DIGITAL COMPUTERS & LOGIC CIRCUITS

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This book is dedicated to
Professor Jack LaPatra
without whose cooperation
this text would not have been possible.

PREFACE

This book is intended to be used in a one-semester introductory course on digital computers and logic circuits. The authors believe that the applications of integrated circuits and systems will be very helpful to electronics and computer technicians. Also, the four chapters pertaining to integrated circuits can be used in pulse and digital circuits courses if the program does not include an introductory course in digital computers. The authors firmly believe that all technical electronics students should study this material because the digital computer market accounts for at least sixty per cent of the total money spent in the electronic industry.

A knowledge of d-c and a-c circuits is necessary to comprehend the material presented in the text. No calculus is required, but skill in basic algebra is desirable. Some knowledge of transistor fundamentals is desirable, but enough of these fundamentals are presented in Chapter 4 to meet this requirement. Integrated circuits and systems and their applications to logic circuits and the digital computer are extensively covered in the text and the accompanying laboratory manual.

The text is supplied with a teachers guide containing hourly lesson plans, problem assignments and answers, or solutions, to the problems not given in the text itself. The laboratory manual follows the text with more than twenty experiments dealing with Boolean algebra, discrete component circuits, and integrated circuits and systems.

The text is essentially divided into three sections: Chapters 1 through 3, Chapters 4 and 5, and Chapters 6, 7 and 8. The first section deals with the mathematics of the computer, e.g. machine language programming, number systems, and Boolean algebra. Such topics as AND, OR, NAND, and NOR gates are illustrated in great detail. Karnaugh mapping is used to simplify Boolean algebra equations. Many examples are provided to help the student master Boolean algebra.

The second section deals with the application of discrete components. Logic circuits such as AND, OR, NAND, and NOR are illustrated with discrete components. Multivibrator circuits and the Schmitt trigger circuit are discussed in detail and practical design examples are illustrated.

The third section deals exclusively with integrated circuits and systems. Chapter six and seven attempt to analyze integrated circuit devices and their application in the digital computer and digital systems field.

Integrated circuits have revolutionized the computer industry. Engineers and technicians have been given new roles because of the reduction of circuit design responsibilities. New responsibilities of a systems nature have been generated, and the first step for the technician in meeting the new challenge is to develop an understanding of the new integrated devices. Resistor-Transistor-Logic has been selected as the most suitable logic line for the transition. The line has a wide variety of circuit and system functions available. The technician and the engineer will find the internal structure of RTL somewhat familiar, since it is fabricated exclusively with resistors and transistors. The choice would appear to be the logical one to afford a smooth transition to the study of integrated circuits.

Chapter eight considers computer design by taking previously discussed machine components and examining various ways to organize them in a useful configuration. In addition, the several peripheral devices and systems available are combined to form a data processing system.

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F. Tedeschi
J. Scigliano

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Chapter 8 COMPUTER DESIGN AND PROCESSING SYSTEMS

Chapter 1

HARDWARE AND SOFTWARE

1-1

INTRODUCTION TO THE DIGITAL COMPUTER

The foundation of computer technology was laid when man learned to count. The first sophisticated counting and calculating device can be traced back to 2000 B.C., when the Chinese developed the abacus.

In 1642, Blaise Pascal developed a semiautomatic adding machine that included gears capable of transmitting a "carry" which is necessary for addition. Baron von Leibnitz modified Pascal's design to include multiplication as well as addition.

During the early part of the nineteenth century, Charles Babbage envisioned a machine that could automatically follow stored instructions. Babbage's design provided for punched cards to feed instructions and was in fact, similar in principle to modern computers. Babbage's ideas were never fully carried out, since the machine tools of the day were incapable of the precision required to construct the components.

Later in the nineteenth century, George Boole developed an entire formal algebra that stated the rules for logical schemes. Little did he know that his insight was later to provide a powerful tool to be used in the development of the modern digital computer.

From Boole's time until sometime during World War II, few new ideas were developed in the field of computers. Pulse techniques, essential to radar, and the solution of complex scientific problems were two of the incentives that motivated scientists to build the early modern computers. These early computers used vacuum tubes, with which there were many problems, in their construction. In 1948, John Bardeen and Walter Brattain, working in the Bell Laboratories, discovered the principle of the **transistor**. In time the transistor, which has a virtually unlimited life, became more reliable and led to the development of more sophisticated computing machines.

The third generation computer employs **integrated circuits** in its design. These devices, because of their cost and size, will eventually replace discrete transistors in computer logic-circuit design. The final chapters of this text will introduce the concepts and applications of integrated circuits.

The impact of the digital computer encompasses several levels and is so widespread that it is difficult to conceive. Hardly a child in this country is not aware of the computer, and most can make cogent comments regarding something they have heard or read on the subject. Few curricula in college-level programs in science, engineering, medicine and some humanities fail to include material on the introduction to applications of the digital computer. And the general population, both knowingly and unknowingly, are exposed to computer applications in their daily lives. There is every indication this is only the beginning. It has been predicted that by the end of this century the electronic digital computer will be recognized by the layman as one of the most important tools man has ever developed.

In a way, another industrial revolution is taking place. In the past, onerous physical tasks have been taken over by machines, and now the computer has become part of the relegation of the most menial mental tasks of humans to machines. Tasks such as record keeping, routine supervision and monitoring, and repetitive process control are commonly handled by the computer.

A natural and important part of this opening material is a review and discussion of some of the most salient applications of the computer to date, followed by a predictive look to the future. Consider first one of the earliest and most important areas of application of the computer—the sciences. For example, the data-processing capability of the machine has been used to great advantage in the biological sciences. The classification of plants and animals is accomplished by processing large amounts of detailed information on each species according to specified criteria. The labor involved is enormous because of extensive computation and data manipulation, and the utilization of the computer is essential. The computer has been described as being capable of doing computations in a few seconds which, when done by hand, would take decades; and in the classification problem the high speed is valuable. Also impressive is the fact that the work is done with a very high degree of precision and reliability, and that the same computer can be arranged to perform many other functions.

This example from the sciences will be complemented by discussion of examples from the areas of business or data processing and control. The division of application areas is a devised one which fails to convey the fact that there is really a continuum of problem types. The scientific problems tend to be those with relatively small amounts of input or output data, but which require a great deal of internal machine manipulation. Business problems generally have more data and less machine manipulation. Other factors contribute to the nature of specific problems. As the data changes from basic numeric or alphanumeric (a combination of letters and numbers) to more abstract representations, the problems tend to be known as "information processing." Examples of symbolic representations are the structure of a branch of mathematics or a computer-programming language. If the machine is designed to solve a special class of problems and then is inserted to control a process where the problems occur, this is a control application.

A mathematical application is exemplified by linear programming, which is a computational technique for finding the maximum or minimum of a mathematical equation subject to certain specified restrictions. Examples of problems to which linear programming has been applied are computing the best combination of inputs into a manufacturing process which will maximize profits, and determining the optimum use of limited resources to achieve some desired objective.

In business applications the computer stores all kinds of records, generates department-status reports, reviews the effects of policy changes, provides measures of productivity, and assists in market research. A simulation of a business enterprise is often useful in predicting the consequences of a managerial decision. For example, "If I merge my company with Company X, what will be our competitive position in Market Y?" In a simulation we are conducting experiments with a computer using a mathematical model that describes the process of interest over a period of time.

An interesting control application concerns the use of the computer in the digital switching center of a telephone control office. The computer is a special-purpose machine whose function is to sequentially handle all requests for service from the subscriber. This complicated task must be accomplished with a very high degree of reliability and must offer economic advantages. The computer will have to do such things as:

1. Guard each subscriber line at all times to determine if it is inactive, busy, dialing, or requesting service.
2. Distinguish dial signals from noise and record the number.
3. Make the requested connection.
4. Classify calls as party line, long distance, intraoffice, or interoffice.
5. Detect the end of calls in order to free the equipment as soon as possible.

6. Send dial or route data to other offices.
7. Determine when the called party has responded during ringing.
8. Keep a record of dial information and status of each call in operation.

The design of a system such as this digital switching center is a major effort. Basic computer units which must be considered are discussed in the next section, but it is interesting to note how a telephone switching machine actually does some of its chores. Typically the machine inspects the status of each line at a 0.1-second interval until a line requests service, then the scanning rate steps up to a 0.01-second interval. As soon as all dialing information is received, the machine searches its memory for routing information, chooses an idle trunk line and establishes the connection. During the ringing and the actual call the line is monitored at 0.1-second intervals to obtain service information and to detect the availability of the equipment for other calls. Though this system description is very simplified, it is an interesting exercise to design a primitive switching center using this description and the computer units of the next section.

In an extended discussion of computer applications, as the examples become more complicated, questions regarding whether or not computers can think inevitably arise. At this time only well-defined and generally menial tasks are given to machines, but some controversy has developed regarding the replacement of people in more difficult tasks. The programming and machine use are so sophisticated that the performance approaches a wider set of human functioning than believed possible only recently. It is not our intention to respond defensively, nor to attempt to alleviate the concern, but rather to demonstrate by an example one of these more provocative applications.

A great deal of effort has been invested in programming machines to play games. This seemingly frivolous direction is based on the fact that successfully playing a game such as checkers requires serious intellectual activity, learned skills, and a logical systematic approach. A. L. Smith has written a series of computer programs for a general-purpose digital computer, and has, in effect, created a checker-playing machine. In this way, "learning" by a computer is investigated. In order to win at checkers, the machine is programmed for a three-step approach.

1. Consider all possible first moves and a few moves, in each case, beyond the first move.
2. Evaluate the resulting alternate board positions by a mathematical procedure.
3. Select a move and make it.

The especially interesting part of the checker player is that based on experience gained in play, all programs are revised. For example, the mathematical procedure in Step 2 would be changed. In effect, therefore, the machine is undergoing a kind of learning.

Because of the richness of computer applications today, we could go on almost indefinitely giving interesting examples. However, an appropriate way to conclude this section would be with a look to the future to try to predict some of the future impact of the computer on our society. Medical diagnosis and monitoring of health-care systems are likely to be performed by computer. More and more computer-assisted business decisions will be made. Professionals will generally be more creative because all routine work will be done by the computer. In fact, one may extend this notion to a view of the uplifting of the functioning of the general population to a level of cultural, scholarly, recreational, and professional activity never before possible. A control-accounting facility could be established for each person and enterprise, removing the need for circulating currency. And again, we could go on and on in listing potential future applications of the computer. It is clear, however, that many future applications will have a sociological impact on our culture, and this must be considered.

1-2
BASIC COMPUTER UNITS

Data processing systems can be divided into four types of functional units (Figure 1-1a and 1-1b):

1. Central processing unit,
2. Storage,
3. Input devices,
4. Output devices.

The **central processing unit** (Figure 1-2) is the controlling center of the entire data processing system. The **central processing unit** is divided into two parts:

1. The **arithmetic/logic** unit,
2. The **control** section.

The **arithmetic/logic unit** performs such operations as addition, subtraction, multiplication, division, shifting, moving, comparing, and storing. It also has the logical ability to test various conditions encountered during processing, and to take action accordingly.

Arithmetic operations are carried out by two main **registers**. A register is a storage device which holds numbers in the arithmetic section. The register must possess the ability to have information read into it, read out of it, and retain its contents after it has been read. The two main registers in the arithmetic section are called the **accumulator register** and the **multiplier-quotient register**. Addition is carried out by passing two sequences of numbers (in a special machine form), one from the storage register and one from the accumulator, into an adder, which performs the

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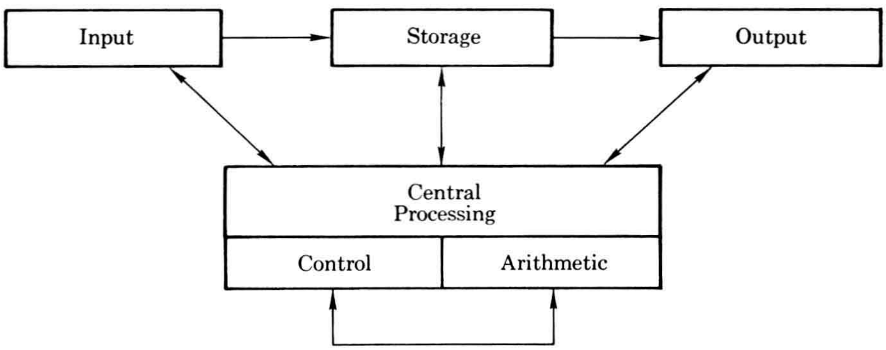
a.



b.

Figure 1-1. Data processing system