MICROPROCESSOR BACKGROUND FOR MANAGEMENT PERSONNEL

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"numerology" list, a list of abbreviations, a table of microprocessors on the market today, and performance plots of benchmark programs.

Chapters 1–6 cover fundamental microprocessor concepts and are intended to give a basic understanding of device operations. Chapters 7 and 8 are oriented toward applications in order to show typical uses for microprocessors. Chapters 9–12 provide an examination of topics of special interest to managers. These four chapters very nearly provide a standalone survey unit for readers interested only in management considerations.

Considerable help was provided in bringing together the material for this book. Cliff Harris read, edited, and made numerous suggestions throughout the text. Cliff, with help from Ted Myers and Dennis Eilers, created the illustrative routines in Chapter 7. Karen Winkler's production work (editing, design, and liaison) was skillful, expeditious, and an important contribution.

Other participants included Ashley McConnell, who provided editing and suggestions; Bob Gregory, who was a consultant on integrated circuit technology; and Arlene Dyckes and Irene Garcia, who helped with typing and a variety of tedious tasks. The manuscript was typed by Patt Cooper, Mirium Arnold, Arlene, and Irene. John Shane, Rick Turner, and Larry Nelson assisted in preparing material. The contents of the book were improved by the invigorating classroom interaction with my Sandia Laboratories students.

I greatly appreciate all the help I received and hope that this book reflects, at least to some extent, the excellence of those contributions.

James Arlin Cooper

Contents

chapter one

Background

1.1. INTRODUCTION

Microprocessors are the key item in *processor-based digital signal processing systems*, which will be examined in this book. This field has already given evidence of becoming one of the richest, most influential, most exciting areas of scientific and engineering endeavor in history. A unique blend of semiconductor technology, computer hardware and software techniques, and logic design has been evolving at a rapid rate over the past few years. The payoffs in extensive computing power, low cost, and small size would have been unbelievable a decade ago.

Our objectives will be to examine microprocessors and related topics from a manager's point of view. Although the scope will necessarily be limited, the understanding obtained should prove valuable as a basis for making decisions or evaluating decisions pertaining to the use of microprocessors in achieving organizational goals.

Of special interest to managers are such topics as consideration of trade-offs involved in selecting microprocessors as basic system components; selection of the preferable technology, manufacturer, and model; determination of personnel requirements and the extent to which they are involved; evaluation of cost effectiveness of hardware and software laboratory support equipment; and examination of special documentation problems.

Near the end of the book we will prognosticate about future trends in microprocessor-based technology and likely impacts on general technology and our society. There is every reason to believe that these impacts will be profound.

1.2. HISTORY

A. Computer Technology

At the beginning of the 1970s, semiconductor technology and computer technology were solidifying an important partnership that yielded the component called a *microprocessor* (see Figure 1.1). Briefly, a microprocessor is a small device that is capable of carrying out "programmed" operations (instructions) in the same fashion as a computer. It is not a computer, or even a "microcomputer," but it does have many of the same central logic functions. These tiny devices quickly had a synergistic impact on the technologies that had given them birth. In addition, they began to cause striking changes in logic design; commercial products, such as games, microwave ovens, and "smart" terminals; and instrumentation. Today, microprocessors are tumbling off semiconductor processing lines at a rate in excess of

Figure 1.1 A microprocessor. This photomicrograph of a microprocessor chip illustrates the complexity of a device actually measuring 4.5 by 5.5 mm. The device shown is a Sandia Laboratories version of the RCA 1802. Courtesy of Sandia Laboratories, Albuquerque, NM.

10,000,000 per year. Many microcomputers (computers that use a microprocessor for their central processing unit) are available for less than $1,000, bringing *personal computers* within a reasonable price range. Microprocessors are found in automobiles, service stations, cash registers, children's games, and educational devices. A microprocessor manufacturer (Intel Corporation) claims to have replaced IBM as the world leader in numbers of computer sales.

However, the contrast between microprocessors and large-scale computers is startling. Figure 1.2 shows part of a modern computing facility (at Sandia Laboratories) containing the typical arrays of logic devices, power supplies, consoles, fast access memory, mass storage memory, and operators. A microprocessor is shown in Figure 1.3 situated on a penny. Although a microprocessor also needs peripheral devices and equipment to peform useful tasks, the overall combination of small size, low cost, low power consumption, and high reliability are incredible when the complexity of tasks that can be accomplished with microprocessors is considered.

The sequence of events that led to microprocessors provides an interesting history (see Figure 1.4).

Charles Babbage (1792–1871) proposed a gear-type digital computer in 1833. Babbage was an English mathematician who devoted about 50 years of his life and a considerable amount of his own and others' financial resources to calculating machinery, but his computer was never built. This

Figure 1.2 Portion of the computing facility at Sandia Laboratories. Courtesy of Sandia Laboratories, Albuquerque, NM.

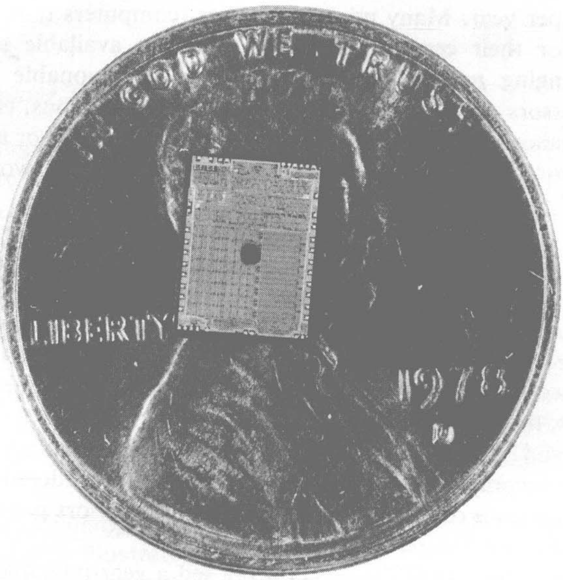


Figure 1.3 Sandia Laboratories version of the RCA 1802 microprocessor (on a penny). Courtesy of Sandia Laboratories, Albuquerque, NM.

is illustrative of the role necessity often plays in technological advances. It was not until World War II that a real need for computers was apparent, although a relay computer was designed at Bell Laboratories in 1937.

The first electronic digital computer was apparently the Colossus, which became operational in 1943 at Bletchley Park, England. It was a 1,500-tube dedicated computer for cryptoanalysis applications. Several computers similar to the first Colossus were built, but a long-lasting cloak of secrecy prevented these devices from contributing significantly to the development of future computers.

In 1943, the ENIAC computer project was begun for the U.S. Army for dedicated ballistic trajectory computations. The project was spearheaded by John Mauchly and J. Presper Eckert of the University of Pennsylvania Moore School of Engineering. The *program* was wired into the machine by plug-in wire interconnections. The ENIAC used about 18,000 vacuum tubes, occupied a 30-ft by 50-ft room, consumed 150 kW of power, and took about 3 years to build—at a cost of $400,000.

Neither the Colossus nor the ENIAC were *stored-program* computers (computers whose program can be "stored" in memory in the same manner

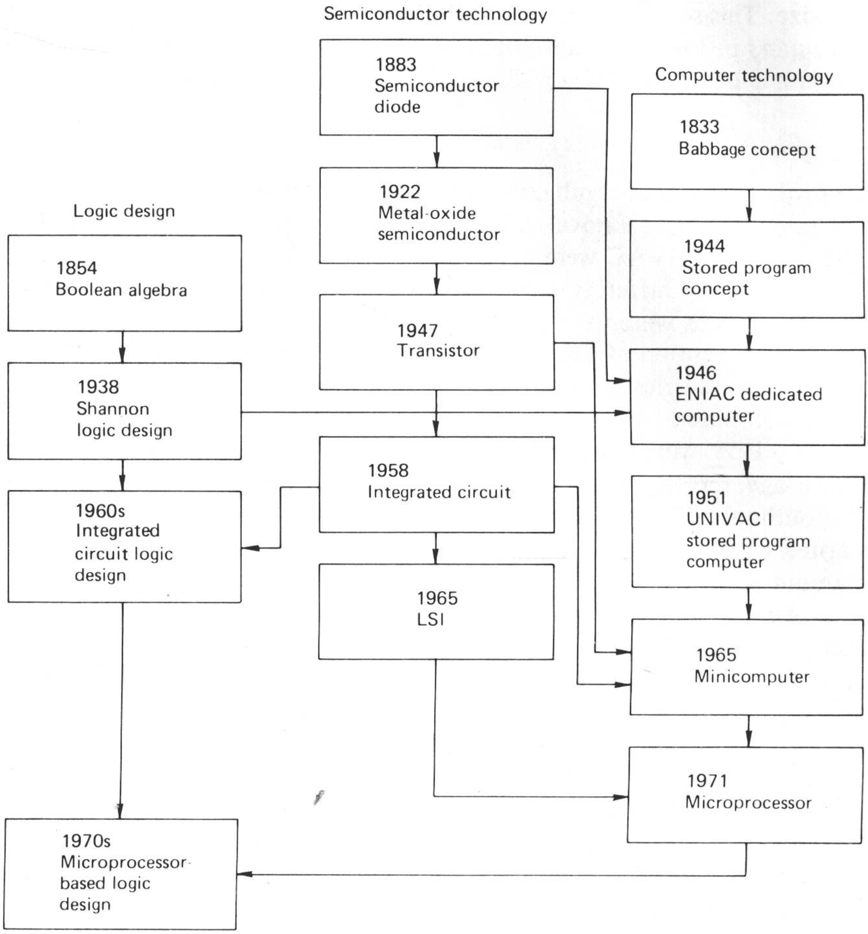


Figure 1.4 History flow chart.

as data). The stored-program (von Neumann[1]) concept was conceived in 1944 and then was built into the UNIVAC I, the first general-purpose commercial computer. The UNIVAC, developed by Remington Rand, used a mercury delay line memory. It gained a special measure of fame by assisting Walter Cronkite in analyzing the 1952 elections.

Transistorized computers, which began to appear in about 1960, had significant improvements in terms of reliability, speed, power consumption,

[1]The common credit to John von Neumann for the stored-program concept is disputed by J. Presper Eckert and John Mauchly.

and size. This soon led to tabletop or rack-mounted computers called *minicomputers* in 1965. The development of microprocessors made *microcomputers* available, these beginning to appear on the market in 1974.

B. Semiconductor Technology

Meanwhile, the semiconductor diode and its capability to perform logic functions had been known since 1883, but systems of the complexity of ENIAC and UNIVAC were not possible until "active" devices were available to provide buffering and drive capabilities as well as logic functions. Vacuum triodes were the active devices used in the first computers.

The invention of the transistor (also an active device) was announced at Bell Laboratories in 1947. This had a major impact on the development of the computer.

By 1958, when transistor usage had begun to generally supplant vacuum-tube usage, the processes that made the integrated circuit possible (including photolithography and solid-state diffusion) became practical. Scientists learned to "batch-process" semiconductor devices on thin *wafers* of germanium or silicon.

An *integrated circuit* consists of an interconnected group of components on a single structure or substrate. The substrate used is almost always silicon because of its nearly ideal electrical properties and because of the relative ease with which it can be processed.

Silicon ingots are grown from a molten vat by inserting a "seed" crystal structure in the vat. As the structure is slowly turned and withdrawn, it develops a relatively large, roughly cylindrical crystalline structure which develops as it is pulled from the vat. This ingot is ground into a cylindrical shape (except for a flat reference edge) and is sawed with a diamond-edged saw into thin slices, or wafers.

The wafers have rectangular integrated circuits processed into their surface with the aid of *photolithography* or a process similar to photolithography. In photolithography, masks are used to selectively introduce processing (deposition of materials and diffusion of controlled impurities) to carefully defined areas of the substrate. This requires a drawing, which can be done by hand for simple integrated circuits but requires computer-aided design for circuits as complex as microprocessors. Figure 1.5 shows the mask detail for a microprocessor. Figure 1.6 shows a wafer containing an array of microprocessors.

Testing is accomplished by *wafer probing* (Figure 1.7) so that bad devices can be marked for deletion from the process. After testing, the wafer is sectioned into individual dice or chips. The chips are assembled into *carriers*, using fine wire bonds to make connections to the chips. The carriers make the contact accessible either directly or by further fan-out into a "dual-in-line package" (DIP) like that shown in Figure 1.8. The device is then sealed by lidding (Figure 1.9) and put through a final test.

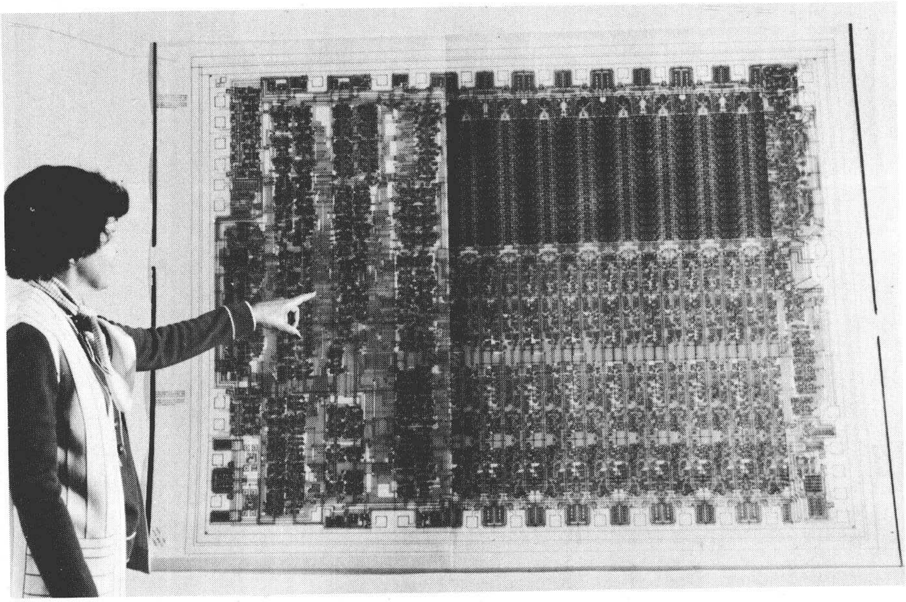
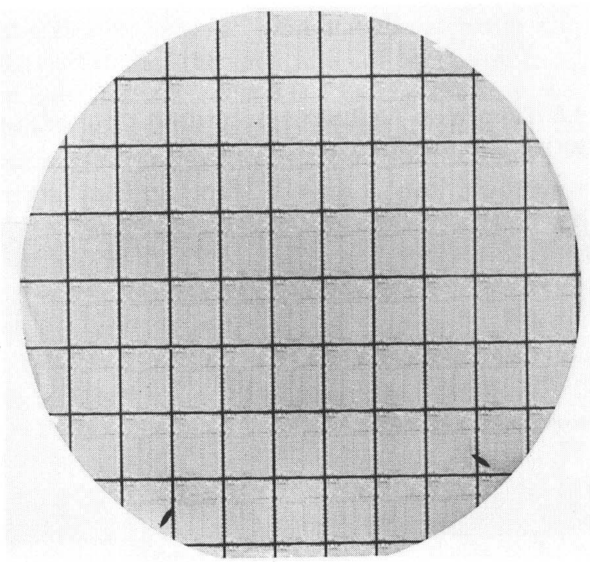


Figure 1.5 Photolithography artwork. Courtesy of Sandia Laboratories, Albuquerque, NM.

Figure 1.6 Wafer (approximately 50 mm in diameter and 0.3 mm thick) containing an array of microprocessors. Courtesy of Sandia Laboratories, Albuquerque, NM.



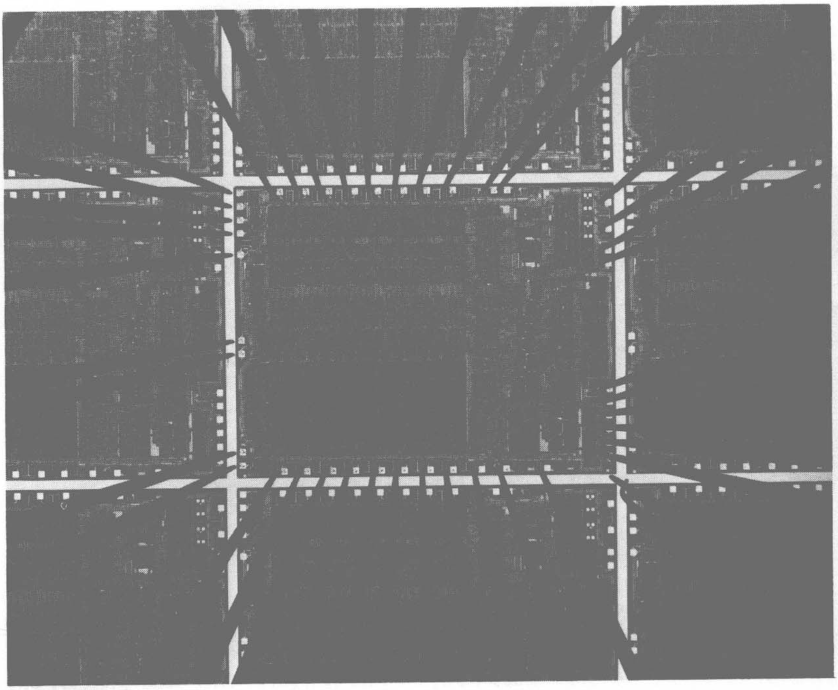
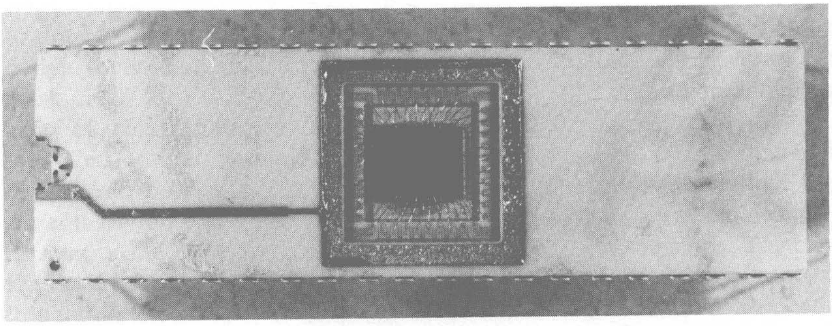


Figure 1.7 Wafer probe testing. Courtesy of Michael E. Justice, Sandia Laboratories, Albuquerque, NM.

Figure 1.8 Chip in dual-in-line package (DIP). Courtesy of Sandia Laboratories, Albuquerque, NM.



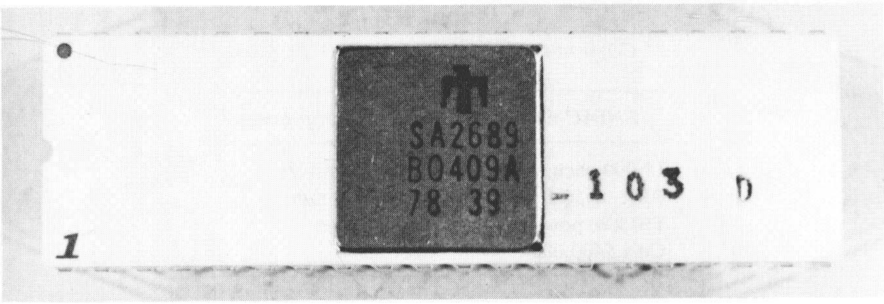


Figure 1.9 Chip in lidded dual-in-line package. Courtesy of Sandia Laboratories, Albuquerque, NM.

The first integrated circuits contained single logic devices. Soon a few devices were fabricated on a single substrate structure (*chip*). This became known as *small-scale integration* (SSI). Technological improvements created the capability to make on the order of 100 devices on a chip—*medium-scale integration* (MSI). The trend continued, and by 1969 the capability to make about 1,000 devices per chip existed. *Large-scale integration* (LSI) had arrived. LSI has been the basis of microprocessor development. However, current technology is capable of densities on the order of 100,000 devices on a chip, and the term *very large scale integration* (VLSI) is commonly used to describe this capability.

LSI technology was first applied to memory devices and custom logic chips in the late 1960s. The microprocessor concept was not utilized until 1969.

In 1969, a Japanese calculator manufacturer (Busicom) contacted a U.S. semiconductor manufacturer (Intel Corporation) to work on a design for an unusually flexible (and programmable) calculator chip set. M. E. (Ted) Hoff, who had studied the application of computers to adaptive learning machines at Stanford University a few years previously, was working on the project. Hoff saw a way to simplify Intel's development effort by using computer technology for the application, and got the immediate support of Intel management. Intel proposed using a *central processing unit* (CPU) chip, a *program* (instructions) memory chip, and a *scratch pad* (temporary memory) chip to implement the calculator. The CPU was labeled the 4004 by Intel and it became known as a *microprocessor*. The complexity of the 4004 was roughly equivalent to that of the ENIAC, but it was twenty times as fast, thousands of times more reliable, cost a ten thousandth as much and occupied a thirty thousandth of the volume, as a result of LSI technology (see Table 1.1).

Before the Intel 4004 was announced as a commercial product in 1971, a similar sequence of events took place. A terminal manufacturer, Datapoint, sent a target specification to Intel and Texas Instruments for a

Table 1.1
COMPARISON OF ENIAC AND INTEL 4004

ENIAC Computer	*4004 Microprocessor*
18,000 vacuum tubes	2,250 transistors
30-ft × 50-ft room	3 mm × 4 mm
150 kW power	0.6 W power
Cost $400,000	Cost $5

chip to be used in intelligent terminal applications. This resulted in the development of the successful Intel 8008 microprocessor, announced in 1972. However, the importance of these developments to general logic design was not immediately appreciated.

C. Logic Design

While the development of the microprocessor was taking place, the discipline of logic design was also evolving and interacting with computer and semiconductor technology. In about 1854, a lawyer-mathematician named George Boole had developed ***Boolean algebra*** as a tool for formalizing thought processes. Boole's work achieved little notice until 1938, when Claude Shannon pointed out its usefulness in designing relay circuits with a capability for performing logic functions. This ***switching theory*** was soon applied to vacuum-tube circuits and became (and still is) a strong basis for logic design.

As semiconductor technology developed, logic designers progressed from using building blocks ranging from gates and flip flops (see Figure 1.10) to integrated circuits such as counters, read-only memories, coders, decoders, multiplexers, demultiplexers, and programmable logic arrays. The advent of LSI allowed the design of complex chips containing ***custom logic***.

However, custom LSI presents economic problems for semiconductor manufacturers. Cost of semiconductors can be minimized by achieving large production runs of standard components. Custom LSI was not attractive for low-volume requirements.

It was about 1973 when the importance of microprocessor-based logic design began to be appreciated. For the logic designer, the microprocessor offered a standard commercial component that could be purchased with confidence that the design had been frozen and well tested. ***Second-sourced devices*** soon became available. Functions could be rapidly designed by programming. Modification and redesign seldom required changing the basic hardware.

The semiconductor manufacturer was able to dramatically reduce