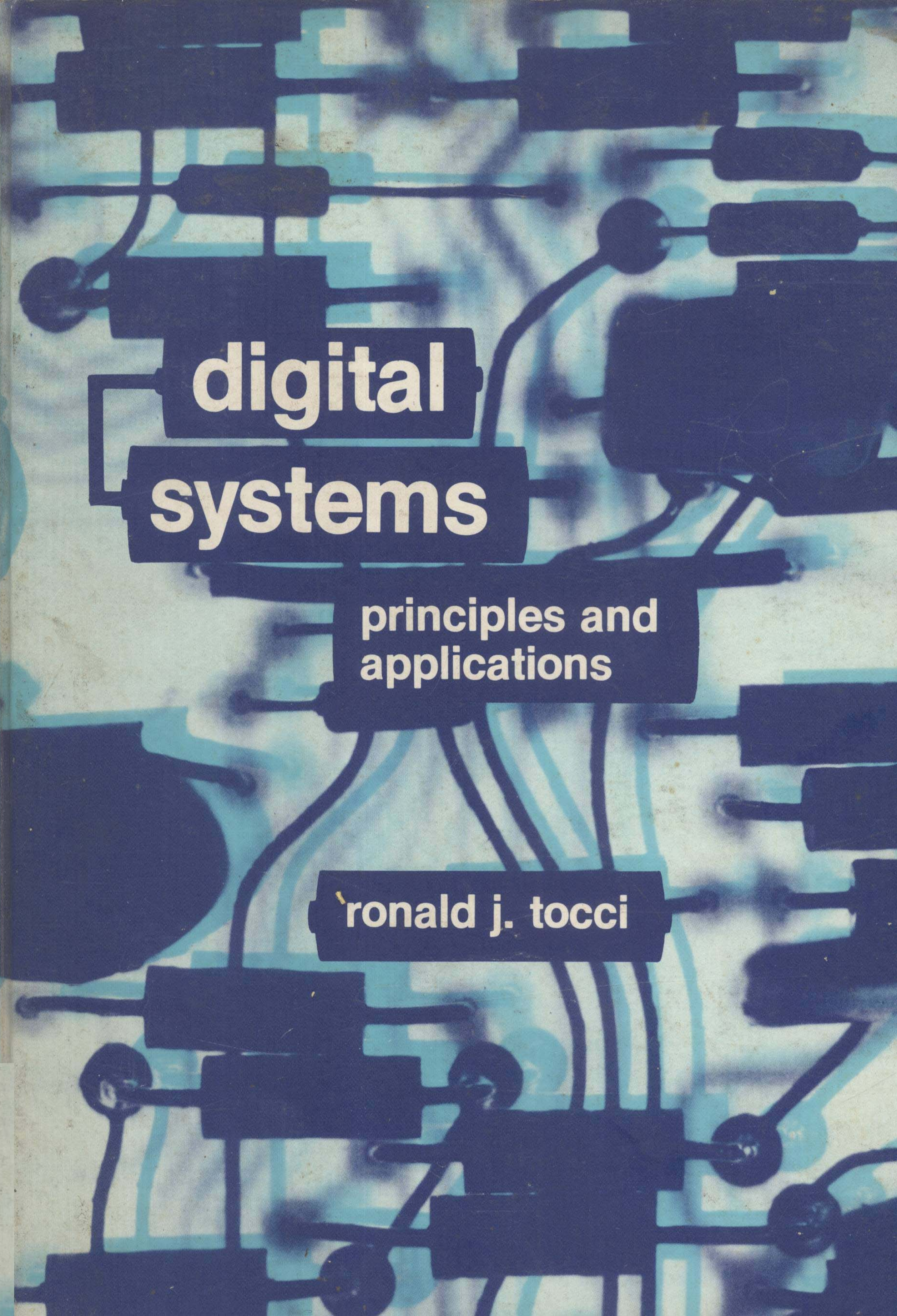

digital systems

principles and applications

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Principles and Applications

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DIGITAL SYSTEMS:
Principles and Applications

To Cathy–

for always believing me when I
tell her this is the last one.

PREFACE

This text presents a comprehensive up-to-date study of the principles and techniques used in modern digital systems and is intended for use in two-year and four-year technology programs.

While a basic electronics background is helpful, more than ninety percent of the material requires no prior electronics training. Hence, the text is well-suited for students of computer science or other non-electronic technologies concerned with digital systems.

The author realizes that there are many texts available for the digital area but he believes that this text offers many features which make it a more sound educational instrument than its predecessors. Among these features are:

1. It is up-to-date in its coverage of digital IC families (TTL, MOS, CMOS, ECL, TRI-STATE LOGIC) and in its coverage of such topics as decoding, encoding, multiplexing, de-multiplexing, strobing, data bussing, and microprocessors as well as the standard topics.
2. It utilizes a block diagram approach to teach the basic digital and logic operations without confusing the reader with detailed circuit diagrams. In Chapter Eight, the reader is introduced to the internal IC circuitry after he has a firm understanding of logic principles. At that point, he can interpret a logic block's input and output characteristics and "fit" it properly into a complete system.
3. Emphasis on The teaching of principles is emphasized, followed by *thoroughly explained* applications of the same principles so that they can be understood and applied to new applications. Among these applications are: the frequency counter, the digital clock, the keyboard entry encoder, the control sequencer, the digital voltmeter, the synchronous data transmission system, the digital computer, and many others.

4. Extensive use of illustrations and practical illustrative examples is made to provide a vehicle to help the reader to understand the concepts involved.
5. Each chapter is followed by numerous questions and problems of various levels of complexity that give student the opportunity to test and examine his understanding of the material. Many of the problems also present modifications to, extensions of, or new applications for the material covered in the chapter, thereby offering the student a chance to expand his knowledge of the material.
6. Chapter Nine explains and shows such applications of digital operations as decoding, encoding, multiplexing, data bussing, etc. These are areas that receive little or no treatment in most competing texts.
7. Chapters Two and Three show step-by-step procedures for both analysis and design of combinatorial logic circuits.
8. Chapter Seven is a comprehensive study of all types of binary counters and counter applications. Included are serial, parallel, variable-MOD, UP, DOWN UP/DOWN, presettable, and shift counters.
9. Chapter Twelve contains an introduction to microprocessors.
10. The topics are presented in a clear, straightforward manner with no unnecessary side issues. A good instructor can use this as an effective base on which to add interesting side-lines to his course.

The author wishes to thank several individuals who contributed to the final version of this work. My warmest appreciation, as always, to Kathy Langworthy for taking my illegible writing and transforming it into a presentable manuscript. Thanks also to my production editor, Eugene Panhorst, for a fine job of editing and to the reviewers for their valuable suggestions.

RONALD J. TOCCI

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chapter one

INTRODUCTORY CONCEPTS

In science, technology, business, and, in fact, in most other fields of endeavor, we are constantly dealing with *quantities*. These 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.

1.1 NUMERICAL REPRESENTATIONS

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 quantity which is directly proportional to the first quantity. An example of analog representation 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 gradually 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 (i.e., 1 mV, 2.3724 mV, 9.9999 mV).

Digital Representations

In *digital representation* the quantities are not represented by proportional quantities but by symbols called *digits*. As an example, consider the digital clock, 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 continuously changes, but the digital clock 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 to the analog representation of time provided by a wristwatch, where the dial reading changes continuously.

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

$$\text{analog} \equiv \text{continuous}$$

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

Because of the discrete nature of digital representations, there is no ambiguity when reading the value of a digital quantity, whereas the value of an analog quantity is often open to interpretation.

EXAMPLE 1.1 Which of the following represent analog quantities and which represent digital?

(a) An electronic counter that counts objects as they move along a conveyor belt.
(b) A current meter.
(c) Daily temperature variations.
(d) Sand grains on a beach.

Solution:

(a) Digital.
(b) Analog.
(c) Analog.
(d) Digital, since the number of grains can be only certain discrete (interger) values and not any value over a continuous range.

1.2 DIGITAL AND ANALOG SYSTEMS

A *digital system* is a combination of devices (electrical, mechanical, photoelectric, etc.) arranged to perform certain functions in which quantities are represented digitally. In an analog system the physical quantities are principally analog in nature. Many practical systems are *hybrid*, in that both digital and analog quantities are present and continual conversion between the two types of representation takes place.

Some of the more common digital systems are digital computers and calculators, digital voltmeters, and numerically controlled machinery. In these systems the electrical and mechanical quantities change only in discrete steps. Examples of *analog systems* are analog computers, radio broadcast systems, and audio tape recording. In these systems the quantities change gradually over a continuous range. For example, in AM radio broadcasting you can tune your radio to any frequency over a continuous band from 535 to 1605 kHz.

Generally speaking, digital systems offer the advantages of greater speed and accuracy and the capability of memory. In addition, digital systems are less susceptible than analog systems to fluctuations in the characteristics of the system components and are generally more versatile in a wider range of applications.

In the real world most quantities are analog in nature, and it is these quantities which are often being measured or monitored or controlled. Thus, if the advantages of digital techniques are to be utilized, it is obvious that many hybrid systems must exist. Chief among these are industrial process control systems in which analog quantities such as temperature, pressure, liquid level, and flow rate are measured and controlled. Figure 1.1 shows the symbolic block diagram of such a system. As the diagram shows, the analog quantity is measured and the measured value is then converted to a digital quantity by an *analog-to-digital* (*A/D*) *converter*. The digital quantity is then operated on by the central processor, which is completely digital and whose output is then reconverted to an analog quantity in a *digital-to-analog* (*D/A*) *converter*. This analog output is fed to a controller, which then exerts some type of effect on the process to adjust the value of the original measured analog quantity.

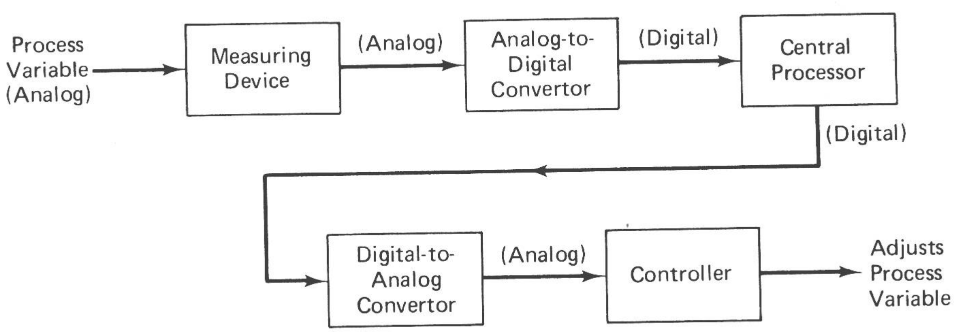

Figure 1.1 Block diagram of typical hybrid process control.