DIGITAL COMPUTER THEORY

Louis Nashelsky

Wiley Series in
Electronic Engineering Technology

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Louis Nashelsky

Assistant Professor, Department of Electrical Technology
Queensborough Community College
of the City University of New York

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RICHARD O. MAYER

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WILEY SERIES IN ELECTRONIC ENGINEERING TECHNOLOGY to Katrin and Kira

Preface

The stimulus for writing this book developed when I first taught a digital computer course at Queensborough Community College. A good textbook with up-to-date coverage, sufficient and clear examples and numerous problems for students was not available. The material presented here is based on what was written and used at the college and improved by the many changes that were shown necessary to make the subject easier to teach. The book should, therefore, be particularly appropriate for classroom use.

The text is divided into three sections, fundamentals, computer circuits, and computer units. The fundamentals section covers basic number systems, computer codes, Boolean algebra, and machine language programming. The computer circuits section presents a detailed study of many modern computer logic circuits and computer blocks. Logic circuits covered are AND, OR, NAND, and NOR gates. The computer blocks include the basic multivibrator circuits—bistable (or flip-flop), monostable (or one-shot), and astable (or clock)—and the Schmitt trigger circuit. The section on computer units covers the memory unit, control unit, arithmetic unit, and input-output unit(s) in separate chapters.

The book contains numerous examples which highlight the important aspects of the chapters to the student. Problems are provided throughout each chapter and at the end of each chapter. This breakdown of problem presentation should allow the instructor to provide suitable problems while he is covering the material of the chapter and then to assign problems relating to the full material of the chapter after it has been completed. (Answers to selected problems are given at the end of the book. The problems for which there are answers are indicated in the text by a line beneath the number.) The text is also supported by many photographs and illustrations which should help the student in understanding digital computer theory and the instructor in presenting it.

There is sufficient material presented in the three sections for curricula in which specific sections of study are more important than others or in which some material has already been covered by a previous course. For example, in a digital computer curriculum in which computer circuits are covered separately, the material in Sections Two and Three is sufficient for another course. If the particular curriculum covers computer units in one course, the material from Chapters 3 through 8, on computer fundamentals and circuits, will provide worthwhile material for a second course. For an advanced high school program only the first section with its coverage of fundamentals may be applicable, but the many examples and problems can be used to good advantage. Another curriculum may need only the material on computer circuits and blocks (Section Two) as the basis for the major part of a course.

In essence, the amount of material provided in the book, and its sequence, is appropriate for a single computer course in a two-year college curriculum but may well be used in many different programs that exist or are developing in schools. The book is divided into sections and chapters that should help the individual instructor find the best grouping for his course or program.

I wish to express my appreciation to the many companies which sent illustrative material for the text. International Business Machines Corporation supplied many of the illustrations and photographs which are used in several chapters (most of them appear in Chapter 12). A number of other fine photographs were supplied by the Burroughs Corporation, Digital Electronics Corporation, General Electric Corporation, and the Minneapolis-Honeywell Corporation.

I should like to pay special thanks to Professor Joseph B. Aidala, head of the Electrical Technology Department at Queensborough Community College, and Professor Leon Katz of the same department for their encouragement and support in the writing of this book. I should also like to thank Mrs. Sylvia Neiman for typing the original manuscript, Mr. Nathan Blumkin for production of the original manuscript used at Queensborough Community College, and Mrs. Ellen Zawel for typing the final copy for publication.

LOUIS NASHELSKY

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Digital Computer Theory

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Introduction

1–1. General

Digital computers have become an important item of study and no doubt will grow in usage and importance. It is, therefore, essential to have an understanding of how the computer is used and how it works. Although calculating machine history can be traced back to the nineteenth century (if not earlier), the modern computer was first considered in the 1930's and actually developed only around 1950. In essence, the modern electronic digital computer has been around for only fifteen years. It seems incredible that in so short a time it could have advanced so far and become so essential a tool in scientific and business operation. There is no doubt that a combination of growth in the technological field and the need for high-speed data processors and calculators have spurred development in this very short time.

Because the word "computer" is a general term, it is necessary to describe the various types of computers and specify which types are to be considered in this book. Broadly speaking, there are digital computers and analog computers. These devices are operationally quite different. The digital computer operates in a world of binary ONEs, and ZEROs (the two digits of the binary number system), manipulating these digits at fantastically high rates. Addition time in many modern computers is less than one microsecond (one-millionth of a second) for binary numbers with as many as forty digits. In other words, the computer could do a million additions per second (if it did not have to perform other information handling operations). Being able to perform arithmetic operations so quickly, the digital computer can perform calculations on large amounts of data in a short length of time. The analog computer, on the other hand, operates in the "real world," handling electrical signals and mechanical positions which represent the physical problem being considered. Neither general nor special-purpose analog computers can provide solution rates of much more than a few hundred cycles per second. However, this slower rate does not necessarily mean that the analog computer is a poorer device. Were this so, the digital computer would have quickly replaced it. Actually, each is superior for specific applications. In fact, in a growing number of fields a combination of analog and digital computer features is used to perform the required operation. Hybrid computers (the term to describe the resulting functional computer unit device) are of increasing importance in certain types of problems, such as air guidance and navigation. It is necessary to convert any analog input data into binary form and after computation reconvert the data to analog form for use in most present special-purpose digital computers. A good distinction between analog and digital computers cannot be made until more is understood about at least one of them.

Digital computers fall into two general categories, general-purpose and special-purpose computers. A general-purpose machine is designed to be programmed to solve a large variety of technical problems. Within a few minutes it can study some medical problem, do financial bookkeeping, study an engineering design, or play checkers with the operator. A special-purpose machine is designed around a specific problem and is optimized to do only that type of problem. As such it is usually smaller, cheaper, and more efficient in performing that specific task. Two examples are production control of a refinery and guidance control of a missile or plane. Both types of digital computer are basically the same in structure. The distinctions are in specific units used to bring data into the computer and feed information out, and in the flexible steps of operation of the general-purpose as compared to the special-purpose machine.

1–2. Digital Computer System

The basic parts of any digital computer are the input unit, arithmetic unit, control unit, memory unit, and output unit. Figure 1–1 shows a simplified block diagram indicating the many computer flow paths. Let us consider a general-purpose machine first; the input units may be paper tape, punched card, magnetic tape, typewriter (specially adapted), or magnetic disk, to list the most common. The input unit provides data and instructions to the computer. To change the type of problem being solved only requires feeding a new set of instructions and data to the computer. Each type of input device is suited to a particular use. Punched cards may contain individual instructions or data, any one of which can be easily changed. Each card can be used to represent a specific item or person, for example, the course card given to each student, the phone or electric bill of each customer, the item of purchase from a company, the specific items held in stock by a company, etc. Punched cards are one of the most useful input devices for such purposes. However, when large amounts of information are to be handled, punched cards become too slow. Magnetic tape can provide input data at a faster rate and allows data to be updated and stored back in the same place. Banking firms, for example, store their records on magnetic tape. So do insurance companies, which handle the largest amount of data in the business field. For processing

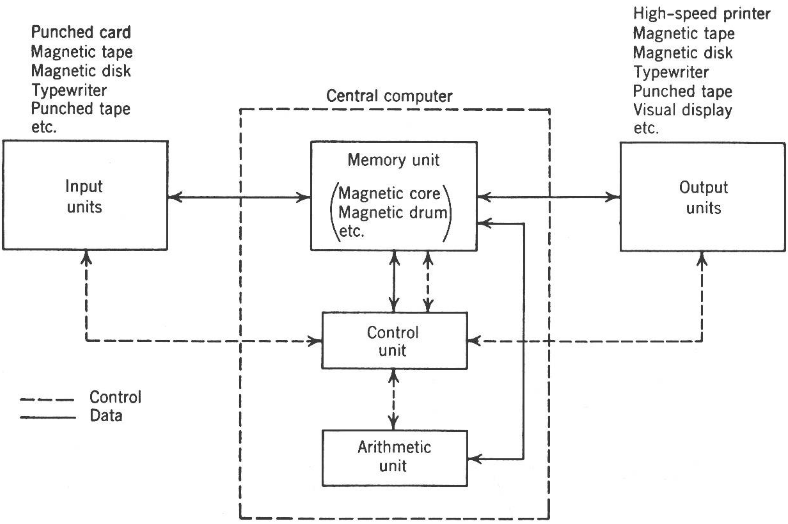

Figure 1–1. Basic computer units, block diagram.

customers' accounts, the computer calls for the input data from the magnetic tape, performs specified operations, and puts revised data back on the tape. Considering the large number of accounts handled, magnetic tape is an essential feature of the operation. Magnetic disk files are very similar in use to magnetic tape and may be considered the same for this discussion. In the chapter on memory devices, different details of each will be considered. Typewriter input provides an easy means of telling the computer to do an operation or asking it about its various parts. It is not used for large data input but mainly for "quick talk" with the computer. As such, it is very useful. The typewriter is also useful for small programs when little time is needed in communication with the computer (as in debugging or troubleshooting operations). Punched tape can be read fast and requires less equipment and less space for data storage than punched cards. Whereas a magnetic tape can have millions of bits of data, a punched tape can be cut to a specific length (depending on the particular problem) and that piece of tape handled quite easily. A magnetic tape may store many different problems and must be handled carefully to avoid erasing the data. A paper tape may be a few inches or feet and is a permanent record. On the other hand, it cannot be updated (revised) as the magnetic tape can and is less useful in that respect.

In concluding this brief description, it should be clear that with the many types of problems to be solved and with so much data to be handled, many different input devices are needed. Each is best for a specific area of work. In fact, larger computer facilities can handle punched card as well as magnetic tape or disk and typewriter for more flexible and efficient operation.

Once data and instructions are fed into the computer, calculations may be carried out. Generally, the instructions (or program) and data are stored in the computer internal memory which is differentiated from the input device (also a memory) by its speed of operation. The internal memory is designed to handle small amounts of data but at very fast rates. The basic computer speed is often limited by the speed of the internal memory. The most popular internal memory used at present is the magnetic core memory. It can operate at a rate of one million words (data or instruction) per second, which means that it can provide words for computation and accept the answers at the rate of one million operations per second. The storage capacity, however, has been limited until recently to only a few thousand words. Computers are now being designed for hundreds of thousands of words of storage. Memory contents may be continually changing, as the computer takes in new data, updates the data, and then reads out the data to make space for more information.

Memory operation is controlled by a main computer unit called the "control unit." It provides control for all computer operations and is the "heart beat" of the system. It interprets the instructions in the memory and tells other units where to take data from, where to feed it to, and what operations to perform. The arithmetic unit performs the addition, subtraction, multiplication, and division operations, and at very high speeds. The arithmetic section can be operated at higher speeds than the memory if it takes a number of steps to complete an addition while the memory is not being used, thus increasing the operating rate of the system. The results of arithmetic operations are fed back to the memory, for storage. It can be read out at a later time to an output unit, which may be a magnetic tape, punched card, typewriter, punched tape, magnetic disk, or high-speed printer. (Many output devices are also used for input operation.) The high-speed printer, the fastest permanent visible record of those just mentioned, is essential when large amounts of data are handled. Specific details of each type of unit are covered in Chapter 12.

The feature of a general-purpose digital computer that is most important in making it a versatile and useful device is its ability to be programmed. A program is a list of statements telling the computer what operations to perform, in what order, and on what data. Modern programming languages allow writing these commands in a simplified manner so that the programmer does not have to describe explicitly each step the computer is to perform. A few instructions may command the computer to perform hundreds of operations. An important point to remember is that if the computer cannot do repeated computations on a large amount of information, it will not be useful. A calculator can be used to solve a problem quickly once to many significant places. To do the same problem, varying the numbers used, for thousands of times may not be reasonable on the calculator but is easy work for a computer.

In addition to programming languages, another important technical achievement that has improved the computer is the use of solid-state components. The first few computers used relays and then vacuum tubes. Relays operate much too slowly, require considerable power, take up large areas, and are not sufficiently reliable. The vacuum tube has too short a lifetime, uses considerable power (operating very hot), and takes up a large amount of space. If we consider that a modern computer requires millions of parts, and malfunctions if even one is bad, the need for reliable components is soon obvious.

The first vacuum-tube computers used thousands of tubes. Any one owning a television set will appreciate the fact that the unit would break down often from tube failure. Moreover, if all the tubes were not replaced after a period of time, the computer would continuously malfunction as one tube after another went bad. With solid-state components—transistors, tunnel diodes, micrologic circuits, etc.—the occurrence of a malfunction because of a breakdown of these components is becoming virtually unknown in modern computers. At present, the auxiliary mechanical equipment—card punchers, card readers, magnetic tape drives, etc.—account for most of the small number of problems that do occur. Because of solid-state components, the computer design has been increased in complexity, allowing much more storage, control, and versatility, without undue taxing of the useful operating time of a computer. The IBM System/360 utilizes the improved reliability and smaller size of micrologic circuits to increase considerably the number of operations done. It has also increased memory size to allow for more computing facility. Figure 1–2 shows both a large computer system (IBM System/360 Model 40) and a small computer (DIGIAC 3080).

A digital computer is designed to perform a specific group of operations. These may include addition of two numbers, subtraction, multiplication, and division. It has a large and fast electronic memory where the numbers (data) to be operated on, the results of the operations, and most essential of all, the instructions, are stored. In addition, the computer is designed to take these stored numbers, compare them to "see" whether they are equal, check their arithmetic sign to "see" whether they are positive or negative, and move data around within the memory. Finally, it can bring in new data and instructions and can feed out data from its memory to provide output of its calculations. Each step or operation of the computer