DIGITAL LOGIC AND SWITCHING CIRCUITS

Operation and Analysis

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PRENTICE-HALL, INC. Englewood Cliffs, New Jersey

Library of Congress Cataloging in Publication

BOYCE, JEFFERSON C.
Digital logic & switching circuits: Operation and analysis.

1. Switching theory. 2. Electronic digital computers--Circuits. I. Title

74-16763

ISBN 0-13-214478-6

10 9 8 7 6 5 4 3 2 1

Printed in the United States of America

PRENTICE-HALL INTERNATIONAL, INC., London
PRENTICE-HALL OF AUSTRALIA, PTY., LTD., Sydney
PRENTICE-HALL OF CANADA, LTD., Toronto
PRENTICE-HALL OF INDIA PRIVATE LIMITED, New Delhi
PRENTICE-HALL OF JAPAN, INC., Tokyo

Preface

The digital age has arrived. Techniques that were confined to the highly complex digital computer just a few short years ago are now applied in common home entertainment and commercial devices. Until recently, engineering and technical personnel have been forced to gain their knowledge of digital techniques either from highly technical digital computer orientated texts, or from "trial and error" on the job. This book bridges the gap by exploring the *general* field of digital techniques. It prepares the reader to recognize, understand, analyze, and troubleshoot digital logic equipments *without* the need to relate to a more complex type of digital device such as a computer. The digital computer has been purposely de-emphasized to illustrate the non-computer applications of digital techniques.

The title of this book, DIGITAL LOGIC AND SWITCHING CIRCUITS: OPERATION AND ANALYSIS, appropriately describes its contents. As will be observed as this book is used, the terms *operation* and *analysis* are closely allied. Following development of the basic concepts of digital logic in the first few chapters, it becomes apparent that separation of the two terms is almost impossible. No interconnection of the hardware elements of digital logic can be made that does not require *analysis* to determine the *operation* of the resulting circuit. *Analysis in this book is used to describe application of the relatively few rules of digital logic to circuits to determine the operation of the circuits.* The circuits may be as simple as two or three interconnected logic elements, or as complex as a digital computer. The same techniques apply.

As a result of reading and applying the principles and exercises provided in this book, the reader should be able to follow logic diagram data flow from input to output. He should be able to use simple Boolean Algebra, truth tables, logic maps, and waveforms to analyze and understand the operation of digital logic equipment. Since the approach to logic tends to be hardware oriented rather than theoretical, minimal electronic and mathematical background is required.

Chapters 1 and 2 are introductory in nature, discussing the basic concepts of digital logic, numbers, and counting. The fundamentals of combinational logic (gates) are presented in Chapters 3 and 4, while Chapters 5 and 6 discuss algebraic and graphical simplification of logic expressions. Combinational logic is summarized in Chapter 7, where procedures for analysis and troubleshooting of this type of logic circuit are developed by introducing the use of troubleshooting flow charts.

The knowledge gained during study of combinational logic is applied in Chapters 8 and 9, where sequential (time-dependent) logic is investigated. Chapter 10 integrates combinational and sequential logic by developing analysis and troubleshooting procedures (once again using flow charts) applicable to circuits containing both types of logic.

If any division of this book is to take place, it should be after Chapter 10. All previous chapters are somewhat theoretical in nature, although approached from a practical viewpoint. The remaining chapters discuss specific types of logic circuits. For example, Chapter 11 is devoted entirely to the subject of counters. Implementation of the counting function is discussed from both the individual logic element packaging method to the integrated circuit (IC) packages currently in use.

Registers are discussed in the same manner in Chapter 12, while miscellaneous logic functions such as adders, comparators, multiplexers, etc. are covered in Chapter 13. Chapters 14 and 15 are somewhat related, since they present the number codes used in digital equipment, the converter devices used with such codes, and the devices used to display information.

Chapter 16 summarizes the complete book by showing the analysis of a simple digital subsystem. An overview of the complete digital field is presented in Chapter 17 by discussing a number of common applications at the block diagram level.

It is impossible to list all of the individuals whose influence and suggestions have resulted in the organization of, and the material in, this book. Mr. Edward Francis of Prentice-Hall and Professor Kosow of Staten Island Community College deserve recognition for their untiring efforts during the evolution of this book. My colleagues in The Boeing Company and at Allan Hancock College, whose encouragement and advice has been invaluable, must receive much of the credit for this effort. The many students who suffered through early versions of portions of this book also should not be overlooked. And, most of all, the patience of an understanding family, all of whom gave up so much so that this book could be developed, must be acknowledged.

JEFFERSON BOYCE

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An Introduction to Digital Logic

Revolution is the mainstay of mankind's survival – not violent revolution, but a steadily progressive change in man's way of life. We shall devote this chapter to a discussion of such basic revolutions as the transportation revolution, the revolution in energy production, and, most importantly, the revolution in machines designed to aid mans' intellectual pursuits.

1–1 AN HISTORICAL BACKGROUND

The Transportation Revolution

Man has progressed rapidly in this century. In the early 1900s, one could travel cross-country only by rail at the convenience of the railroad. Today the same trip is routinely made by auto, at the individual's convenience – a revolutionary accomplishment!

Still more fantastic has been the transportation revolution brought about by the airplane. The first powered flight by the Wright brothers in 1903 led to the beginning (accelerated by World War I) of the first passenger service in 1919 between London and Paris. Today hundreds of millions of passengers and a large volume of freight traffic are carried yearly.

Even "the sky is the limit no longer." Man now travels outside the earth's atmosphere. It is almost commonplace for astronauts (or cosmonauts) to orbit the earth. A few individuals have even travelled to the moon (¼ million miles), landed, explored its surface, and safely returned with samples of another planetary body. For many of us, perhaps, travel within our planetary system may become a reality in this century. Can anyone deny the "transportation revolution?"

The Energy Revolution

Similar progress has been achieved in man's application of energy. The 1900 census showed that the largest percentage of power for industrial use was furnished by steam engines. Today electrical power has taken over almost completely.

The big energy breakthrough occurred when man developed the ability to harness the atom. Although a direct result of wartime effort, peaceful applications of nuclear power will soon revolutionize our lives. The Atomic Energy Commission predicts that by 1980 approximately 150 million kilowatts of electrical power will be produced by U.S. nuclear power plants. In addition, nuclear explosions used for excavation, and nuclear energy that powers seagoing vehicles, desalinates water, and acts as a tracer in medical applications are only some of the hundreds of other practical applications. Only man's imagination can limit new and varied uses for nuclear power.

Intelligent Machines

Last – but not least – in our revolutionary progress is the growing partnership between man and machine. The eighteenth century Industrial Revolution may soon take second billing to an "intellectual revolution." The concept of applying "intelligent machines" to many of man's fields of endeavor has existed for centuries, but only the evolution of electronic techniques made this concept a reality.

One of the earliest such devices that man built was the *abacus*. This digital machine appears in history prior to the birth of Christ. The example shown in Fig. 1–1 is a modified form that represents the alterations made by the Japanese and the Chinese civilizations. A skilled abacus operator can successfully compete with modern, mechanical desktop calculators.

Little progress was made in the development of machine aids until the appearance in 1642 of Blaise Pascal's desk calculator. Pascal's device, using simple gears, could add and subtract. Due to a lack of mechanical precision, other mathematicians could not improve Pascal's machine beyond achieving multiplication.

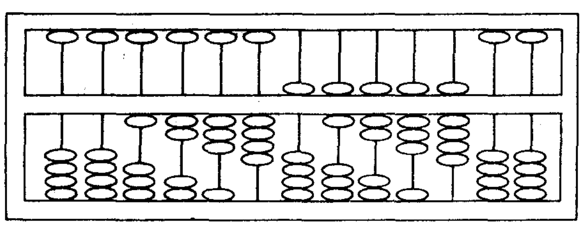

Figure 1–1 Japanese abacus, or Soroban

The next major milestone associated with the development of digital machines occurred in the early 1800s. Charles Babbage envisioned a mechanical device that incorporated many principles of the modern digital computer. His "Difference Engine" was developed to calculate and print mathematical tables. Again, imperfect materials, a shortage of precision tools, withdrawal of government support (after 1843), and a lack of understanding among his associates resulted in the abandonment of his project after several incomplete models had been constructed.

As scientists developed techniques that applied electrical and electronic principles to record storing, account handling, and bookkeeping, new, more versatile machines appeared. Once again, the impetus of wartime activities (World War II) spurred development; in 1940 a computer using relays was devised, and pulse techniques developed for radar were incorporated into applied mathematics. Thus automation requirements, arising from production needs, resulted in machines that could peform routine tasks without human intervention. Soon these production machines were capable of making decisions concerning quality, quantity, and so forth.

The general development of electronic computers in World War II has been followed by an almost endless activity in the design and application of these "intelligent machines." Textbooks, papers, and magazines abound on both technical and non-technical aspects of the "care and feeding" of computers. *The computer merely uses techniques that have existed for years.*

Our primary concern in this text is to explore these basic techniques and their diverse applications; however, we shall pay particular attention to the study of that broad field of digital techniques that can be applied to data communication and to data processing. Since the term *digital techniques* may be unfamiliar, we shall begin by comparing them with common analog techniques.

1–2 ANALOG (LINEAR) VS. DIGITAL TECHNIQUES

Analog (Measuring) Devices

An *analog* (linear) *device* is basically a measuring instrument. The measured analog signal can take on an infinite number of possible values. For example, consider temperature. The liquid thermometer (an analog device) measures and displays an approximate value. With sufficient precision, a thermometer reading of +70°F. might actually appear as +69.92987°F. There are an infinite number of possible temperatures between +69°F. and +70°F. The only limitation on resolution is the accuracy of the measuring device.

With a liquid thermometer, however, the *actual* temperature is not really being measured. Instead, the height of an enclosed column of liquid (mercury or alcohol) is made *analogous* to the temperature. The thermometer is a *transducer* that converts temperature into the expansion of a liquid column. Analog devices can also transduce physical phenomena into electrically measurable quantities using magnitudes or phases of voltages and currents, electrical resistances, shaft rotation, and the like. In such cases, the primary factor in the analog device* is the *magnitude* of the electrical signal: that is, how large or how small is it?

Digital (Counting) Devices

Whereas the analog signal is usually a *smooth, continuously varying signal*, the digital signal has a *discrete, discontinuous character.* A major criterion for any digital device is the presence (or absence) of a signal – not its actual value. We want to know not *how much* something has changed but only *if* it has changed. Numerical values are represented directly as *digits* (not as continuously varying quantities). *The digital device counts, while the analog device measures.*

In a digital device, the presence, absence, and repetition rate of the signals are the important factors – not the signal amplitude. The digital system transmits only discrete (step) changes and is discontinuous. (The analog system transmits physical quantity in a smoothly and *continuously* varying manner.)

An ordinary, hand-operated tally counter is a simple example of a digital device (Fig. 1–2). The counting lever must be pushed all the way down to register a count. There is no middle position of the lever that can register a half count. *It either counts one digit, or it does not count.*

Today all digital systems are based on whether something is actually there, whether it is true or false, whether there is a hole in a punched card, and so forth. Even mammoth, multimillion dollar computers are based on this simple yes/no decision. Complexity results when the equipment is instructed to make such decisions millions of times a second.

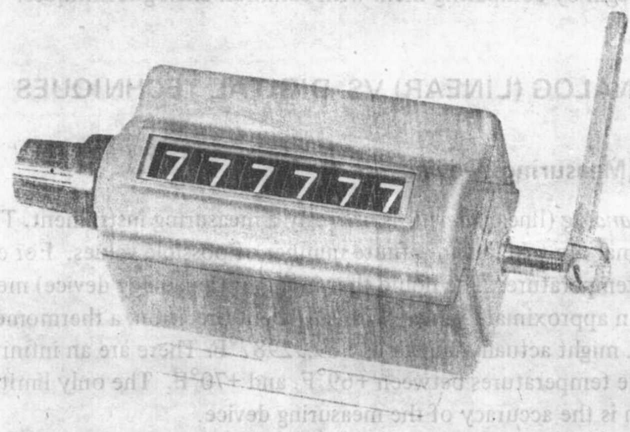

Figure 1–2 Tally counter (courtesy of Veeder-Root, Hartford, Conn.)

* Electronic components used with analog devices or transducers are mentioned in this text only where signals from such devices are to be converted to digital operation.

Digital Applications

Digital techniques are persistently invadi 'g fields that formerly used analog techniques. For example, remote measuring equipment, which once depended on analog methods, is now being replaced by digital equipment. Analog measurements are converted at their source to digital signals, then transmitted, processed, stored, and acted upon at some remote point prior to readout and action (Fig. 1–3).

Thus telephone conversations are being broken up by digital equipment, combined into a composite signal, transmitted, and decoded at some distant terminal. Some approaches to telephone transmission actually convert conversations to digital values instead of just "breaking-up" information (Fig. 1–4).

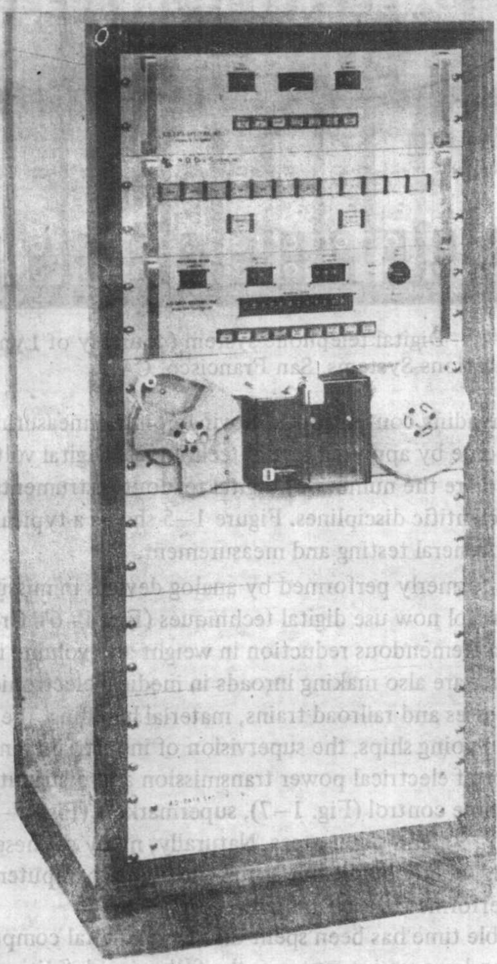

Figure 1–3 **Data logging system** (courtesy Analog Digital Data Systems, Inc.)

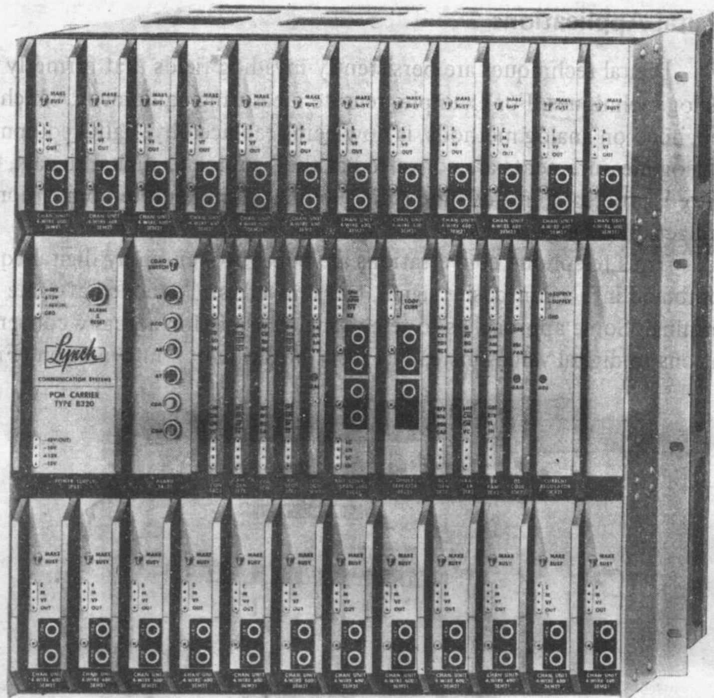

Figure 1–4 Digital telephone system (courtesy of Lynch Communications Systems, San Francisco, CA.)

Inaccuracies in reading conventional, moving-pointer, measuring instruments are being overcome by applying digital techniques. Digital voltmeters are common today, and so are the number of digital readout instruments available to the technical and scientific disciplines. Figure 1–5 shows a typical digital multimeter design for general testing and measurement.

Many functions formerly performed by analog devices in missile and aircraft guidance and control now use digital techniques (Fig. 1–6). Greater accuracy results, and a tremendous reduction in weight and volume is effected.

Digital techniques are also making inroads in medical electronics, the control of industrial processes and railroad trains, material handling, the monitoring and operating of ocean-going ships, the supervision of industrial plant functions, the centralized control of electrical power transmission and distribution, automobile servicing, machine control (Fig. 1–7), supermarkets (Fig. 1–8), the stock exchange (Fig. 1–9), and other areas. Naturally, many of these functions require the use of a digital computer, but again, the digital computer is just another device that performs tasks with digital assistance.

Since considerable time has been spent discussing digital computers versus digital data handling and processing systems, the following definitions should help to differentiate the two.

Figure 1–5 Digital voltmeter (courtesy of Hickok Electrical Instrument Co., Cleveland, Ohio)

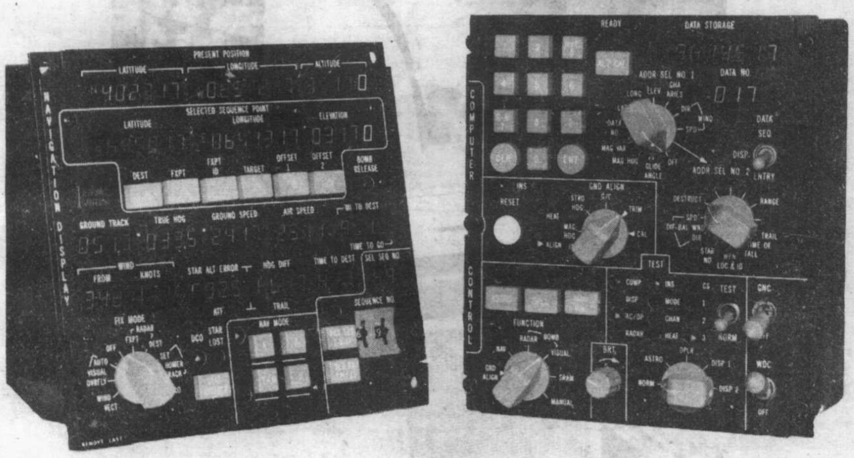

Figure 1–6 F-111 navigation display unit (left) and computer control (right) (courtesy of Singer-General Precision, Inc., Kearfott Div., Little Falls, N.J.)

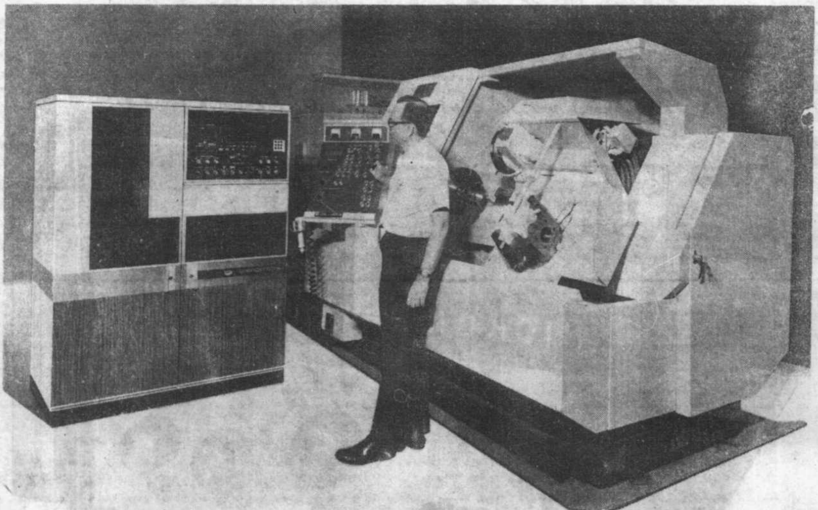

Figure 1–7 Dynapath System 4 numerical controller (courtesy of Bendix Industrial Controls Division, Detroit, Michigan).

Figure 1–8 Digital supermarket stock control (courtesy of Digitronics Corp., Albertson, L.I., N.Y.)