MICROPROCESSORS IN INDUSTRY

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Preface

Microprocessors In Industry was written to provide the knowledge and design techniques that are required to apply microprocessors to the automation of industrial and commercial products as well as manufacturing and process control. The book relates the development of today's microprocessors to sensors, data-acquisition, and automatic control applications and provides a basis for the design considerations necessary to achieve a successful and efficient microprocessor application from initial design concepts to system manufacturing or sell-off.

The designer must have a thorough knowledge of microprocessors as well as the design techniques used to apply these devices. This text primarily relates the application of today's modern microprocessors for dedicated data-acquisition and automatic control when interfaced with various types of sensors and control elements. It is intended as a single-source reference book for the graduate engineer, but the various sections can also be presented at the undergraduate level. Discussions are included on the basic structure and technology of microprocessors, the various chips available, industrial sensors, data-acquisition, data conversion, interfacing, programming, control system elements, applications, and system design. This spectrum of topics is included to assist the reader not only in obtaining an understanding of the technology, but in applying the technology to actual product applications. Each chapter contains a number of review problems to provide the reader with a better understanding of the topics discussed.

Microcomputers are a popular topic in industry. In writing a book on microprocessors, it is important that any book have an originality that will justify it. Some books are written for software engineers with little hardware theory, while some books are written from the hardware viewpoint with very little software acknowledgement. This book attempts to rectify these shortcomings by treating both areas. Another unique path for this book is the mating of microprocessors with control hardware.

Chapter 1 considers the microprocessor structure. The basic building blocks are presented along with the methods used to perform the arithmetic and logical operations under program control, for the microprocessor is only one element in the microcomputer system. As a component, it allows new areas of industrial applications that were impractical before because of cost and size. These new areas of application can be considered to have a fundamental impact on the structure of the industrial control industry.

Memory is necessary in the microcomputer system to store programs and data used by the microprocessor. Thus, the first chapter presents an overview of the most common memory chips used in microcomputers systems: RAMs and ROMs. An analysis of the information flow in a typical microcomputer system is presented as well as an overview of instruction operations.

The development of microprocessors has been possible due to the advances in semiconductor process technology. Chapter 2 reviews modern semiconductor technology, with particular attention to those used in microprocessors. Integrated circuit techniques are discussed, and the important microprocessor and memory technologies are presented.

Chapter 3 considers the major characteristics of a number of popular microprocessor units. The chapter begins with a review of the evolution of microprocessors and then continues into the major product lines.

This chapter serves as a reference on microprocessor products. Much more detailed information is available from the manufacturers. This chapter discusses the general characteristics and their significance in an application to the user.

In Chapter 4, the major characteristics of transducers used in industrial applications are presented. Included in this chapter are the method of operation and operating ranges for temperature, pressure, and flow transducers.

Chapter 5 considers the types of data-acquisition circuits used in industrial applications and how to choose the best components for a particular application. The following topics are presented: single-channel systems, multichannel systems, multiplexing, sample-holds, signal-conditioning amplifiers, common-mode, isolation, and filtering. There is also an overview of plant-wide techniques. With the advent of distributed processing and computer networks, these are topics of high importance.

In order to process the data, it must be in digital form so that the data can be used for controlling a process, generating information for displays, or stored for future use. The basic method for getting the data into digital form is the analog to digital converter. Chapter 6 presents an overview of conversion methods along with their advantages and disadvantages. A review of binary codes is presented along with guides for applying converters. The chapter concludes with a number of synchro conversion techniques for ac measurement systems.

Interfacing the microprocessor is the subject of Chapter 7. The microprocessor interface is one of the most important elements in the microcomputer system. This chapter considers the hardware and software techniques required for a successful interface. Among the topics considered are interfacing the microprocessor with a data-acquisition system, microprocessor interface chips, programming the interface unit, and standard digital data interfaces. This is an important chapter, and the subject is one which may cause the most problems for the user.

Chapter 8 considers the control elements and the analysis of the total control system. The final element in the control system is the motor or solenoid used to provide the control function. The microprocessor is of little value to the industrial designer unless it can be used to modify the final control parameter. This chapter reviews the control techniques for solenoids and stepping motors. The control system analysis topics include closed and open loop control and system response characteristics. Much has been written on control theory and techniques, but this chapter emphasizes how the theory and techniques can be implemented when using a microcomputer.

Microprocessors will have a significant impact on all industries in the next five to ten years. As a low-cost product, microprocessors will cause the elimination of many competing technologies and products. The industrial firms that successfully use microprocessor technology will emerge with a larger share of the marketplace. Chapter 9 considers a number of important industrial application areas for microprocessors such as low-cost computers and controls, automotive devices, communicative networks, telephone switching, and process control. This chapter presents a real opportunity to the reader for developing even more unique applications. Emphasis is on industrial applications, including both the visible microcontroller/computer system and the buried microcomputer in an analytical instrument or other intelligent product.

The development of an operating microprocessor system starting with a microprocessor and associated parts can be a formidable task. Chapter 10 considers the hardware and software tools available to the designer. Also considered in this chapter are the techniques for selecting the best microprocessor and development path for the application. Included are these topics: development aids, hardware systems, software packages, assemblers, cross-assemblers, languages, editors, loaders, simulators, and PROM programmers.

This book would not have been possible without the help of many from a number of universities and industrial firms. I wish to thank those who have contributed the wealth of articles and books to this area of science and engineering. I am grateful to Dean Morris of the California Polytechnic State University for allowing me a forum to initially present many of the concepts illustrated in this book and to the students who attended these courses and provided valuable feedback during this initial development.

I am also indebted to those in the aerospace, automotive, communica-

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I am especially grateful to the following individuals who through their discussions and writings provided inspiration and guidance in this fast moving technology: Robert Noyce and Gordon Moore of the Intel Corporation, Carver Mead of the California Institute of Technology, Harry Garland of Cromemco, Thomas Harrison of IBM, and Béla Lipták of Béla G. Lipták Associates, P.C.

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Contents

1. Microprocessor Structure

COMPUTERS AND MICROCOMPUTERS

All computers have a central processor, some memory, and a way to bring data in and present it to the outside world. What is unique to the microcomputer is that the processor is usually on one semiconductor chip, and memory and input/output circuits may also be on that same chip, or the memory and the I/O circuits are at least on chips on the same circuit board.

Microcomputers are not only small but low in cost relative to larger computers. Typically, a microcomputer is used where there are only a few different tasks to perform or where the string of instructions (the program) is fixed. The range of input/output equipment to which the microcomputer is connected is limited compared to larger computers, and speed and efficiency may not be as important.

Microcomputers are found in microwave ovens, laboratory instruments (see Figure 1.1), machine tools, and electronic cash registers. High-speed punched card readers, line printers, and large magnetic tape or disk memories are not required in these applications. The input/output is limited to a keyboard with a digital display or a connection through a telephone line

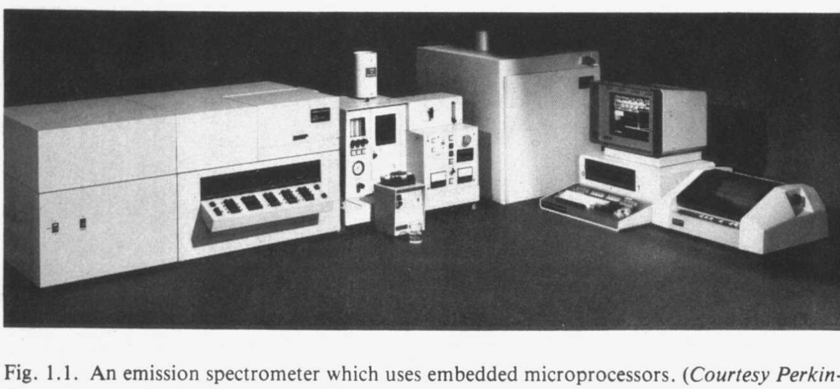

Fig. 1.1. An emission spectrometer which uses embedded microprocessors. (*Courtesy Perkin-Elmer Corporation.*)

to a larger computer. The program remains fixed; the task remains basically the same.

The larger computers, the "minicomputers," tend to handle a wider ranger of tasks. The minicomputer is usually contained in an enclosure about the size of a breadbox, and it may have a printing device and a magnetic tape output. It is capable of handling the paperwork for a small office—payroll, inventory, and other activities that can change from day to day. However, the line between microcomputers and minicomputers is changing, with some microcomputers approaching minicomputer performance. (See Figure 1.2.)

Larger than minicomputers are the "mainframe" computers, used in large offices such as insurance companies. These computers deal with large files of data such as millions of insurance policies. With mainframes, many magnetic disks and tapes are connected to the computer in order to store data, so the input/output scheduling can become a major task. Mainframe computers may be used to handle "scientific" computations such as those needed to produce the daily weather forecast for a section of the nation.

Fig. 1.2. This multiuser, multitasking transaction processing system is microcomputer-based. Yet it contains features previously available only on mainframes. (*Courtesy Intel Corporation.*)

Here, speed and efficiency in arithmetic, using computations far beyond what is found in most microcomputers, are needed.

The typical microcomputer application is the task that is small, relatively fixed, not too demanding of input/output paths, and requiring fast efficient arithmetic. (See Figure 1.3)

The typical microcomputer itself is a small box with a convenient mounting arrangement. It has its own self-contained power supply, along with terminals to which wires or cables are connected that lead to sensors and output devices such as keyboards, as well as temperature and pressure sensors, level

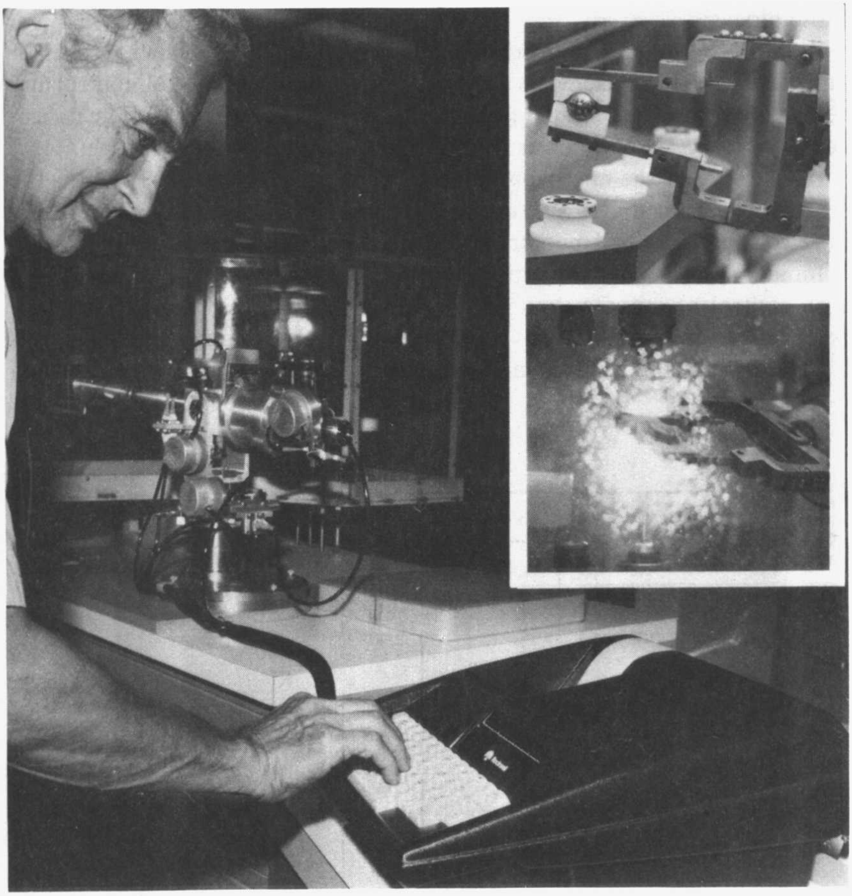

Fig. 1.3. Working in a chamber filled with nitrogen and using pressurized liquid Freon (lower insert), a robot cleans precision ball rotors (upper insert) used in submarine navigational systems. It is controlled by a microprocessor priced under $1000. (*Courtesy Rockwell International.*)

detectors, and flowmeters. Output devices include automatic typewriters, printers, video screens, electric motors, valves, solenoids, lighted displays, and actuators of various types.

The microcomputer may also "talk" to larger computers, floppy disks, magnetic tapes, remote terminals, and other peripherals.

MICROPROCESSOR COMPONENTS

Designing with microprocessors has become more of a programmer's task than a circuit designer's. Circuits fit together like blocks, while software tends to hold the blocks together. In this chapter, we will examine some of those blocks.

A microcomputer is a group of circuits, which include a microprocessor and other processing elements. It also has input/output lines for control and communications and enough memory to contain the programs. The microcomputer only needs a power source and a program in order to operate.

At the core of the microcomputer system is the microprocessor. It is the central processing unit (CPU) of the computer, and it has arithmetic processing circuits and control memory for its instruction set. (Even a simple microcomputer system and its microprocessor require a list of instructions, along with control of input/output operations and communications in order to perform a task. (See Figure 1.4) Although a CPU for a computer can be constructed by utilizing various medium scale integration (MSI) functions such

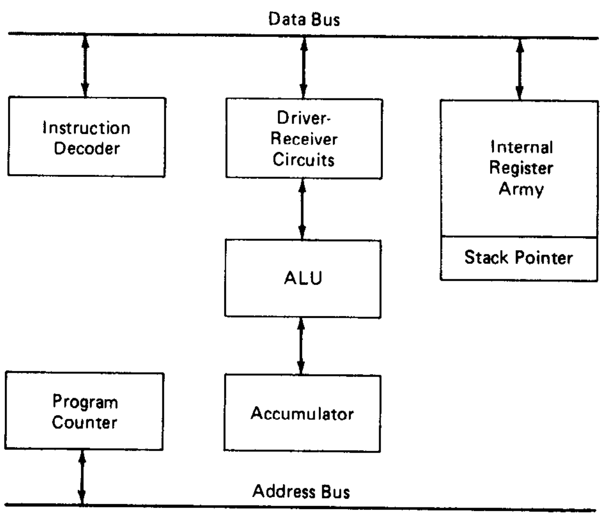

Fig. 1.4. A typical microprocessor configuration.

as registers, ALUs, and decoders, such a CPU may require hundreds of IC packages; it can, though, be tailored for a particular application. However, when the CPU is in large scale integration form (LSI), it becomes a microprocessor (also called a "processor-on-a-chip"). Unlike a custom-designed CPU, the functional characteristics of the microprocessor are fixed by the internal architecture. The only access available to a microprocessor is through the terminals of the package.

A microprocessor may be on a single semiconductor chip, or it may be on several interconnecting chips. The microprocessor performs the functions of instruction decoding from program memory and execution of the program, along with the synchronization and generation of control signals required for input/output operations. It tends to have the same functional configuration as any computer. The required functional blocks include an arithmetic logic unit (ALU) for processing instructions, an instruction decoder, register banks for temporary storage during arithmetic operation, and timing and control circuits such as clock oscillators, frequency dividers, and counters for sequencing (see Figure 1.5).

Memories are used to hold programs and any data that must be manipulated by the instructions. Programs are stored in the memory as a series of binary words, each word having from 4 to 16 bits, depending on the microprocessor used. Each word or series of words represents an instuction or data that the microprocessor will decode or act upon when that information is presented at the processor input.

The microprocessor communicates with the outside world via three paths—(1) the data bus, (2) the address bus, and (3) the control bus. The data bus is a group of parallel-line signals that permit bidirectional digital-data

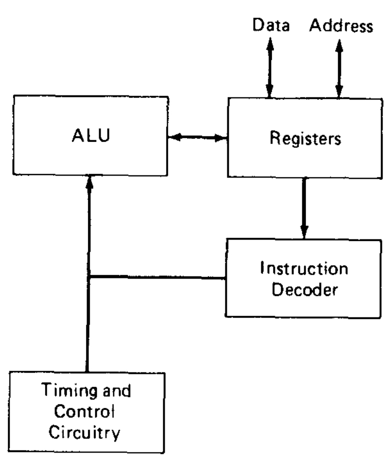

Fig. 1.5. Microprocessor components.

transfer. It may have 4, 8, 12, or 16 lines, depending on the microprocessor. Digital words transmitted over the data bus are either instructions for the processor, data to be manipulated, or the processed results of an operation.

A typical microprocessor like the 6800 has eight pins to which wires are attached for the movement of data into and out of the device. These eight wires constitute the data bus, and information can flow in both directions along the bus (during different times.) This technique is called "multiplexing."

In addition to the data bus the 6800 microprocessor also has a group of 16 pins, to which wires can be attached, that are used to move binary words called addresses; together they are called the "address bus." The address bus carries information outward only, from the microprocessor to memory and input/output chips. The signals on the address bus are used to select a certain part of memory or I/O section.

There is also a group of assorted control signals that enter and leave the microprocessor. Some of these may carry control signals back and forth between the microprocessor and the memory, and I/O chips. They are usually grouped together and called the "control bus." Other wires may go back and forth between the microprocessor and support chips. No connection is made directly to the registers, the ALU, or other internal components. Microprocessors have many of the features common to all computers. The characteristic that makes the microprocessor unique is that the CPU is contained in just a few integrated circuit packages. (A complete 6800 CPU board is shown in Figure 1.6.)

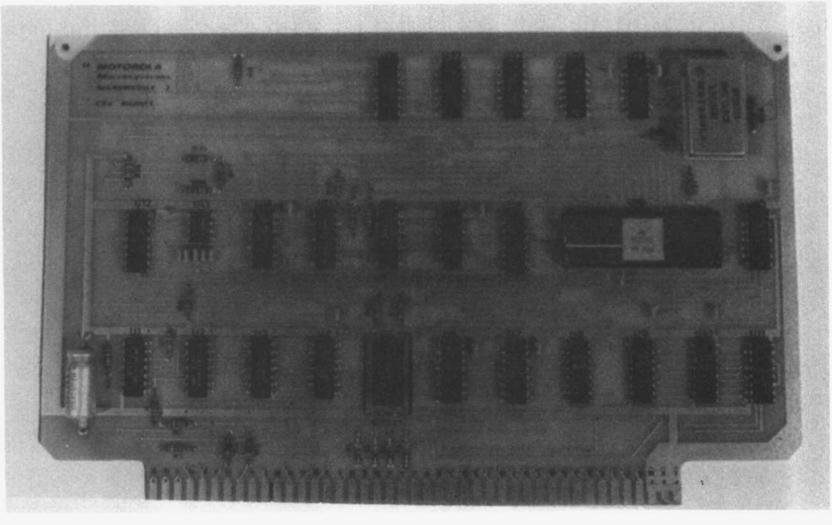

Fig. 1.6. This 6800 CPU board contains bus buffering and power reset circuits, clock circuitry, memory select logic, and timing and control for memory refresh operations. (*Courtesy Siltran Digital.*)

ARITHMETIC LOGIC UNITS

The arithmetic logic unit (ALU) can vary from a simple adder to a complex unit that can perform many arithmetic and logic functions. If the arithmetic logic unit cannot perform a function directly, several instructions may be necessary to produce the desired result.

Adders

The binary addition of all the combinations of two digits can be shown in a truth table. Only the 1 + 1 situation produces a carry. A two-input OR gate can accept these combinations as inputs and produce the correct sum as an output except when the 1 + 1 combination occurs. (See Figure 1.7.)

A circuit that will accept two inputs representing the augend and addend digits and produce output signals representing the sum and carry is known as a half-adder. The term half is employed since this adder circuit can only add together two variables at a time and does not consider the possible carry that might have occurred from the next lower bit. There are several ways of implementing the half-adder; two circuits are shown in Figure 1.8.

The correct addition of two numbers may be carried out by half-adders if several are connected together. For instance, the parallel addition of two third-order binary numbers is accomplished in Figure 1.9.

$$\text{Augend: } X_3 = 1, X_2 = 1, X_1 = 1$$
$$\text{Addend: } Y_3 = 1, Y_2 = 0, Y_1 = 1$$

Serial addition of two binary numbers may be accomplished using the circuit shown in Figure 1.10. The only additional element needed is a delay of one bit time to move any possible carry into the next higher bit time.

A full-adder circuit has three inputs and two outputs. The inputs are the addend, augend, and any possible carry from a preceding bit. The outputs are a sum and possible carry. Figure 1.11 shows a typical full-adder. Connecting full-adders together to form a parallel binary addition unit involves no extra circuitry and only one full-adder per bit. Figure 1.12 indicates the system of connecting full-adders in parallel for the addition of two 3-bit numbers. A full-adder can also be used for serial binary addition by using a one-bit delay to move the carry forward to the next bit time as shown in Figure 1.13.

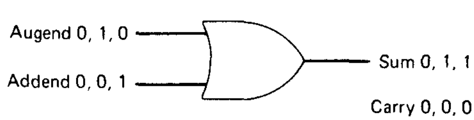

Fig. 1.7. Using the OR gate as an adder.

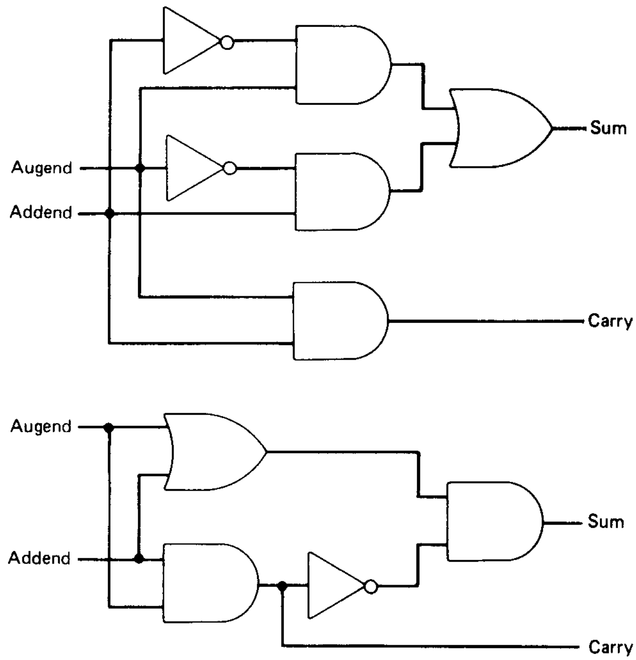

Fig. 1.8. Half-adders.

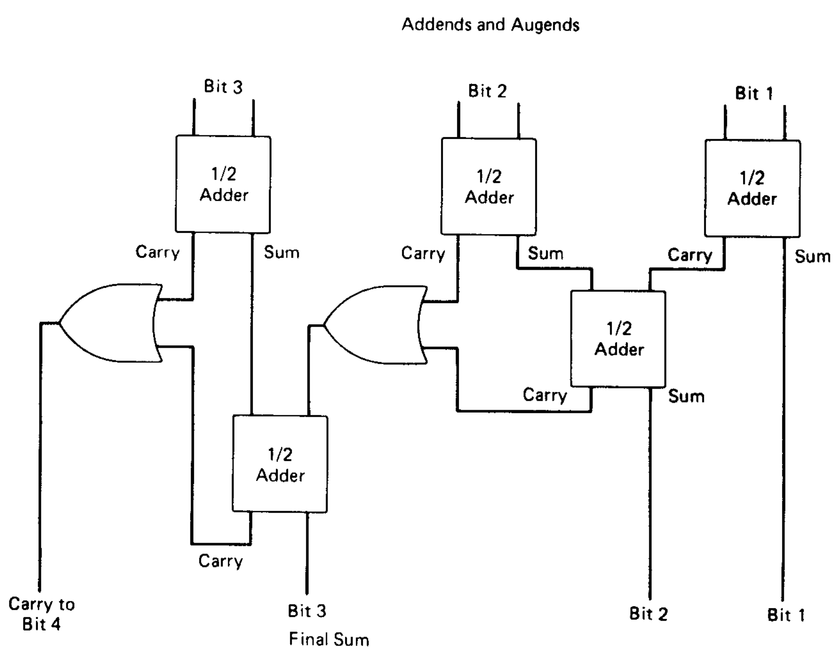

Fig. 1.9. Parallel addition with half-adders.

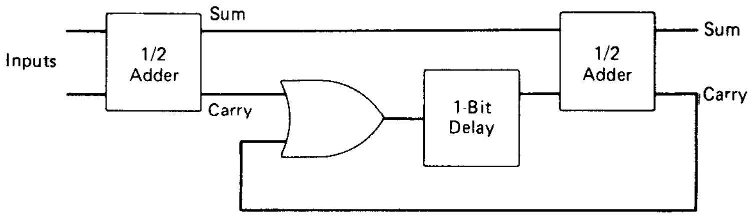

Fig. 1.10. Serial addition with half-adders.

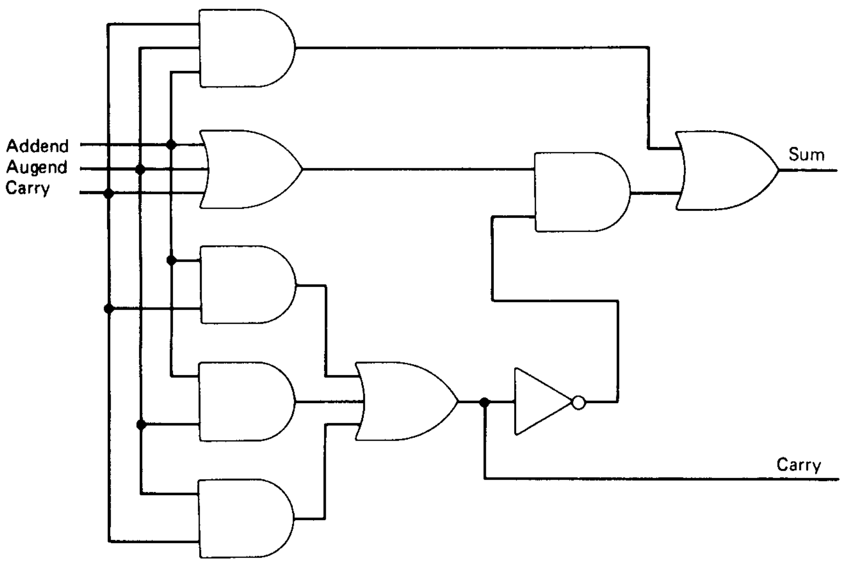

Fig. 1.11. Full-adder.

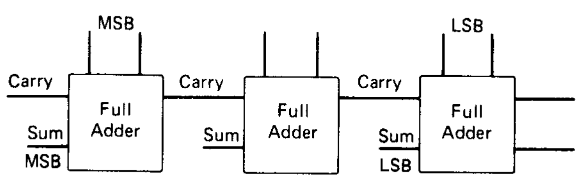

Fig. 1.12. Parallel adder using full-adders.