on at least one input causing its output to be LOW and, thus, the final output *X* from the inverter is HIGH. This HIGH output is then used to activate an indicator.

FIGURE 5–4

Related Problem Write the Boolean expression for the AND-OR-Invert logic in Figure 5–4 and show that the output is HIGH (1) when any two of the inputs *A*, *B*, and *C* are LOW (0).

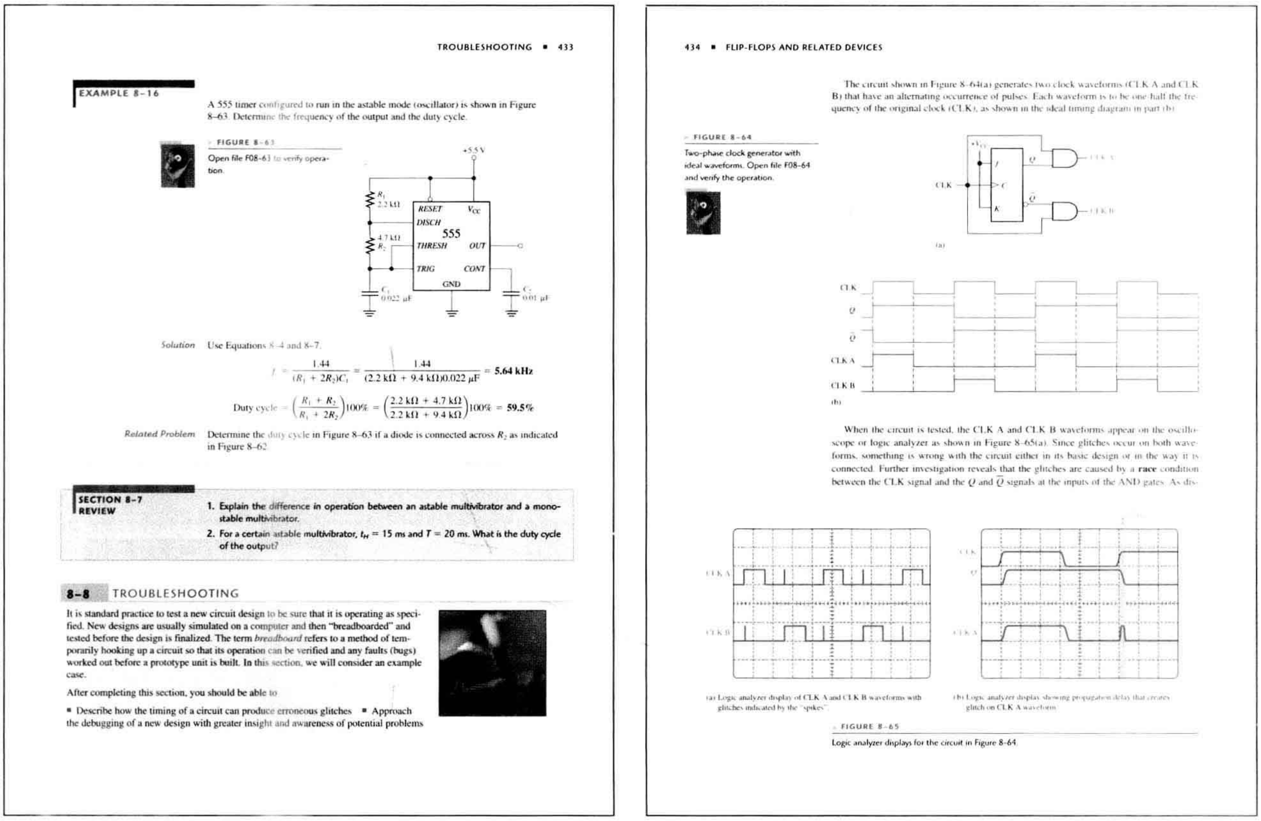


FIGURE P–4

Representative pages from a portion of a typical Troubleshooting section.

are implemented in a series of activities called System Assignments. Some Digital System Applications are limited to a single chapter and others extend over two or more chapters. Specific Digital System Applications are as follows:

- Tablet counting and control system: Chapters 1 and 2
- Digital display: Chapter 4
- Storage tank control system: Chapter 5
- Traffic light control system: Chapters 6, 7, 8, 9, and 11
- Security entry system: Chapters 10 and 12

Although they are not intended or designed for use as laboratory projects, many of the Digital System Applications utilize realistic representations of printed circuit boards and instruments to provide experience in relating schematics to actual boards, identifying IC packages, and obtaining data from certain instrument readings and displays. Because omission will not affect any other material in the text, Digital System Applications may be treated as optional. Figure P–5 shows a portion of a Digital System Application feature.

Chapter End Matter

The following study aids end each chapter.

- Summary
- Key term glossary

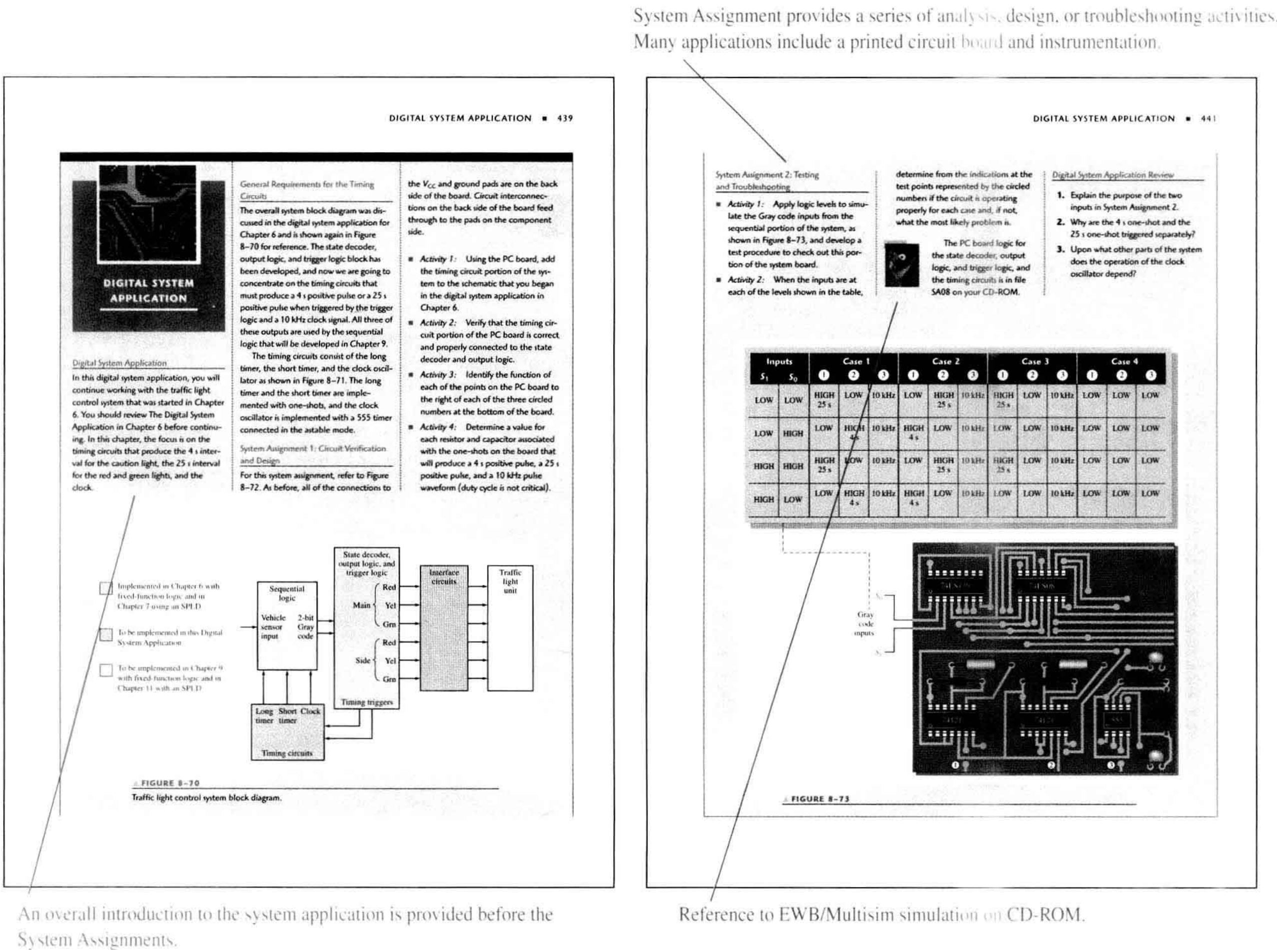


FIGURE P–5

Representative pages from a typical Digital System Application.

- Self-test
- Problem set that includes some or all of the following categories: Basic, Troubleshooting, Digital System Application, Design, and EWB/Multisim Troubleshooting Practice
- Answers to Section Reviews
- Answers to Related Problems for Examples
- Answers to Self-Test

Book End Matter

- Data Sheets
- Error Detecting and Correcting Codes
- Code conversion and table of powers of two
- Comprehensive glossary
- Answers to odd-numbered problems
- Index

Suggestions for Teaching with *Digital Fundamentals*

Generally, course emphasis or time limitations determine the topics to be covered in a course. It is not uncommon to omit or condense topics or to alter the sequence of certain topics in order to customize the material for a particular course. The following suggestions for selective coverage, light coverage, or omission do not imply that a given topic is less important than others, but in the context of a specific program, the topic may not require the emphasis that the more fundamental topics do. Also, these suggestions do not necessarily reflect all possibilities for sequence alteration, selective or light coverage, or omission. In any particular program, there may be other areas that can be considered.

Suggestions for altering the sequence of chapters:

1. If you wish to cover logic gates earlier in the course, Chapter 1 can be covered lightly or some of its topics can be postponed. Chapter 3 on logic gates can be covered before Chapter 2 on number systems, operations, and codes.
2. Coverage of Chapter 7 on Programming PLDs can be postponed until after Chapter 10. This way, Chapters 7 and 11 can be covered consecutively, if that works best in your course.
3. All or parts of Chapter 15 can be covered at just about any point in the text beginning in Chapter 3, or it can be omitted.

Some chapters that can be considered for selective coverage:

1. Chapter 1, Introductory Digital Concepts
2. Chapter 2, Number Systems, Operations, and Codes
3. Chapter 4, Boolean Algebra and Logic Simplification
4. Chapter 15, Integrated Circuit Technologies

Chapters that can be considered for omission without affecting other coverage:

1. Chapter 7, Combinational Logic Programming with ABEL
2. Chapter 11, Sequential Logic Programming with ABEL
3. Chapter 13, Introduction to Microprocessors, Computers, and Buses
4. Chapter 14, Introduction to Digital Signal Processing
5. Chapter 15, Integrated Circuit Technologies

Depending on your program, there may be additional topics that can be treated lightly or omitted. For example, the Digital System Application features can be omitted without affecting any other topics, or they may be assigned for extra credit or as special projects.

Acknowledgments

This revision of *Digital Fundamentals* has been realized by the combined work and skills of many people. I think that we have accomplished what we set out to to, and that was to further improve an already very successful textbook and make it even more useful to the student.

Those at Prentice Hall who have, as always, contributed a great amount of time, talent, and effort to move this project through its many phases in order to produce the book as you see it, include, but are not limited to, Rex Davidson, Kate Linsner, and Dennis Williams. I am grateful that Lois Porter once again agreed to edit the manuscript on this project. Without her help, I would probably be—well, I don't want to think about that. Also, Jane Lopez and Steve Botts have done another beautiful job with the graphics. Gary Snyder created all of the EWB and Multisim circuit files for the Electronics Workbench

CD-ROM. My thanks and appreciation go to all of these people and others who were directly involved in the project.

In the revision of this and all textbooks, we depend on expert input from many users as well as nonusers. My sincere thanks to the following reviewers who submitted many valuable suggestions and provided lots of constructive criticism for the preparation of this new edition.

Sudqi H. Alayyan, Texas Tech University

Farahzad Behi, Embry Riddle University

Bob L. Bixler, Austin Community College

Bruce Bush, Albuquerque Technical Vocational Institute

Albert A. Heaney, California State University, Fresno

Keith Quigley, Midlands Technical College

Saeed Shaikh, Miami-Dade Community College

Johnny W. Wortham, Southwest Tennessee Community College

I also want to thank all of the members of the Prentice Hall sales force whose efforts have helped to make this text available to a large number of users. In addition, I am grateful to all of you who have adopted this text for your classes or for your own use. Without you we would not be in business. I hope that you find this eighth edition of *Digital Fundamentals* to be even better than earlier editions and that it will continue to be a valuable learning tool for the student.

Tom Floyd

Brief Contents

Contents

- Identify pin numbers on integrated circuit packages
- Describe the PLD, discuss the various types, and state how PLDs are programmed
- Recognize digital test instruments and understand how they are used in troubleshooting digital circuits and systems
- Show how a complete digital system is formed from the basic functions in a practical application

KEY TERMS

Key terms are in order of appearance in the chapter.

- Analog
- Digital
- Binary
- Bit
- Pulse
- Clock
- Timing diagram
- Data
- Serial
- Parallel
- Logic
- Input
- Output
- Gate
- NOT
- Inverter
- AND
- OR
- Integrated circuit (IC)
- PLD
- Troubleshooting

INTRODUCTION

The term *digital* is derived from the way computers perform operations, by counting digits. For many years, applications of digital electronics were confined to computer systems. Today, digital technology is applied in a wide range of areas in addition to computers. Such applications as television, communications systems, radar, navigation and guidance systems, military systems, medical instrumentation, industrial process control, and consumer electronics use digital techniques. Digital technology has progressed from vacuum-tube circuits to discrete transistors to complex integrated circuits, some of which contain millions of transistors.

This chapter introduces you to digital electronics and provides a broad overview of many important concepts, components, and tools.

■■■ DIGITAL SYSTEM APPLICATION PREVIEW

The last feature in many chapters of this textbook uses a system application to bring together the principal topics covered in the chapter. Each system is designed to fit the particular chapter to illustrate how the theory and devices can be used. Throughout the book, four different systems are introduced, some covering two or more chapters.

All of the systems are simplified to make them manageable in the context of the chapter material. Although they are based on actual system requirements, they are designed to accommodate the topical coverage of the chapter and are not intended to necessarily represent the most efficient or ultimate approach in a given application.

This chapter introduces the first system, which is an industrial control system for counting and controlling items for packaging on a conveyor line. It is designed to incorporate all of the logic functions that are introduced in this chapter so that you can see how they are used and how they work together to achieve a useful objective.

WWW. VISIT THE COMPANION WEBSITE

Study aids for this chapter are available at

http://www.prenhall.com/floyd