Digital Computer Circuits & Concepts

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PREFACE

The primary intent of this text is to close the gap that currently exists between academic theoretical instruction and current industrial practices in digital electronics.

Within the last few years, there have been rapid technological advances in the computer field. The need for clear, comprehensive, and practical information on currently available digital devices has grown just as rapidly.

This text is written primarily for students in technical schools, junior colleges, and community colleges, and for electronics technicians currently employed in the field of digital computers. It is written at such a level that it can also be used in high school electronics programs.

The text will help prepare students for positions in the industry by providing a firm foundation in the basic concepts of logic circuits. To help the student master these basic concepts, the text is illustrated with over 300 drawings, and many practical examples are worked out in detail. Numerous circuits from manufacturers, including practical data, are used throughout the text.

For the practicing digital electronics technician, the text will serve as an excellent reference because modern digital devices and circuits are discussed.

In Chapter 1, the evolution of computers and some applications are discussed. The various number systems needed to understand and work with computer circuits and systems are introduced in Chapter 2. Alphanumeric and interchange codes are also presented here. Chapter 3 covers binary arithmetic, including octal, hexadecimal, and BCD.

Logic, logic functions, logic symbology, and Boolean algebra are presented at a conceptual level in Chapter 4. Gates and flip-flops are discussed in Chapters 5, 6, and 7. Chapter 8 is devoted to the implementation of logic functions. The concepts presented in Chapter 4 are applied in Chapter 8.

Registers, encoders and decoders, counters and timing circuits are covered in Chapters 9 through 12. The arithmetic logic unit (ALU) and its associated circuits are presented in Chapter 13. In Chapter 14 memory units are discussed, including RAMs and ROMs.

Chapter 15 introduces a hypothetical microprocessor (LIMP) that is used to introduce basic microprocessor concepts. Microprocessor and computer architecture are covered. LIMP's instruction set is introduced.

In Chapter 16, interface concepts are presented using LIMP. Input and output ports are covered, along with control and status ports. Bus concepts are explained and applied.

In Chapter 17, LIMP is used to introduce microcomputer programming. Concepts learned in Chapters 15 and 16 are used in some practical examples. Flow diagrams, subroutines, stacks, assembly process, and I/O routines are included.

Some of the commercially available microprocessors are described in Chapter 18. A practical application of a microcomputer system is presented. Both hardware and software concepts are included.

Many people have contributed in the preparation of the manuscript. We would like especially to express our appreciation to the many companies who were very helpful in making available to us their application notes and circuits. Special thanks go to the other members of the Electronics Department at San Jose City college, who offered their advice and opinions. Finally, we would like to acknowledge the untiring efforts of Corine Deem for typing and preparing the manuscript.

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SURVEY OF DIGITAL COMPUTERS AND APPLICATIONS

Computing devices were in use long before the advent of modern computers. The use of mechanical means to perform arithmetical calculations has always been one of man's goals. The first counting machine was probably the *counting board,* which consisted of several stiff wires or reeds on a wooden frame. Each wire had ten sliding beans–representing 0 to 9.

Perhaps the earliest known mechanical calculating device was the *abacus,* developed independently by both the Chinese and the Greeks over 4000 years ago. The abacus was the earliest known device that had the capability of denoting a *carry.* The abacus is still used today in China and Japan.

Around 1615 John Napier invented and published tables of logarithms. He devised "Napiers Bones," which were numbered squares used in calculations. William Oughtred used Napier's logarithms in designing the first slide rule in 1621.

An important step in the development of "computing" machines took place in France in 1642: A 19-year-old inventor, Blaise Pascal, having tired of adding long columns of digits, designed and constructed an adding machine. Pascal's machine was composed of a series of gears, each with ten teeth to represent numbers 0 through 9. The gears were turned with a stylus, and when a 9 was reached, it automatically *carried* to the next gear. This same principle is still used in modern electromechanical calculators.

In 1671, Baron Von Leibnitz constructed a machine called a *step reckoner.* Like Pascal's machine, it could add, but it could multiply as well. Twenty years later, Leibnitz improved his machine so that it could also divide and extract roots.

In 1725, Basile Bouchon, a Frenchman, invented punched paper tape for operating cloth-weaving machines. A roll of punched paper was moved past the needles so that only where a hole appeared was the needle allowed to pass through.

In 1801, another Frenchman, J.M. Jacquard, designed a system of binary coded cards for controlling looms. Both the punched paper tape and the punched cards are used today in modern computer systems.

In 1833, Charles Babbage invented a machine called the *analytical engine.* This machine was based on basic principles identical to those used in modern digital computers. Babbage was probably the first man to visualize a general-purpose computer complete with a programming scheme and memory units. He even made use of Jacquard's punched cards for input and output data. Unfortunately, Babbage's computer was never completed. The industry and technology of his time were not sufficiently advanced to produce the components with the necessary tolerances.

In 1854, George Boole, an English mathematician, published *An Investigation of the Laws of Thought on Which Are Founded the Mathematical Theories of Logic and Probabilities.* This work formed the basis of *logical algebra,* in which simple thought processes were represented mathematically. It is important to note here that Boole did not relate his algebra to mechanical or electrical devices.

In 1866, Dr. Herman Hollerith devised a method of recording data on punched cards. Because of the punched card, the 1890 census was completed in less than one-third the time required for the 1880 census. This system is sometimes referred to as the *unit record system* because data is stored as units on cards which can be used repeatedly.

C.E. Shannon, in 1938 at M.I.T., wrote a paper on how an electrical circuit consisting of switches and relays could be represented by mathematical expressions. The basic techniques developed by Shannon are required in the design of all types of switching circuits today.

Howard Aiken designed the first general-purpose computer, the Mark I, a joint venture of Harvard University and IBM. This computer used electromagnetic relays and punched cards.

Among the leading contributors to modern computer technology were an electrical engineer, J.P. Eckert, Jr., and a physicist, J.W. Mauchley. In 1945 at the University of Pennsylvania, they completed the Electronic Numerical Integrator and Calculator (ENIAC). The ENIAC used vacuum tubes and was therefore the first all-electronic computer. It was wired to perform a specific sequence of calculations. If a different program was required, thousands of circuits had to be rewired because the computer was not able to *store* a program.

The ENIAC was a huge machine, weighing over 30 tons. It had 19,000 tubes and hundreds of thousands of resistors, capacitors, and inductors. It occupied 15,000 square feet of floor space and consumed almost 200 kilowatts of power. Nevertheless, it could perform 5000 additions per second. (Modern computers can perform millions of additions per second.)

In 1944, Von Neumann began to develop the logical design of a computer capable of a stored program. The program could be changed at will—without the rewiring of the computer.

1.1 MODERN COMPUTERS

The first computers of the late 1940s and early 1950s used relays and vacuum tubes for their logic circuits. Power and tube failures were common. First-generation computers that were commercially available, such as the UNIVAC I, IBM 701, IBM 704, etc., used vacuum tubes. These computers were used essentially for single job operations.

With the advent of the transistor, second-generation computers were designed in the late 1950s. These were general-purpose computers—smaller, faster, and much more reliable. Integrated circuits (ICs) were used in the third-generation computers in the 1960s. Examples of third-generation computers are the IBM 360 series and the UNIVAC 1108.

Fourth-generation computers of the late 1960s to the present utilize solid-state medium-scale integration (MSI) and large-scale integration (LSI). Here, entire processing systems are fabricated on a single silicon chip.

An example of a large computer system is the ILLIAC IV, designed at the University of Illinois and assembled at the Burroughs Corporation in Paoli, Pennsylvania. The ILLIAC IV is actually a series of 64 "slave" computers capable of executing about 200 million instructions per second. Most computers solve problems by a series of sequential steps (*linear programming*). The ILLIAC IV, however, can perform up to 64 simultaneous computations (*parallel programming*).

1.2 ANALOG COMPUTERS

There are two general types of computers—analog and digital. An analog device is one whose operation is "analogous" to a mechanical or electrical quantity. It solves problems by using some mathematical model—for example, a mercury thermometer is an analog device; it compares the expansion of a column of mercury with the surrounding temperature.

Analog computers can be used in simulating the performance or characteristics of some future product. For example, the performance of a proposed new jet plane could be simulated by an analog computer long before actual construction begins. All of the design variables—such as wingspan, thrust, and other engineering data—could be fed into the computer, and the output would represent the performance characteristics. Any changes in input variables would immediately affect the output, thereby achieving the desired characteristics.

However, the accuracy of analog computers is limited. The reasons for this are the tolerance limitation of electronic components and our limited ability to read and interpret scales and graphs.

1.3 DIGITAL COMPUTERS

Digital computers operate on the numbers ONE and ZERO—the only digits in the binary number system. The computer can manipulate these digits at extremely high speeds and with great accuracy. High-speed computers can perform the addition cycle in less than 100 nanoseconds. Whereas accuracy in analog computers is limited, the limitation to accuracy in digital computers is the number of digits used. For example, if a number has 32 digits, the binary place accuracy obtainable is equal to 2^{32}.

1.4 WHAT A COMPUTER DOES

A digital computer is an electronic device that consists of input and output devices, arithmetic and control circuits, and a memory. Before the computer can do any work, a program of instructions must be supplied. These instructions are written by a programmer in a language that the computer "understands." This information can be put on punched cards, punched tape, or magnetic tape. A computer operator will sometimes sit at a console and simply type out the instructions. We therefore need to communicate with a computer through some appropriate input device.

The input data is then taken by the computer and translated or coded into some number code or machine language with which the computer can proceed to operate. After all the operations are completed, the coding process is "reversed" at the end, and machine language is translated back into a language we can understand.

Speed is an essential element of input and output devices, just as it is with the internal operation of computers. For example, some of these machines can "read" magnetic tape at a rate of hundreds of inches per second. Thirty thousand printed lines per minute can be reproduced by some output terminals.

Another characteristic of the digital computer is its ability to *store* information. The storage process involves taking the data received as input and "filing" it in a preselected location. This data may be retrieved when called upon, or it may be further processed and returned to storage at another location. The facility of storage is usually an electronic unit or device known as *memory*. The size of the memory may vary from a few thousand to many million binary digits.

Perhaps the biggest advantage of the computer is its ability to manipulate figures and symbols and to perform enormous quantities of arithmetic computations millions of times faster than any human—even one assisted by the slide rule, abacus, or adding machine. Calculations that would require months, and even years, can be done by the computer in a matter of seconds or minutes.

The arithmetic process is essentially one of addition or subtraction. Multiplication and division can be considered as rapid repetition of addition and subtraction, respectively. The arithmetic capacity of the computer is essential in many areas of modern technology. For example, the instantaneous computations involved in space flight make space travel a reality. Weather, census, insurance, etc., all require vast and rapid calculations of an enormous amount of data. The engineering designs of skyscrapers, bridges, and planes are made possible by the arithmetic capacity of the computer.

Another fundamental property of the computer is its ability to make a logical choice. The computer is capable of "comparing" two numbers and "knowing" whether they are equal or if one is greater or less than the other. The ability to compare and make logical choices allows the computer to select the next course of action. For example, suppose a program instructs the computer to add or otherwise calculate until a stated amount is reached and then stop. The