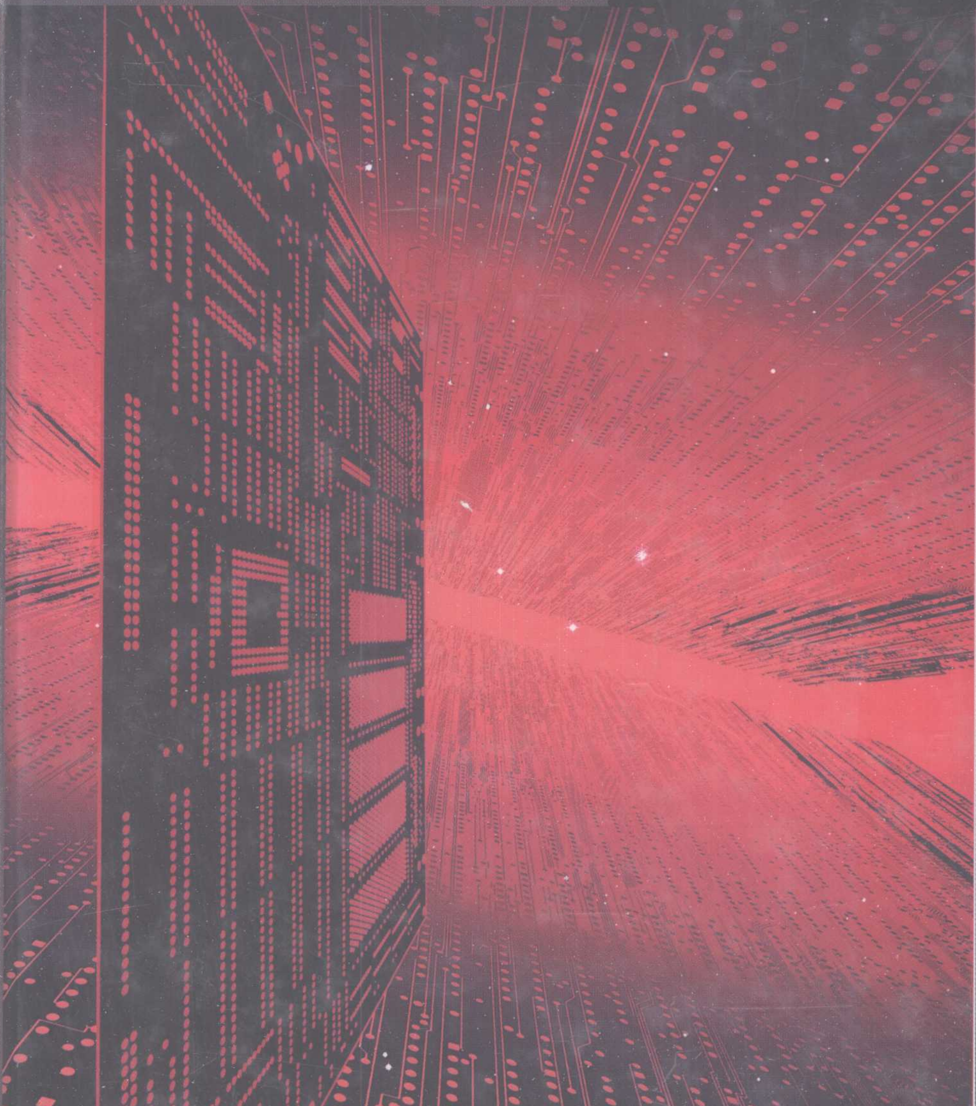
Digital Fundamentals

6TH Edition



FLOYD

SIXTH EDITION

DIGITAL FUNDAMENTALS

THOMAS L. FLOYD

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PREFACE

Digital Fundamentals, Sixth Edition, offers comprehensive coverage in an easy-to-read style. As in previous editions, this edition provides a well balanced coverage of basic concepts, up-to-date technology, practical applications, and troubleshooting. Some topics have been strengthened and improved, and two new chapters on programmable logic devices (PLDs) have been added. This book has been thoroughly reviewed, and every effort has been made to ensure that the coverage is accurate and up to date.

You will probably find more topics than can be covered in one term because of time limitations or program emphasis. This breadth of topics provides flexibility in designing your course to meet the specific goals of your program. For example, some of the mathematical, design-oriented, troubleshooting, or system application topics may not be appropriate for certain programs. Some programs do not cover PLDs or do not provide an introduction to microprocessors in the digital fundamentals course. These topics can be easily omitted or lightly touched on without affecting other coverage.

Features

- Two new chapters on PLDs (Chapter 7 and Chapter 11).
- Digital System Application sections with "Digital Workbench" assignments that include analysis, design, and troubleshooting.
- A revised chapter on memories, including a new section on flash memories.
- A comprehensive glossary at the end of the book.
- New coverage of 5-variable Karnaugh maps.
- A full-color format.
- A related exercise in each worked example.
- An overview and list of objectives at the opening of each chapter.
- An introduction and objectives at the beginning of each section within a chapter.
- Review questions at the end of each chapter section.
- A summary at the end of each chapter.
- A multiple-choice self-test at the end of each chapter.
- Extensive problem sets

The improved ancillary package for this edition includes

- Two lab manuals: *Digital Experiments Emphasizing Systems and Design,* Fourth Edition, by David Buchla, and *Digital Experiments Emphasizing Troubleshooting,* Fourth Edition, by Jerry V. Cox.
- Instructor's Resource Manual.
- Test Item File (hard copy).
- DOS PH Custom Test (Test Item File on disk).
- Transparency masters and 4-color transparencies.
- Electronics Workbench Data Disk.
- Bergwall Video.

Illustration of Chapter Features

Chapter Opener Each chapter begins with a two-page opener, as shown in Figure P–1. The left page includes a listing of the sections within the chapter and a list of chapter objectives. The right page has a chapter overview, a list of specific devices introduced in the chapter, and a preview of the Digital System Application.

Section Opener Each section within a chapter begins with a brief introduction that provides a general overview of the material to be covered and a list of section objectives. This is illustrated in Figure P–2.

Section Review Each section ends with a review consisting of questions or exercises that focus on the main concepts presented in the section. Answers to these section reviews are at the end of the chapter. This is also illustrated in Figure P–2.

Worked Examples and Related Exercises Frequent examples help to demonstrate and clarify basic concepts or illustrate specific procedures. Each example concludes with a related exercise that reinforces or expands on the example. Some related exercises require a repetition of the example using different parameters or conditions. Others focus on a more limited part of the example or encourage further thought. Answers to all the related

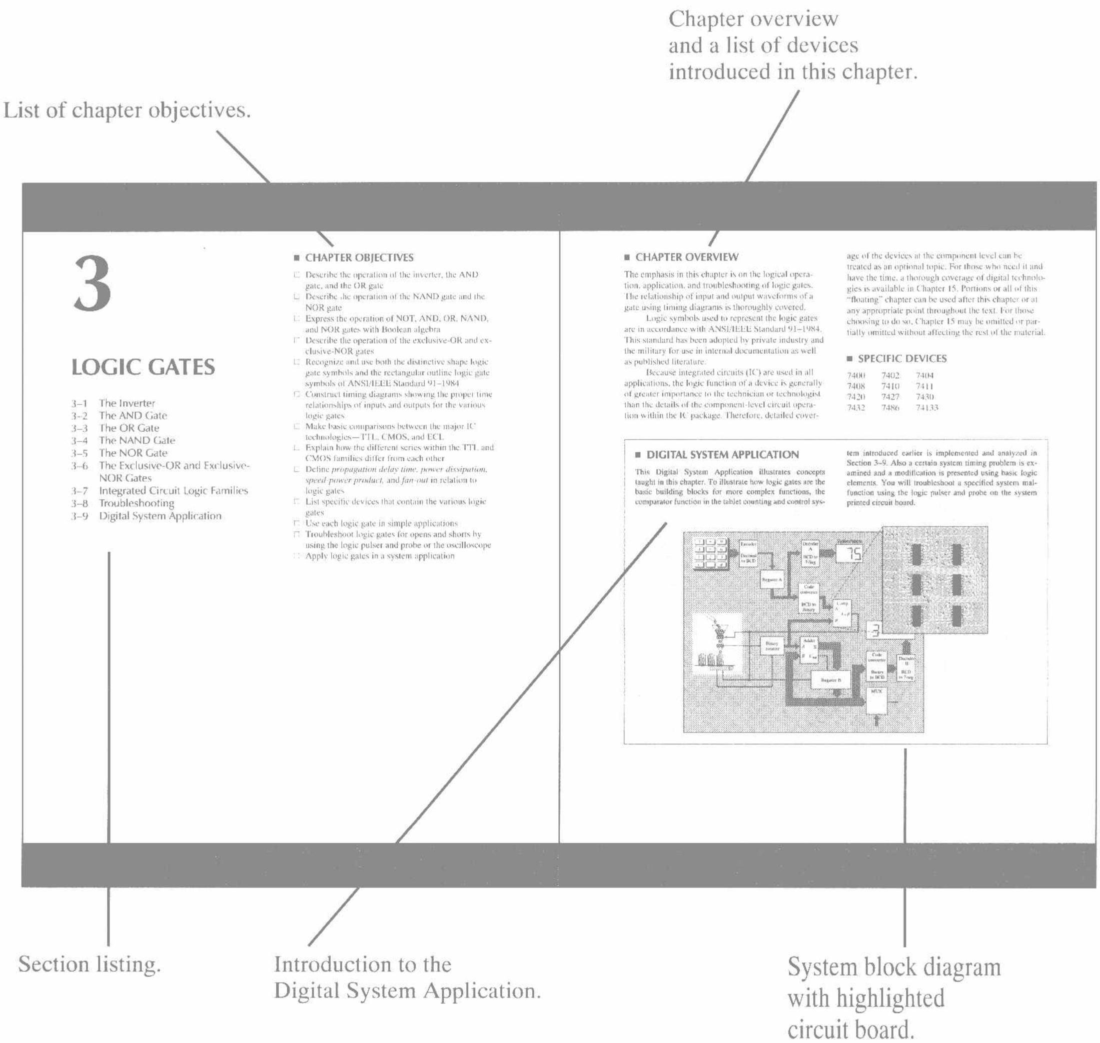

FIGURE P–1
Chapter opener.

FIGURE P–2
Section opener and section review.

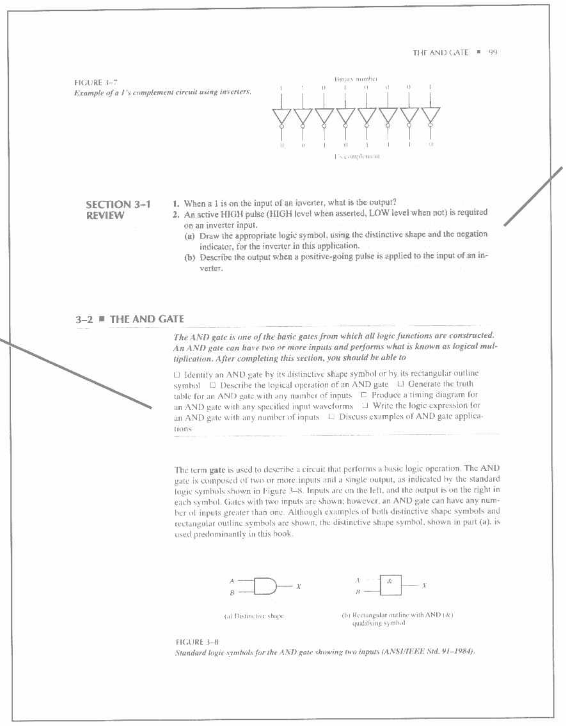
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FIGURE 3–7
Example of a 1's complement circuit using inverters.

SECTION 3–1 REVIEW

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 from which all logic functions are constructed. 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 logical 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.

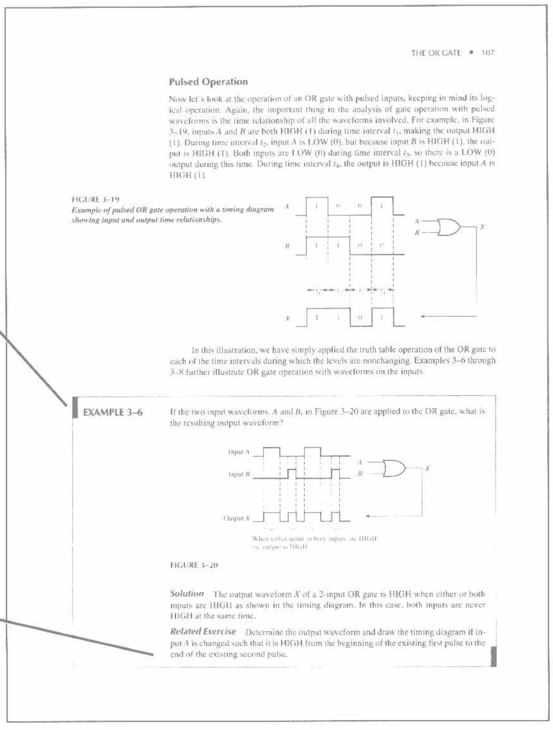
(a) Distinctive shape (b) Rectangular outline with AND (&) qualifying symbol

FIGURE 3–8
Standard logic symbols for the AND gate showing two inputs (ANSI/IEEE Std. 91–1984).

exercises are found at the end of the book. A typical worked example and related exercise are shown in Figure P–3.

Troubleshooting Section Many chapters include special troubleshooting sections that emphasize troubleshooting techniques and the use of test instruments as applied to situations related to chapter topics. These sections are optional and can be omitted without affecting the rest of the material.

FIGURE P–3
An example and related exercise.


THE OR GATE ■ 107

Pulsed Operation

Now let's look at the operation of an OR gate with pulsed inputs, keeping in mind its logical operation. Again, the important thing in the analysis of gate operation with pulsed waveforms is the time relationship of all the waveforms involved. For example, in Figure 3–19, inputs A and B are both HIGH (1) during time interval t_1, making the output HIGH (1). During time interval t_2, input A is LOW (0), but because input B is HIGH (1), the output is HIGH (1). Both inputs are LOW (0) during time interval t_3, so there is a LOW (0) output during this time. During time interval t_4, the output is HIGH (1) because input A is HIGH (1).

FIGURE 3–19
Example of pulsed OR gate operation with a timing diagram showing input and output time relationships.

In this illustration, we have simply applied the truth table operation of the OR gate to each of the time intervals during which the levels are nonchanging. Examples 3–6 through 3–8 further illustrate OR gate operation with waveforms on the inputs.

EXAMPLE 3–6 If the two input waveforms, A and B, in Figure 3–20 are applied to the OR gate, what is the resulting output waveform?

When either input or both inputs are HIGH, the output is HIGH

FIGURE 3–20

Solution The output waveform X of a 2-input OR gate is HIGH when either or both inputs are HIGH as shown in the timing diagram. In this case, both inputs are never HIGH at the same time.

Related Exercise Determine the output waveform and draw the timing diagram if input A is changed such that it is HIGH from the beginning of the existing first pulse to the end of the existing second pulse.

Digital System Application The last section of each chapter (except Chapters 14 and 15) presents a practical application of the concepts and devices covered in the chapter. Each application is based on a "real world" system. Many include analysis, design, and troubleshooting elements that are implemented in a series of "Workbench" activities. Some system applications are limited to a single chapter and others extend over two or more chapters. The Digital System Applications and their associated chapters are as follows:

- Tablet counting and control system: Chapters 1, 2, 3, and 4
- Digital control system for a lumber mill: Chapter 5
- Traffic light control system: Chapters 6, 7, 8, 9, and 11
- Security entry system: Chapters 10 and 12
- Satellite antenna positioning system: Chapter 13

Many of the system applications involve realistic representations of printed circuit boards that provide experience in relating schematics to actual circuits and identifying physical devices. Solutions to the Workbench activities are in the Instructor's Resource Manual. Although the Digital System Application is a very effective feature, it is optional and can be omitted or given limited coverage without affecting other material. A portion of a typical Digital System Application section is shown in Figure P–4.

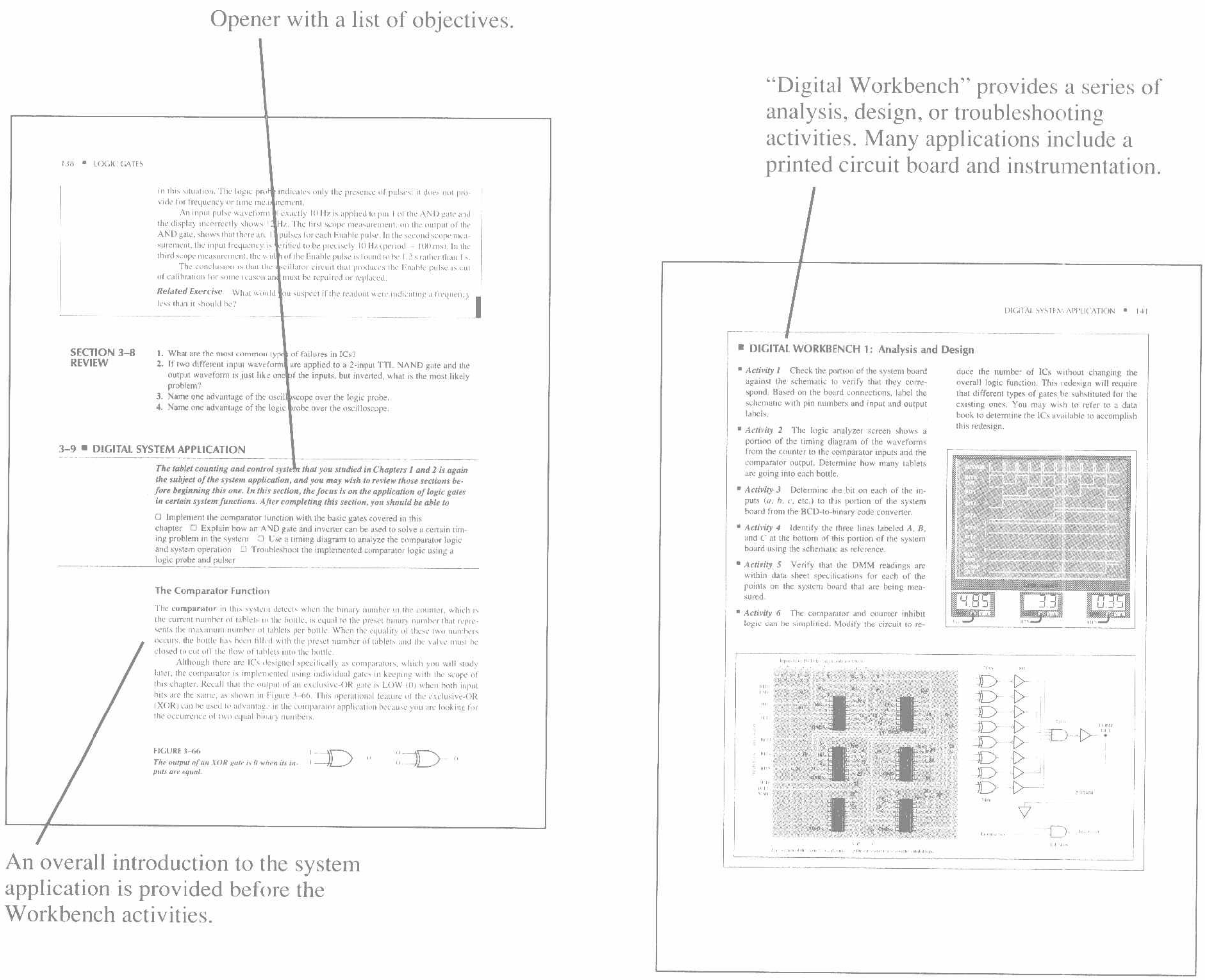


FIGURE P–4

Representative pages from a typical Digital System Application section.

Chapter End Matter At the end of each chapter are a summary, a multiple-choice self test, and a sectionalized problem set (except Chapter 14). The problem sets include basic problems, troubleshooting problems, system application problems, and special design problems when applicable.

Content and Organization

This textbook contains fifteen chapters, beginning with basic digital concepts in Chapter 1 and progressing through number systems, logic gates, Boolean algebra, combinational logic including PLD implementation, sequential logic including PLD implementation, memories, and interfacing, and ending with a basic introduction to microprocessors and microcomputers in Chapter 14.

Chapter 15 covers digital circuit technologies and discusses the operating characteristics and parameters of the major IC families. This chapter can be used in whole or in part at various appropriate points as a "floating" chapter, at the discretion of the instructor. Its placement as the last chapter in the book is intended to facilitate this flexible usage, and a tab edge design is provided for quick and easy reference.

Chapters 7 and 11 provide an introduction to programmable logic devices (PLDs) and can be treated as optional if desired. Either or both of these chapters can be omitted without affecting other topics. Chapter 7 follows the coverage of combinational logic and provides an introduction to PLDs and PLD programming for combinational logic functions. Chapter 11 follows the coverage of sequential logic and continues the PLD coverage from Chapter 7 with an introduction to the implementation of sequential logic using PLDs.

Chapter 14 provides a brief introduction to microprocessor and microcomputer concepts and the development of the major microprocessor families. The Intel 8088 microprocessor is used as a basic model or "launching pad" for teaching basic concepts because of its relative simplicity. The basic elements are common to more recent devices, so the concepts learned can be applied to other, more advanced, microprocessors.

As in previous editions, the ANSI/IEEE std. 91-1984 logic symbols with dependency notation are introduced gradually and conservatively at appropriate points, while the use of the more traditional symbols is retained throughout. Although it is important to become familiar with this standard, its symbols and notation represent, in many cases, a significant departure from many traditional symbols, and thus a gradual and limited introduction is quite appropriate. A full treatment of the ANSI/IEEE standard is provided in the Instructors Resource Manual. Omission of this coverage will not affect the rest of the material.

At the end of the book are the answers to odd-numbered end-of-chapter problems, answers to the related exercises for examples, several representative data sheets, a table of code conversions, a table of powers-of-two, a short coverage of error detection and correction codes, a comprehensive glossary, and the index.

Suggestions for Use

If time limitations or course emphasis restricts the topics that can be covered, as is generally the case, several possibilities for selective coverage exist. Suggestions for light treatment or omission do not imply that a given topic is less important than others, but that, in the context of a specific program, the topic does not require the emphasis that the more fundamental topics do. Since course emphasis, level, and available time vary from one program to another, the omission or lighter treatment of selected topics must be made on an individual basis and, therefore, the following suggestions are intended only as a general guide.

1. Chapters that may be considered for selective coverage:

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

2. Chapters that may be considered for omission:
   - Chapter 7 Introduction to Programmable Logic Devices
   - Chapter 11 Sequential Logic Applications of PLDs
   - Chapter 13 Interfacing
   - Chapter 14 Introduction to Microprocessors and Microcomputers
3. Troubleshooting sections and/or Digital System Application sections can be omitted. Other specific topics on a section-by-section basis that may be considered for omission are:
   - 2–7 Arithmetic Operations with Signed Numbers
   - 2–9 Octal Numbers
   - 4–10 Karnaugh Map POS Minimization
   - 4–11 Five-Variable Karnaugh Maps
   - 6–3 Ripple Carry versus Look-Ahead Carry Adders
   - 6–10 Parity Generators/Checkers
   - 8–3 Master-Slave Flip-Flops
   - 9–4 Design of Synchronous Counters
   - 9–9 Logic Symbols with Dependency Notation
   - 10–7 Shift Register Counters
   - 10–10 Logic Symbols with Dependency Notation
   - 12–7 Special Types of Memories

Depending on your program, there may be additional topics that could be skimmed over or omitted.

The order in which certain topics appear in the text can be altered at the instructor's discretion. For example, portions of Chapter 2 (Number Systems and Codes) can be covered at a later point in the chapter sequence. As another example, Chapter 7 (Introduction to Programmable Logic Devices) can be delayed until after Chapter 10 and covered in sequence with Chapter 11 (Sequential Logic Applications of PLDs).

Digital System Applications These sections are very useful for motivation and as an introduction to real-world applications of basic concepts and devices. Possible uses are

1. As an integral part of the chapter to illustrate how the concepts and devices can be applied in a practical situation. The Workbench activities can be assigned for homework or as a class miniproject.
2. As extra credit assignments.
3. As in-class activities to promote discussion and interaction and to help answer the "need-to-know" question that many students have.

For the Student

All of the material in this preface is intended to help both you and your instructor make the most effective use of this textbook as a teaching and a learning tool.

Acquiring knowledge and skills in any discipline is hard work, and perhaps even more so in the field of electronics. You must use this book as more than just a reference. You must really dig in by reading, thinking, and doing. Don't expect every concept or procedure to become immediately clear. Most of the topics are not overly difficult but some may take several readings, working many problems, and help from your instructor before you really understand them.

In order to master the material in each section you should first read the material, then go through each example step-by-step, work the related exercises, and complete the review exercises. After completing a chapter, you should first work through the self-test and then, as a minimum, work the problems assigned by your instructor. Check your answers at the end of the chapter or book. Be sure to ask questions in class about anything that you do not understand.

The problems at the end of each chapter provide varying degrees of difficulty. In any technical field, it is important that you work lots of problems. Working through a problem gives you a level of insight and understanding that reading or classroom lectures alone do not provide. Never think that you can fully understand a concept or procedure by simply watching or listening to someone else. In the final analysis, you must do it yourself.

■ ACKNOWLEDGMENTS

I hope you will agree that this sixth edition of *Digital Fundamentals* is the best yet. Many people have contributed valuable ideas and constructive criticism for this new edition. It has been thoroughly reviewed for both content and accuracy.

Again, it is have been a pleasure to work with the people at Prentice Hall. Their enthusiasm and dedication to quality continue to be a source of inspiration to me. My appreciation goes to Dave Garza, Carol Robison, and Mary Harlan for their efforts on this project.

Special thanks to Lois Porter who has, once again, done an amazingly thorough job of copy editing the manuscript, and to Gary Snyder of Bently-Nevada Corporation for his excellent work in checking the manuscript for accuracy. Also, Dave Buchla of Yuba College has provided many valuable suggestions for improvements to the book.

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Last, but not least, a special thanks to my wife, Sheila.

CONTENTS

■ CHAPTER OVERVIEW

The concept of a digital computer can be traced to Charles Babbage, who developed a crude mechanical computation device in the 1830s. The first functioning digital computer was built in 1944 at Harvard University, but it was electromechanical, not electronic. Modern digital electronics began in 1946 with an electronic digital computer called ENIAC, which was implemented with vacuum-tube circuits. Even though it took up an entire room, ENIAC didn't have the computing power that your hand-held calculator does.

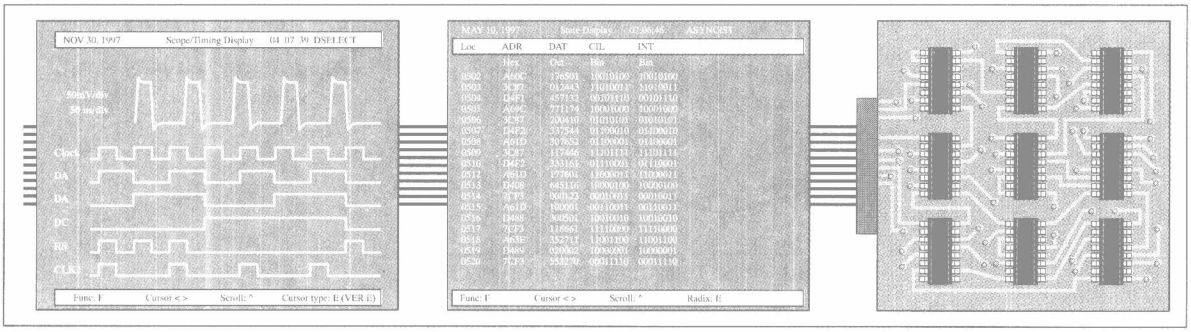
The term *digital* is derived from the way computers perform operations, by counting digits. For many years, applications of digital electronics were confined to computer systems. Today, digital technology is applied in a wide range of areas in addition to the computer. Such applications as telephone 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 integrated circuits.

■ DIGITAL SYSTEM APPLICATION

The last section in most chapters of this textbook uses a system application to bring together many of 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, five 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.

Section 1–7 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 an overall objective.



1–1 ■ DIGITAL AND ANALOG QUANTITIES

Electronic circuits can be divided into two broad categories, digital and analog. Digital electronics involves quantities with discrete values, and analog electronics involves quantities with continuous values. Although you will be studying digital fundamentals in this book, you should also know about analog because many applications require both. After completing this section, you should be able to

☐ Define *digital* ☐ Define *analog* ☐ Explain the difference between digital and analog quantities ☐ Give examples of how digital and analog quantities are used in electronics

An **analog*** quantity is one having continuous values. A **digital** quantity is one having a discrete set of values. Most things that can be measured quantitatively appear in nature, in analog form. For example, the air temperature changes over a continuous range of values. During a given day, the temperature does not go from, say, 70° to 71° instantaneously; it takes on all the infinite values in between. If you graphed the temperature on a typical summer day, you would have a smooth, continuous curve similar to Figure 1–1. Other examples of analog quantities are time, pressure, distance, and sound.

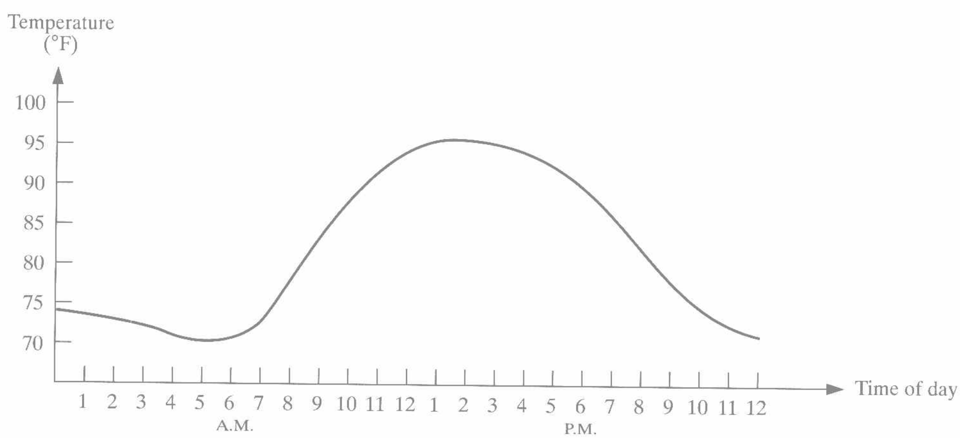


FIGURE 1–1
Graph of an analog quantity (temperature versus time).

Rather than graphing the temperature on a continuous basis, suppose you just take a temperature reading every hour. Now you have sampled values representing the temperature at discrete points in time over a 24-hour period, as indicated in Figure 1–2. You have effectively converted an analog quantity to a form that can now be digitized by representing each sampled value by a digital code. It is important to realize that Figure 1–2 is not the digital representation of the analog quantity.

Digital has certain advantages over analog in electronics applications. For one thing, digital data can be processed and transmitted more efficiently and reliably than analog data. Also, digital data has a great advantage when storage is necessary. For example, music when converted to digital form can be stored more compactly and reproduced with greater accuracy and clarity than is possible when it is in analog form.

*Boldface terms in the text are defined in the glossary.