DIGITAL SYSTEMS

PRINCIPLES AND APPLICATIONS

FIFTH EDITION

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RONALD J. TOCCI

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Principles and Applications

FIFTH EDITION

Ronald J. Tocci

Monroe Community College

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PREFACE

This book is a comprehensive up-to-date study of the principles and techniques of modern digital systems. It is intended for use in two-year and four-year programs in technology, engineering, and computer science. Although a background in basic electronic devices is helpful, a major portion of the material requires no electronics training. Those portions of the text that utilize electronic concepts can be skipped over without adversely affecting the comprehension of the logic principles.

GENERAL IMPROVEMENTS

This fifth edition contains several general improvements to the previous edition. In addition to being updated, some of the material has been rewritten for greater clarity and thoroughness. The chapter glossaries have been combined into one comprehensive glossary located in Appendix I for more easy reference. The answers to *all* section review questions have now been provided and placed at the end of the chapter. Examples were added where it was felt they were needed to further illustrate the new principles or procedures, bringing the total number of examples to over 200. Short-answer drill questions are now included with the end-of-chapter problems to provide a quick check on the reader's understanding of the basic concepts. Problems have been added to each chapter so that there are now about 450 of them. Some of these are applications that show how the logic devices or circuits presented in the chapter are used in a typical microcomputer system. The more difficult problems have been flagged as such for the instructor's convenience. The Answers to Selected Problems at the end of the text now include answers to almost all of the end-of-chapter questions and problems. Finally, a third color has been added to the book's design to help highlight certain elements of the material.

SPECIFIC CHANGES

In addition to these pedagogical improvements, there are several changes in the topical coverage. The major ones are:

Chapter 4: New section on parity generator and checker circuits.

Chapter 5: Introduction of state transition diagrams. New section on microcomputer application.

Chapter 7: New optional section on design of synchronous counters. Extensive use of state transition diagrams. Introduction to and problems using a bidirectional shift register (the 74194).

Chapter 8: Material on different IC packages.

Chapter 9: New section on code converter circuits.

Chapter 10: Added flowchart and timing diagram for SAC operation. New section on other ADC methods including tracking ADC and dual-slope ADC. New section on digital storage oscilloscope.

Chapter 11: Added function generator application. Expanded material on programmable logic devices to include PROM, PLA, PAL, and EPLDs with examples of how to determine and symbolize fuse conditions for a desired truth table. Added section on NVRAM. Decreased material on magnetic core and added coverage of optical disk and CD ROM.

RETAINED FEATURES

This edition retains all of the features that made the previous editions so widely accepted. It utilizes a block diagram approach to teach the basic logic operations without confusing the reader with the details of internal operation. All but the most basic electrical characteristics of the logic ICs are withheld until the reader has a firm understanding of logic principles. In Chapter 8 the reader is introduced to the internal IC circuitry. At that point, the reader can interpret a logic block's input and output characteristics and "fit" it properly into a complete system.

The treatment of each new topic or device typically follows these steps: the principle of operation is introduced; thoroughly explained examples and applications are presented often using actual ICs; short review questions are posed at the end of the section; and finally, in-depth problems are available at the end of the chapter. Ranging from simple to complex, these problems provide instructors with a wide choice of student assignments. These problems are often intended to reinforce the material without simple repetition of the principles. They require the student to demonstrate comprehension of the principles by applying them to different situations. This also helps the student develop confidence and expand his or her knowledge of the material.

The IEEE/ANSI standard for logic symbols is introduced and discussed with minimum disruption of the topic flow, and, if desired, can be omitted completely or in part. The extensive troubleshooting coverage is spread over Chapters 4 through 11 and includes presentation of troubleshooting principles and techniques, case studies, 25 troubleshooting examples, and 60 *real* troubleshooting problems. When supplemented with hands-on lab exercises, this material can help foster the development of good troubleshooting skills.

SEQUENCING

It is a rare instructor who uses the chapters of a textbook in the sequence in which they are presented. In fact, I must admit that, for many different reasons, I do not use my own books in that way. This book was written so that, for the most part, each chapter builds on previous material, but it is possible to alter the chapter sequence somewhat. The first part of Chapter 6 (arithmetic operations) can be covered right after Chapter 2 (number systems), although this would produce a long interval before the arithmetic circuits of Chapter 6 are encountered. Much of the material in Chapter 8 (IC characteristics) can be covered earlier (e.g., after Chapter 4 or 5) without causing any serious problems.

This book can be used in either a one-term course or in a two-term sequence. When used in one term, it may be necessary, depending on available class hours, to omit some topics. Here is a list of sections and chapters that can be deleted with minimum disruption. Obviously, the choice of deletions will depend on factors such as program or course objectives and student background.

1. *Chapter 1:* all
2. *Chapter 2:* Sections 6 and 7
3. *Chapter 4:* Sections 7 and 8; Sections 10–13 if troubleshooting is not to be covered
4. *Chapter 5:* Sections 3 and 25
5. *Chapter 6:* Sections 5, 7, 11, 13, 16, 18, 20
6. *Chapter 7:* Sections 10, 14–23
7. *Chapter 8:* Sections 9, 17–21
8. *Chapter 9:* Sections 6, 10, 11
9. *Chapter 10:* Sections 6, 13–16
10. *Chapter 11:* Sections 9, 18–22
11. *Chapter 12:* all

ACKNOWLEDGMENTS

Prior to starting work on this edition, we sent an extensive questionnaire to many users and former users of previous editions. I am grateful to all of those who responded with their comments, critiques, and suggestions. Their input was invaluable as I went through the process of deciding what changes to incorporate in the new edition. I am particularly grateful to Gregory L. Moss of Purdue University for his many excellent suggestions. All of them were carefully considered, and most of them are part of this edition.

As always, the people at Prentice-Hall were a pleasure to work with. I was especially fortunate to have Ed Jones as my production editor again (I hope he has forgiven me for my unintentional failure to acknowledge his major contribution to the last edition). His thoroughness and attention to detail far exceeds that of any of the numerous production editors who have worked with me on previous writing projects. Once again, Alice Barr provided the combination of open-minded leadership, gentle encouragement, and infectious enthusiasm that I needed to keep me going.

Finally, another special thank you to my colleague and friend Frank Ambrosio, for his work on the glossary, index, and Instructor's Manual. The timely and dependable way in which he completed his tasks made it easy for me to stay on schedule.

Ron Tocci
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1

INTRODUCTORY CONCEPTS

Outline

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1-2 Digital and Analog Systems
1-3 Digital Number Systems
1-4 Representing Binary Quantities
1-5 Digital Circuits
1-6 Parallel and Serial Transmission
1-7 Memory
1-8 Digital Computers

Objectives

Upon completion of this chapter, you will be able to:

- Distinguish between analog and digital representations.
- Name the advantages, disadvantages, and major differences among analog, digital, and hybrid systems.
- Understand the need for analog-to-digital converters (ADCs) and digital-to-analog converters (DACs).
- Convert between decimal and binary numbers.
- Identify typical digital signals.
- Cite several integrated-circuit fabrication technologies.
- Identify a timing diagram.
- State the differences between parallel and serial transmission.
- Name various memory elements.
- Describe the major parts of a digital computer and understand their functions.

Introduction

When most of us hear the term "digital," we immediately think of "digital calculator" or "digital computer." This can probably be attributed to the dramatic way that low-cost, powerful calculators and computers have become accessible to the average person. It is important to realize that calculators and computers represent only one of the many applications of digital circuits and principles. Digital circuits are used in electronic products such as video games, microwave ovens, and automobile control systems, and in test equipment such as meters, generators, and oscilloscopes. Digital techniques have also replaced a lot of the older "analog circuits" used in consumer products such as radios, TV sets, and high-fidelity sound recording and playback equipment.

In this book we are going to study the principles and techniques that are common to all digital systems from the simplest on/off switch to the most complex computer. If this book is successful, you should gain a deep understanding of how all digital systems work, and you should be able to apply this understanding to the analysis and troubleshooting of any digital system.

We start by introducing some underlying concepts that are a vital part of digital technology; these concepts will be expanded on as they are needed later in the text. We will also introduce some of the terminology that is necessary when embarking on a new field of study, and will add to it in every chapter. A complete glossary of terminology is presented in Appendix I.

1-1 NUMERICAL REPRESENTATIONS

In science, technology, business, and, in fact, most other fields of endeavor, we are constantly dealing with *quantities*. Quantities are measured, monitored, recorded, manipulated arithmetically, observed, or in some other way utilized in most physical systems. It is important when dealing with various quantities that we be able to represent their values efficiently and accurately. There are basically two ways of representing the numerical value of quantities: **analog** and **digital**.

Analog Representations In *analog representation* one quantity is represented by another which is proportional to the first. An example is an automobile speedometer, in which the deflection of the needle is proportional to the speed of the auto. The angular position of the needle represents the value of the auto's speed, and the needle follows any changes that occur as the auto speeds up or slows down.

Another example is the common room thermostat, in which the bending of the bimetallic strip is proportional to the room temperature. As the temperature changes gradually, the curvature of the strip changes proportionally.

Still another example of an analog quantity is found in the familiar audio microphone. In this device an output voltage is generated in proportion to the amplitude of the sound waves that impinge on the microphone. The variations in the output voltage follow the same variations as the input sound.

Analog quantities such as those cited above have an important characteristic: *they can vary over a continuous range of values*. The automobile speed can have any value between zero and, say, 100 mph. Similarly, the microphone output might be anywhere within a range of zero to 10 mV (for example, 1 mV, 2.3724 mV, 9.9999 mV).

Digital Representations In *digital representation* the quantities are represented not by proportional quantities but by symbols called *digits*. As an example, consider the digital watch, which provides the time of day in the form of decimal digits which represent hours and minutes (and sometimes seconds). As we know, the time of day changes continuously, but the digital watch reading does not change continuously; rather, it changes in steps of one per minute (or per second). In other words, this digital representation of the time of day changes in *discrete* steps, as compared with the representation of time provided by an analog watch, where the dial reading changes continuously.

The major difference between analog and digital quantities, then, can be simply stated as follows:

$$\text{analog} \equiv \text{continuous}$$
$$\text{digital} \equiv \text{discrete (step by step)}$$