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the BUGBOOK® VI

INTRODUCTORY EXPERIMENTS IN DIGITAL ELECTRONICS, 8080A MICROCOMPUTER PROGRAMMING, AND 8080A MICROCOMPUTER INTERFACING

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PREFACE

Welcome to the new electronics revolution. In ten years, integrated circuit technology has transformed the digital integrated circuit chip from an expensive electronic component containing only simple logic functions and few transistors into a highly complex component containing up to ten thousand transistors. The computer-on-a-chip is here! It contains everything--central processing unit, read/write memory, read-only memory, and interface circuitry--required of a digital computer. Within several years, you will be able to purchase a handful of such chips for $100 to $200. By 1982, there may be one billion microcomputers in existence. Right now, only 250,000 minicomputers and large computers in the United States. A computer revolution? Certainly.

In education, we believe that the new electronics revolution will create important opportunities and changes:

- More students, including engineers, chemists, biologists, physicists, agricultural scientists, biochemists, and experimental psychologists, will need to learn about digital technology and microcomputers.

- Theoretical courses on Boolean algebra, Karnaugh mapping, and the like will become less important for the majority of students who are interested in digital technology.

- Students of computer science will be exposed to more digital hardware, *e.g.*, in laboratory courses on digital electronics and microcomputers. Many students will have their own microcomputers.

- Hundreds of microcomputers will be present on the typical community college or university campus. Perhaps thousands.

- Courses in digital telecommunications and digital controls will grow in importance.

In the face of these changes, one thing will remain essentially invariant: the time that a student spends in school. If anything, the number of credit hours required for graduation will decrease. Educators will be faced with the problem of incorporating the above topics into various curricula without cutting back on other important courses. How can this be done? Perhaps by integrating several courses together and covering only essential concepts.

This series of modules on digital electronics, microcomputer interfacing, and microcomputer programming is an attempt to integrate these three subjects into a single unified course. This course is oriented toward laboratory experiments, for we believe that this is the best way to convey the excitement and importance of the new electronics revolution. The three subjects will be given approximately equal weight: you will learn how to program a microcomputer, how to interface a microcomputer to external digital devices, and how the external devices operate from a digital point of view. Important digital concepts will be illustrated both with integrated circuit chips and with microcomputer programs, usually side by side in the same or adjacent Units.

For the reader of these modules, little or no background in digital electronics or microcomputers is assumed. You will first treat microcomputers and integrated circuit chips as *functional modules*. With exposure to the modules, you will gradually learn their basic operational characteristics. We will not discuss how they are manufactured, since the technology is sophisticated and changes every several years.

Bugbooks V and VI are laboratory-oriented texts in a series of books that approach the field of electronics in a somewhat different manner. Rather than start you, as is customarily done in introductory electronics courses, with experiments on electronic *components*, such as *resistors*, *capacitors*, *diodes*, and *transistors*, we instead introduce you immediately to *integrated circuit chips*, the so-called "bugs" of our Bugbooks. We also introduce you immediately to the concepts of *logic switches*, *lamp monitors*, *pulsers*, and *displays*; show you how to use such auxiliary functions; and provide you with many experiments that are based upon connections between integrated circuit chips and such devices. All this is done in *Bugbooks I* and *II. Logic & Memory Experiments Using TTL Integrated Circuits.*

Once you have mastered the basic concepts of digital electronics and are knowledgeable with the techniques of wiring digital circuits using integrated circuit chips, we expose you to more complicated digital chips and digital systems. You learn how to wire the universal asynchronous receiver/transmitter (UART) as a digital communications device between your simple circuits and a teletypewriter. You learn how to interface an 8080-based microcomputer as well as most of the important concepts associated with microcomputer programming and interfacing. Work on the UART chip is performed with the aid of a 70-page Bugbook, *Bugbook IIA. Interfacing & Scientific Data Communication Experiments Using the Universal Asynchronous Receiver/Transmitter (UART) and 20 mA Current Loops.* The principles and techniques of 8080-microcomputer interfacing and programming are discussed in the 592-page Bugbook, *Bugbook III. Microcomputer Interfacing Experiments Using the Mark 80* R *Microcomputer, an 8080 System.* Bugbook IV, which is on the use of the 8255 programmable peripheral interface chip, is still in pereparation at the time of writing of this preface. We have delayed it in order to permit the completion of Bugbooks V and VI.

Bugbooks V and VI, which consist of 23 chapters and 870 pages, is an experiment in digital electronics education. As mentioned earlier, we are attempting to integrate the subjects of digital electronics, microcomputer interfacing, and microcomputer programming into a single unified course. In effect, we are consolidating the material found in Bugbooks I, II, and III into a single laboratory textbook. The concepts and techniques of microcomputer programming and interfacing are discussed at the same time that you learn basic digital concepts and perform experiments on popular TTL integrated circuit chips such as the 7400, 7402, 7404, 7442, 7475, 7490, 7493, 74121, 74125, 74126, 74150, 74154, 74181, and 74193. Some material in the earlier Bugbooks has been omitted, and much new material added, specially in the microcomputer sections.

We believe that the pendulum of digital electronics will now move steadily towards the use of microcomputers. Such being the case, there will be considerable incentive in educational institutions to introduce microcomputers at an early stage in a student's curriculum. What is true for the college student should also be true for the professional scientist or engineer who desires to update his knowledge of digital electronics. Bugbooks V and VI are directed toward such individuals.

Bugbooks V and VI are self-instructional texts. Answers to all experimental and review questions will be found in the texts. When you perform an experiment, we shall tell you what you should observe. Who can use these books successfully? They are directed toward the same audience as Bugbooks I through III. You need no initial background in digital electronics or microcomputers. If you have the ability to organize and grasp new concepts, to extrapolate knowledge to new situations, and to perform experiments in wiring digital circuits carefully, you should enjoy these Bugbooks. Bugbooks V and VI lend themselves very nicely to a self-study program for professionals who desire to update their skills in digital electronics and microcomputers. Remember that Bugbooks I through III treat the same material either in greater detail or in a slightly different way.

We have found wide acceptance of our Bugbooks in formal classes as well as by individual users in the United States and abroad. Selected Bugbooks are being translated into German, Japanese, French, Italian, Chinese, and Malaysian. If you are interested in further details concerning such translations, or in translating the books to other languages, please contact us.

We have also observed a need for additional educational material in the field of electronics that is experiment-based but is directed towards more specific topics. This need is being filled by an additional series of Bugbooks called the Bugbook Application Series. The first book in this series is *The 555 Timer Applications and Sourcebook, with Experiments* and is written by Howard Berlin. Howard has just completed his second book in the series, *The Design of Active Filters, with Experiments*, and is currently preparing a third book, *Designing with Operational Amplifiers, with Experiments*. Dr. Stanley Wolf is writing an Applications Series Bugbook on the theory and uses of oscilloscopes. We expect this series to grow rapidly as we identify authors who can fill in the needed areas in electronics with experimental-based books along the style lines characteristic of the Bugbooks.

Short courses on digital electronics and microcomputer interfacing are available in conjunction with the Continuing Education Center and Extension Division at Virginia Polytechnic Institute & State University. For further information, please write or call Dr. Norris H. Bell, Continuing Education Center, Blacksburg, Virginia 24061, telephone (703) 951-6328. The speakers at such short courses include Peter Rony, David Larsen, Paul Field, and Frank Settle (Virginia Military Institute; Dr. Settle is editor of *Digital Directions*, which describes teaching techniques, applications, and useful products in the digital electronics and microcomputer areas). Short courses on microcomputers are also given by Mr. Jonathan A. Titus and Dr. Christopher A. Titus; contact them at Tychon, Inc., Blacksburg, Virginia 24060. Jon designed the Mark 80 and Dyna-Micro R (or MMD-1) microcomputers, and Chris has extensive experience in microcomputer programming and system design.

We wish to again than those individuals who continue to back our educational efforts. Mr. Murray Gallant and E&L Instruments, Inc. have supported the development of the MMD-1 microcomputer by Jon Titus at Tychon, Inc. Mr. Bob Veltri has provided us with excellent photographs of the hardware. Our wives are no longer quite so patient. After hearing about the glories of microcomputers and reading about the "smart home," the now expect us to interface our households. Mañana.

March, 1977

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UNIT NUMBER 16

WHAT IS INTERFACING?

INTRODUCTION

This unit introduces you to a few of the objectives of interfacing and provides definitions for some of the concepts involved.

OBJECTIVES

At the completion of this unit, you will be able to do the following:

- Distinguish between microprocessor and microcomputer.
- Define data processor.
- Distinguish between hardware and software, and give examples of each.
- Define controller.
- Discuss the spectrum of computer-equipment complexity, from hard-wired logic to the large mainframe computers.
- Describe the three important busses in an 8080A-based microcomputer.
- List five important control signal lines on the Dyna-Micro microcomputer.
- Define synchronous, I/O device, CPU, and memory.

THE SMART MACHINE REVOLUTION

In preceding units, we have provided you with information on basic digital electronics that you will need as you *interface* an 8080-based microcomputer. We still have more subjects to cover--three-state bussing, shift registers, arithmetic/logic units, and buffers--but you already have been exposed to the logic operations, AND, OR, NAND, NOR, and exclusive OR; the gating characteristics of the four basic gates; decoders; latches and flip-flops; counters; monostable multivibrators; input/output devices such as logic switches, pulsers, clocks, and displays; digital codes; and the important terms, strobe, enable, disable, gate, and inhibit. Before you jump into the subject of microcomputer interfacing, we believe that it would be useful to provide you with some perspective on why you would want to interface a microcomputer in the first place.

For those of you who have access to the McGraw-Hill publication, *Business Week*, we would direct your attention to the July 5, 1976 issue and the article entitled, "The Smart Machine Revolution: Providing Products with Brainpower." Some excerpts from the article are as follows:

- " 'This is the second industrial revolution,' says Sidney Webb, executive vice-president of TRW Inc. 'It multiplies man's brainpower with the same force that the first industrial revolution multiplied man's muscle power.'

  The engine of the revolution is the microprocessor, or computer-on-a chip, a tiny slice of silicon that is the arithmetic and logic heart of a computer. The first surge of products with microprocessor brains is just now starting to hit the marketplace, and this is demonstrating that never before has there been a more powerful tool for building 'smart' machines--machines that can add decision-making, arithmetic, and memory to their usual functions. Included in the first wave of smart machines are:

  The smart watch
  The smart scale
  The smart mobile phone
  The smart can-making system
  The smart video game

  A tidal wave of smart products such as these is on the way. They will dramatically change the marketplace for consumer, commercial, and industrial products. The computer-on-a-chip, powering the brains of smart products, will spawn new industries and thousands of new companies. And in the process it will wipe out some existing companies, and even some industries."

- "The key to the sudden surge in sales of microprocessors and to the wave of new smart machines they will power is simply price. C. Lester Hogan, vice-chairman of Fairchild Camera & Instrument Corp., demonstrated this element dramatically at a Boston convention a few weeks ago. He pulled 18 microprocessors from his pocket and tossed them out to his audience. 'That's $18 million worth of computer power--or it was 20 years ago,' he said. Hogan explained that his $20 microprocessor is as powerful as International Business Machines' first commercial computer, which cost $1 million in the early 1950s. 'The point I'm making,' Hogan said, 'is that computer power today is essentially free.'

  Even a year ago, those $20 microprocessors cost more than $100, and the sudden slash in price led designers to start work on the beginnings of the flood of smart products. Switching from conventional electronic parts, such as integrated circuits, to the MPU cuts design time and manufacturing costs because it replaces hundreds of ICs and other parts. Once the MPU is designed into a product, it can provide tremendous marketing advantages; a product's functions can be altered not by a costly redesign of its electronics but simply by changing the instructions, or software, stored in the MPU's memory. New features can be added with little increase in cost, and the new smart machines can handle work that could not be done economically before."

o "The most exciting new products to come from the computer-on-a-chip will be for the consumer. Microprocessors will go into homes, autos, appliances, and other consumer goods in far greater numbers than into other products. 'Between 7 and 10 microprocessors will be in each home by 1980,' predicts Andrew A. Perlowski, who heads microprocessor activities at Honeywell Inc. His company is already hard at work on energy management and security systems for the home."

o "In the factory, the computer-on-a-chip is dropping the cost of electronic intelligence so low that it is turning the smallest product units into smart machines. And it is speeding the day of the automated factory by linking the smart production machines, sensors, and other instruments into distributed data acquisition and control systems.

Factory automation has moved slowly, partly because manufacturers did not want an entire plant shut down because one bit in a computer failed. 'The advantage of the MPU is that it chops up the control job in smaller pieces, and an individual MPU won't pull down a whole network if it fails,' says Sheldon G. Lloyd, engineering vice-president at Fisher Controls Co. 'The microprocessor makes it economically possible to develop and build hierarchical systems.'

In a hierarchy, the microprocessors in the smart production machines are linked to supervisory minicomputers that collect and send management reports and status information to a central factory computer. At the top is the big corporate computer, which when linked to the factory system, will be able to generate up-to-the-second financial reports for the entire company."

o "Many jobs now being done by microprocessors were too small to automate before. Dow Chemical Co. is considering MPUs for a variety of jobs 'where computations are required that aren't quite complex enough to justify a minicomputer,' says Charles R. Honea, process instrument manager at Dow's Texas Div. For instance, Dow uses microprocessors to calculate the flow of ethylene piped into the plant. The information was charged manually and required half a dozen people. 'And it was always a day behind,' Honea says. 'You had no way of knowing how much ethylene you used today.'

The process industries are a conservative lot, partly because of the reliability needed in control gear to keep their plants running continuously. It usually takes five to six years for a major technology breakthrough to find widespread use in the process control industries. 'Microprocessors will be no different,' says Nicholas P. Scallon, vice-president for marketing at Fisher Controls. 'But the microprocessor will speed up automation,' he says, 'by breaking up control loops into smaller segments. Instead of trying to control the whole system, we will use a dedicated microprocessor to control such tings as a boiler, an evaporator, or a catalytic conversion.'"

- "Software is not only the biggest problem now for the MPU users, but it is also where most of the costs are. 'Software costs are actually even more for a microcomputer than for a minicomputer,' says Richard Marley, a New Hampshire consultant who has designed smart products for several small companies. He says that he spends up to $100,000 on every software design, while the cost of hardware designs is down to around $20,000."

- "The microprocessor is probably affecting no other single industry as much as the instruments business. In the next two years, predicts technology consultant Lynwood O. Eikrem, analytical instruments using microprocessors will rise from 2% to 50% of the market. 'Companies are rushing into microprocessors, and those who don't move fast will lose market,' he says.

  So far the biggest MPU effort is coming in digital test instruments, such as voltmeters, counters, and frequency synthesizers, and in such analytical instruments as spectrometers and chromatographs. 'Probably 90% of digital instruments selling for $2000 or more will use microprocessors by 1980,' says industry analyst Galen W. Wampler."

- "Over the next several years, smart products and machines will spread at an ever increasing rate. Software will become available so that anyone will be able to program a microcomputer. Schools will be turning out a flood of young people familiar with microprocessors and eager to build products with them. The semiconductor industry will continue to develop more powerful parts. 'In the next 5 to 10 years we will be able to turn out 1 million devices on a single chip,' predicts Richard L. Petritz, vice-president of New Business Resources, a venture capital company. This will mean that the power either of a large mainframe computer or of a complete minicomputer with large amounts of memory will be available on a single chip."

- "Development time is so short for a smart product now and the entry costs are so low that there will be 'myriad examples of new companies spawning, with bright, young fellows developing MPU-based products,' says Fairchild's Hogan. Petritz says: 'The MPU will reduce the application of electronics essentially to that of writing a computer program, and the average person can be educated to program a computer.'

  That spells danger for the established companies. Already, manufacturers have to be looking at microprocessors 'or somebody will come along and obsolete their product,' warns Donald V. Kleffman, a marketing manager at Ampex Corp. Says Kessler of NCR: 'There will be many new companies coming in with MPU technology, and they will replace some of the old companies. A lot of companies will be beaten down.'

  When that time comes, microprocessors will be everywhere--from the smart machines of the factory and the office to the handheld, personal microcomputers costing less than $100, and the personal mobile telephone."

We shall amplify on some of the above points in the following sections.

MICROPROCESSOR VS MICROCOMPUTER

We have had difficulty in finding a good definition for the term, *digital computer*. In looking around for such a definition, we found an excellent pair of paragraphs by Donald Eadie in his book, "Introduction to the Basic Computer," that provide some insight into what is meant by the term, *processor*. Thus:

> "This chapter serves as a general introduction to the field of digital devices, with particular emphasis on those devices called *computers*, or more properly, *data processors*. The name data processor is more inclusive because modern machines in this general classification not only compute in the usual sense, but also perform other functions with the data which flow to and from them. For example, data processors may gather data from various incoming sources, sort it rearrange it, and then print it. None of these operations involve the arithmetic operations normally associated with a computing device, but the term computer is often applied anyway."

> "Therefore, for our purpose a computer is really a data processor. Even such data processing operations as rearranging data may require simple arithmetic such as addition. This explains why a certain amount of imprecision has entered our language and why confusion exists between the terms *computer* and *data processor*. The two terms are so loosely used at present that often one has to inquire further to determine exactly what is meant."[15]

Eadie thus defined the term, *data processor*, as follows:

data processor	A digital device that processes data. It may be a computer, but in a larger sense it may gather, distribute, digest, analyze, and perform other organization or smoothing operations on data. These operations, then, are not necessarily computational. Data processor is a more inclusive term than computer.[15]

It is tempting to define the term, *microprocessor*, as follows:

microprocessor	An extremely small data processor.

At the moment, the microprocessor does not quite have such a definition. As semiconductor manufacturers develop the capability to manufacture an entire computer on a single chip, including memory and I/O ports, we believe that the term, microprocessor, will assume the meaning given above.

At the moment, there is a distinction between a *microprocessor* and a *microcomputer*. To quote the Texas Instruments Incorporated "Microprocessor Handbook:"

> "This lesson begins with the word 'microprocessor.' To some people microprocessor means microcomputer. To other people the words microprocessor and microcomputer are different. To them, 'microprocessor' is a broader and more generic term which describes an extremely small electronic system capable of performing specific tasks. Thus, microcomputer is an application of microprocessors."[16]

At the moment, we consider a microprocessor to be a single integrated circuit chip that contains approximately 75% of the power of a very small digital computer. It usually cannot do anything without the aid of support chips and memory. In contrast, a microcomputer is a full operational computer system based upon a microprocessor chip. Such a system contains memory, latches, counters, input/output devices, buffers, and a power supply in addition to the microprocessor chip. There may be as much cost involved in the other hardware components as there is in the microprocessor chip itself.

While on this subject, we would also like to quote from the article by Laurence Altman in the April 18, 1974 issue of *Electronics*:

> "What a microprocessor is . . . but first, what it isn't. A microprocessor is not a computer but only part of one. To make a computer out of a microprocessor requires the addition of memory for its control program, plus input and output circuits to operate peripheral equipment. Also, the word is not short for microprogrammable central processing unit. For though some microprocessors are controlled by a microprogram, most are not."
>
> "What a microprocessor is, then, is the control and processing portion of a small computer or microcomputer. Moreover, it has come to mean the kind of processor that can be built with LSI MOS circuitry, usually on one chip. Like all computer processors, microprocessors can handle both arithmetic and logic data in bit-parallel fashion under control of a program. But they are distinguished both from a minicomputer processor by their use of LSI with its lower power and costs, and from other LSI devices (except calculator chips) by their programmable behavior."
>
> "In short, if a minicomputer is a 1-horsepower unit, the microprocessor plus supporting circuitry is a 1/4-hp unit. But as LSI technology improves, it will become more powerful. Already single-chip bipolar and CMOS-on-sapphire processors are being developed that have almost the capability of the minicomputer."

As an example of what is coming in the near future, we would like to quote from an announcement in the June, 1976 issue of *Digital Design*:

> "PROCESSOR, PROGRAM ROM AND DATA RAM FIT ON ONE CHIP
>
> The availability of a microprocessor chip with on-board RAM and ROM may hasten the day when designers can change their computer applications by merely plugging in a new cheap computer rather than entering a different program.
>
> One such microcomputer, priced at under $10 in quantities of 10,000, includes a 1344 × 8 program ROM and a 96 × 4 data RAM all packaged on a single chip with a Rockwell PPS-4 processor. Designated the PPS-4/1, the microcomputer also provides 31 input/output channels with dual interrupt capability.
>
> According to its manufacturer, Rockwell's Microelectronic Device Div., Anaheim, California, the microcomputer will cut the cost of electronic systems for peripheral controllers, appliance controls and other industrial applications.
>
> Input/output options for the 50-instruction IC include two 4-bit channels which can be simultaneously used for testing or comparing data; two 4-bit I/O channels and 10 discrete I/O lines. Two interrupt request input lines, one of which can automatically trigger an echo signal, provide priority input and status capabilities."

There is more to the announcement, but the point that we wish to make is that this single chip is much closer to a true *computer-on-a-chip* than most microprocessor chips that are currently on the market. The 8080A microprocessor chip discussed in this Bugbook is still a microprocessor; it contains no built-in read/write memory, ROM, or I/O capability.

HARDWARE VS SOFTWARE

Hardware and *software* are important terms that will be used repeatedly in this unit. It is appropriate, therefore, to define them early:

hardware — The mechanical, magnetic, electronic, and electrical devices from which a computer is fabricated; the assembly of material forming a computer.[15]

software — The totality of programs and routines used to extend the capabilities of computers, such as compilers, assemblers, narrators, routines, and subroutines. Contrasted with hardware.[5]

The Dyna-Micro microcomputer, along with any integrated circuit chips, wire, breadboarding aids, and peripheral devices, are all considered to be the hardware. The programs and subroutines that you use and write are the software. In time, you will observe that it requires considerable effort to write good programs that take maximum advantage of available memory, the instruction set, and the time that is required to execute individual instructions.

WHAT IS A CONTROLLER?

Graf has defined a *controller* as

controller — An instrument that holds a process or condition at a desired level or status as determined by comparison of the actual value with the desired value.[2]

Controllers can be analog or digital, and can be electronic, mechanical, electromechanical, or pneumatic, or some combination of these. A *digital controller* acquires the actual value of the condition in digital form and compares it to the desired value contained within the controller. If there is any difference between the two, a digital signal is sent out to the device, machine, or process to initiate actions to reduce this difference. The digital controller itself consists either of integrated circuit chips and discrete components that are wired to a printed circuit board, or else a computer of any size with a limited number of chips to serve as an interface between the computer and the external world.

The question of cost becomes an important factor when one considers the use of computers as controllers. One would not control 100 devices, each with a value of $500, with a $1,000,000 computer; the use of such a large computer to control $50,000 worth of equipment is a form of overkill. On the other hand, such a computer would be useful in the control of a $20,000,000 chemical plant. However, with today's technology, it is doubtful that a million dollar computer would be required; probably $200,000 would buy a very large minicomputer system that would serve the requirements of the plant. One can justify the cost of a computer/controller if it represents only a modest percentage of the cost of operating a process or producing a product. The trade-offs in cost and performance constantly change as the prices of computer systems decrease. With the advent of microcomputers, it is quite likely that the cost of controlling equipment will decrease at no sacrifice in reliability.

WHERE MICROCOMPUTERS FIT

The *Business Week* article that we excerpted earlier in this unit should provide you with some perspective concerning the potential applications for microcomputers. We would like to discuss this subject in further detail with the aid of Figure 16-1 and Table 16-1.

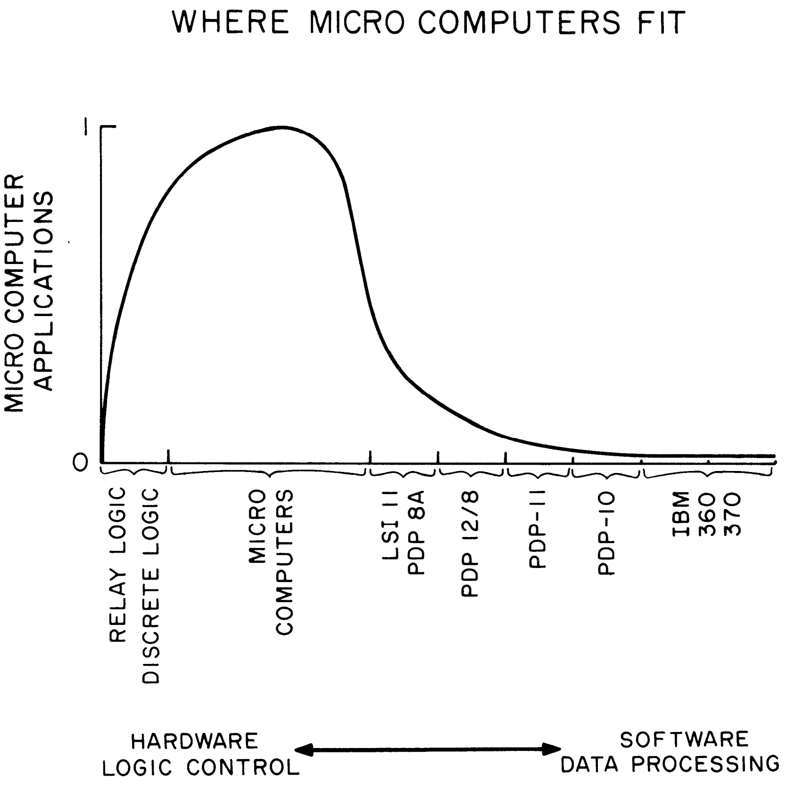


Figure 16-1. Schematic diagram that depicts applications that are foreseen for microcomputers, which will carve out their own niche between discrete logic and inexpensive minicomputers.

WORD LENGTH	1	2	4	8	16	32	64
COMPLEXITY	Hard-wired logic	Programmed logic array	Calculator	Microprocessor	Minicomputer	Large computer	
APPLICATION		Control		Dedicated computation		Low-cost general data processing	High-performance general data processing
COST	Under $100 *(1974)*			$1000 *(1974)*		$10,000 *(1974)*	$100,000 and up *(1974)*
MEMORY SIZE	Very small 0-4 words	Small 2-10 words		Medium 10-1000 words		Large 1000-1 million words	Very large More than 1 million words
PROGRAM	Read-only						Reloadable
SPEED CONSTRAINTS	Real time	Slow		Medium			Throughput-oriented
INPUT-OUTPUT	Integrated	Few simple devices		Some complex devices			Roomful of equipment
DESIGN	Logic	Logic + microprogram		Microprogram macroprogram			Macroprogram high-level language software system
MANUFACTURING VOLUME	Large						Small

Table 16-1. This chart depicts the spectrum of computer-equipment complexity, from simple hard-wired logic systems to high-performance general data processing equipment. This chart is adapted from an article by Wallace B. Riley in the October 17, 1974 issue of *Electronics*. The article indicates that the chart is based on Pro-Log Corporation material.

In Figure 16-1, we have plotted the number of microcomputer applications, on a normalized scale of 0 to 1, versus the type of application. As can be observed, we do not expect many of today's microcomputers to be used as number-crunching machines or as substitutes for simple relay logic systems. Basically, most of the exciting microcomputer applications will fall between discrete random logic (gates and flip-flops) on one hand and inexpensive minicomputers on the other. Microcomputers are carving out an entirely new market, one that has not been previously served either by minicomputers--owing to their cost--or by complex digital circuits. This is the domain of the "smart" machine. The domain will grow at the expense of both discrete random logic and minicomputers as the cost of microcomputers decreases.

At the moment, it is not cost effective to construct minicomputers or large computers from microcomputer chips. The problem with minicomputers is software. Data General and Digital Equipment Corporation have an important advantage over Intel, Texas Instruments, and National Semiconductor in the amount of sophisticated software available for the popular PDP 8, PDP 11, and NOVA minicomputers. We believe that this advantage will not last for more than several years. Versions of BASIC are already available for 8080 microcomputers, and an APL package is currently being developed. The minicomputer manufacturers have responded by developing microcomputers that have software compatability with the minicomputers. The best of these is probably the new NOVA microcomputer. We will see a merging of minicomputer and microcomputer technology.

At the higher end of the computer spectrum, microcomputers are not currently being used to replace large number-crunching computers of the PDP 10, IBM 360, and IBM 370 class. However, one California company has proposed the use of 256 8080A microcomputers arranged in the form of a "hypercube." According to them, such a computer would rival or exceed large computers in number-crunching capability. It is quite possible that future computer generations will take advantage of distributed computer architecture. Again, the problem is software development.

Table 16-1 depicts the spectrum of computer equipment complexity, from simple hard-wired logic systems to high-performance data processing equipment. Costs are declining across the board. Every five years, the cost for an equivalent amount of computing capability decreases approximately ten-fold.

COMPUTER HIERARCHIES

A *hierarchy* is a series of items classified according to rank or order.[2] Microcomputers will control the behavior of individual machines or instruments. Minicomputers will collect data from groups of microcomputers and compare such data to more complex mathematical models, such as the model of a process that is being controlled by ten microcomputers. Larger computers might periodically interrogate minicomputers for the status of entire processes, and might format the received information in a manner that is easy to understand by production supervisors. In Figure 16-2, we depict a hierarchy consisting of seven 8080-based microcomputers and a single minicomputer. Communication between the microcomputers and minicomputer most likely will be serial.

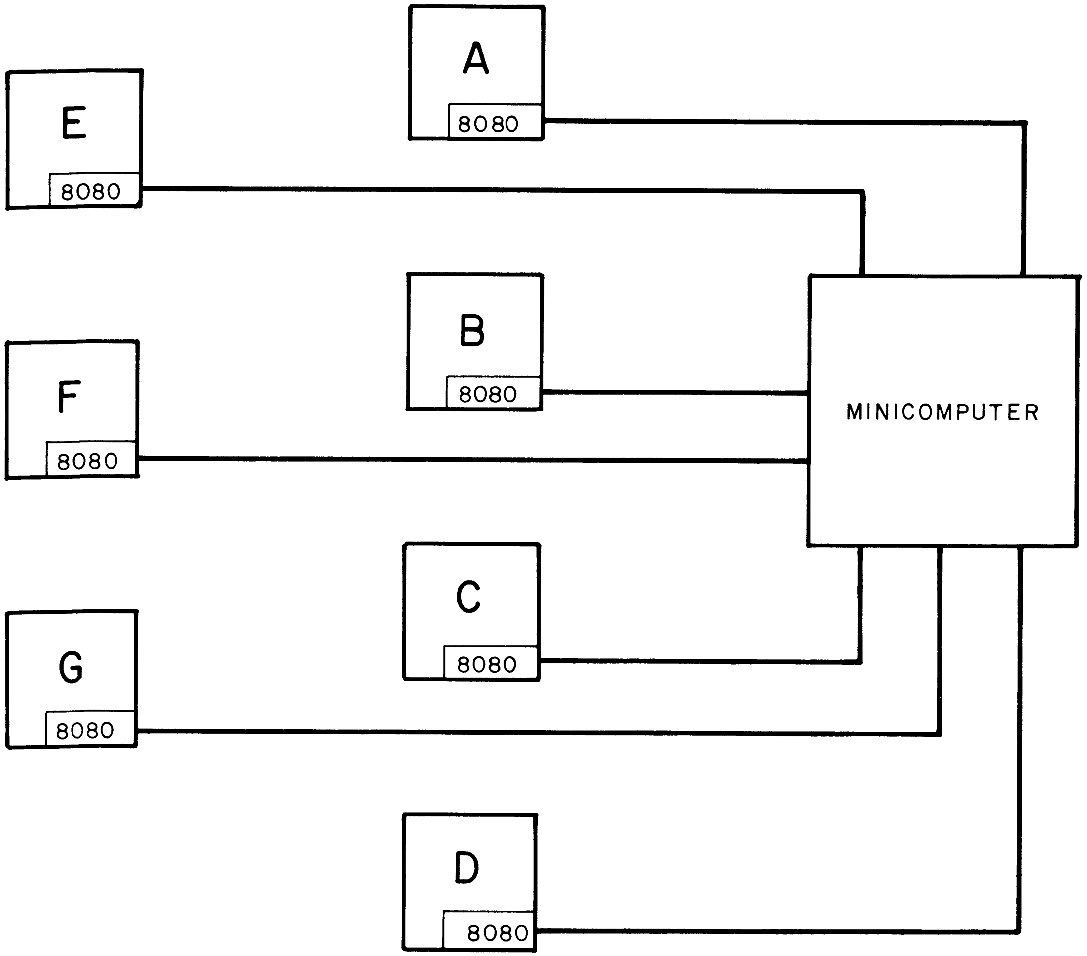
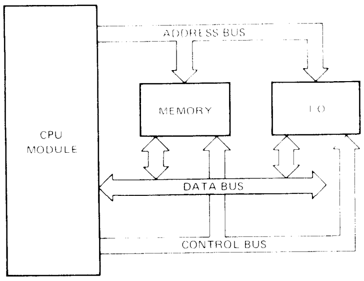


Figure 16-2. An example of a computer hierarchy. The individual instruments A through G are controlled by built-in 8080 microprocessors. These microprocessors also communicate back and forth with the minicomputer, which monitors the operation of the entire system.

A TYPICAL 8080 MICROCOMPUTER

A typical microcomputer constructed from an 8080A microprocessor chip is shown below:



Courtesy of Intel Corporation,
Santa Clara, California

Several definitions are in order.

bus — A path over which digital information is transferred, from any of several sources to any of several destinations. Only one transfer of information can take place at any one time. While such transfer of information is taking place, all other sources that are tied to the bus must be disabled.

bidirectional data bus — A data bus in which digital information can be transferred in either direction. With reference to an 8080A-based microcomputer, the bidirectional data path by which data is transferred between the CPU, memory, and input-output devices.

address bus — A unidirectional bus over which digital information appears to identify either a particular memory location or a particular I/O device. The 8080A address bus is a group of sixteen lines.

address — A group of bits that identify a specific memory location or I/O device. An 8080A microcomputer uses sixteen bits to identify a specific memory location and eight bits to identify an I/O device.

control — Those parts of a computer which carry out instructions in proper sequence, interpret instructions, and apply proper signals.[14]

control bus — A set of signals that regulate the operation of a microcomputer system, including I/O devices and memory. They function much like "traffic" signals or commands. They may also originate in the I/O devices, generally to transfer to or receive signals from the CPU. According to the Intel Corporation literature, a control bus is a unidirectional set of signals that indicate the type of activity--memory read, memory write, I/O read, I/O write, or interrupt acknowledge--in current process.

I/O Abbreviation for input-output.

I/O device Input/output device. A card reader, magnetic tape unit, printer, or similar device that transmits data to or receives data from a computer or secondary storage device.[2] In a more general sense, any digital device, including a single integrated circuit chip, that transmits data to or receives data or strobe pulses from a computer.

CPU Abbreviation for central processing unit.

central processing unit (large computer) Also called central processor. Part of a computer system which contains the main storage, arithmetic unit, and special register groups. Performs arithmetic operations, controls instruction processing, and provides timing signals and other housekeeping operations.

central processing unit (microprocessor) A single integrated circuit chip that performs data transfer, control, input-output, arithmetic, and logical operations by executing instructions obtained from memory.

memory Any device that can store logic 0 and logic 1 bits in such a manner that a single bit or group of bits can be accessed and retrieved.

A typical microcomputer constructed from an 8080A chip possesses all of the minimum requirements for a digital computer:

- o It is programmable, with the data and program instructions capable of being arranged in any sequence desired.
- o It is digital.
- o It is clocked (in most microcomputers, the internal operations in the CPU chip proceed synchronously).
- o It contains an arithmetic/logic unit, located within the CPU chip, that performs arithmetic and logic operations.
- o It can exchange data with memory or I/O devices.
- o It contains "fast" memory; speed is an important requirement for a functional digital computer.

ADDRESS BUS

The Intel 8080A microprocessor chip contains a 16-bit address bus that is used for the identification of specific memory locations or specific I/O devices. It is a unidirectional bus, which means that address information can only be output from the 8080A chip. When addressing memory, 2^{16} = 65,536 different memory locations can be accessed. We say that the 8080A is a "64K" device, where the "K" is an abbreviation for kilobyte, or 1024 bytes.

The Intel 8080A address bus is also used to supply the 8-bit device code for *input and output devices*. When addressing input-output devices, the address bus bus assumes a new identity, i.e., it is subdivided into two identical 8-bit device code bytes, either of which you can use when wiring an interface circuit to I/O devices. When addressing I/O devices using the IN or OUT microcomputer instructions, you can address 2^8 = 256 different input devices and 2^8 = 256 different output devices.

Whenever you encounter the term, *bus*, you should be alert for the possibility that different types of information appear on the bus lines at different times. In the case of the 8080A address bus, this is certainly true. Most of the time, the information that appears on the address bus is the address of a specific memory location. Occasionally, the information that appears on the address bus is a device code. The microcomputer knows when the bus is being used to access memory and when it is being used to identify I/O devices: *it provides the appropriate control pulse that informs you what it is doing!* We shall discuss these control pulses in a section below.

BIDIRECTIONAL DATA BUS

The Intel 8080A microprocessor chip contains an 8-bit bidirectional data bus that permits eight bits of data, known as a *byte*, to be transferred between the 8080A chip and memory or I/O devices. Different types of information appear on the data bus lines at different times. Much of the time, the data that appears is an instruction byte from memory. At other times, the data that appears on the data bus is one of the following:

- A data byte that is being input from an input device.
- A data byte that is being output to an output device.
- A data byte that is being written into or read from memory.
- Control status bits used to derive some of the control bus signals.
- A HI or LO address byte that is being stored in an area of memory called the *stack*.
- A HI or LO address byte that is being retrieved from the stack.
- An instruction byte that is being jammed by an I/O device during an interrupt.

How do you know when these different types of data transfers are occurring? The microcomputer tells you, *by providing the appropriate control or status pulses that inform you of the type of activity in current progress*. It should be clear now that an understanding of the control bus is essential to the understanding of the behavior of the 8080A microcomputer. Such a statement is true for any type of digital computer that you encounter.

CONTROL BUS

Although called a control bus, the set of signals in question do not actually comprise a bus since different types of information do not appear on the individual signal lines at different times. Each signal line is uni-directional and uni-functional. With this caveat, we shall continue to call the set of control signals associated with the 8080A chip a control bus; the term is too widely used in the microcomputer literature for us to suggest any reasonable alternative.

The five basic types of activities in which the 8080A microprocessor chip engages are the following:

1. Memory Read
2. Memory Write
3. I/O Read
4. I/O Write
5. Interrupt/Interrupt Acknowledge

Some useful definitions include the following:

read To transmit data from a specific memory location to some other digital device. A synonym for *retrieve*.

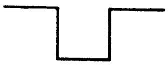
write To transmit data from some other digital device into a specific memory location. A synonym for *store*.

interrupt In a digital computer, a break in the normal execution of a computer program such that the program can be resumed from that point at a later time.

Five separate control signal lines are provided, one for each of the above activities. These lines have the following abbreviations:

1. Memory Read: $\overline{\text{MEMR}}$
2. Memory Write: $\overline{\text{MEMW}}$
3. I/O Read: $\overline{\text{I/O R}}$ or $\overline{\text{IN}}$
4. I/O Write: $\overline{\text{I/O W}}$ or $\overline{\text{OUT}}$
5. Interrupt Acknowledge: $\overline{\text{INTA}}$ or $\overline{\text{I ACK}}$

Observe that in all cases the signal is a negative clock pulse,



The pulse width depends on the speed of the 8080A-based microcomputer; for the Dyna-Micro microcomputer, which is clocked at 750 kHZ, the pulse width is 1.333 µs.

The uniqueness of each of the control signals can be seen with the aid of the truth table given on the following page. These control signals are available on the SK-10 bus socket on the Dyna-Micro printed circuit board (Figure 16-3). You will use them, specially $\overline{\text{IN}}$ and $\overline{\text{OUT}}$, to gate the transfer of data between digital integrated circuit chips(wired on the breadboard)and the CPU of the 8080A-based microcomputer.

$\overline{\text{MEMR}}$	$\overline{\text{MEMW}}$	$\overline{\text{IN}}$	$\overline{\text{OUT}}$	$\overline{\text{IACK}}$	Operation
0	1	1	1	1	Read byte from memory
1	0	1	1	1	Write byte into memory
1	1	0	1	1	Read byte from I/O device
1	1	1	0	1	Write byte into I/O device
1	1	1	1	0	Strobe byte into instruction register during an interrupt, interrupt acknowledge

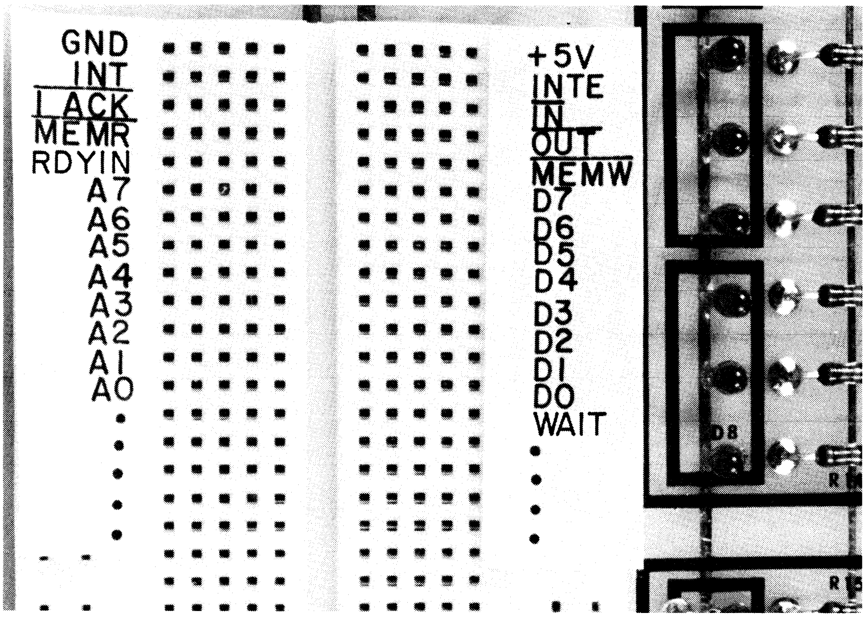


Figure 16-3. Signals available on the Dyna-Micro microcomputer bus socket as of the summer, 1976. A0 through A7 are the eight least signficant bits on the address bus; D0 through D7 are the bidirectional data bus; INTE is the interrupt enable flip-flop output; INT is the interrupt request input; and $\overline{\text{MEMR}}$, $\overline{\text{MEMW}}$, $\overline{\text{IN}}$, $\overline{\text{OUT}}$, and $\overline{\text{IACK}}$ are output control signals. RDYIN and WAIT are used with the single-step circuit described in Unit Number 11, Experiment No. 5.

WHAT IS INTERFACING?

Interfacing can be defined as the joining of members of a group (such as people, instruments, etc.) in such a way that they are able to function in a compatible and coordinated fashion.[17] By"compatible and coordinated fashion," we usually mean synchronized. Some important definitions include the following:

synchronous In step or in phase, as applied to two devices or machines. A term applied to a computer, in which the performance of a sequence of operations is controlled by clock signals or pulses. At the same time.

synchronous computer A digital computer in which all ordinary operations are controlled by a master clock.

synchronous operation Operation of a system under the control of clock pulses.

synchronous logic The type of digital logic used in a system in which logical operations take place in synchronism with clock pulses.

sync Short for synchronous, synchronization, synchronizing, etc.

to synchronize To lock one element of a system into step with another.

synchronization pulses Pulses originated by the transmitting equipment and introduced into the receiving equipment to keep the equipment at both locations operating in step.

synchronous inputs Those inputs of a flip-flop that do not control the output directly, as do those of a gate, but only when the clock permits and commands.

The above defintions have been obtained from reference 2. We can thus define *computer interfacing* as

computer interfacing The synchronization of digital data transmission between a computer and external devices, including memory and I/O devices.

Although the details of computer interfacing vary with the type of computer employed, the general principles of interfacing apply to a wide variety of computers. For the 8080A microcomputer, the basic objectives of interfacing are summarized in Figure 16-4. If you desire to interface the microcomputer, your object is to:

o Synchronize the transfer of 8 bits of data between the microcomputer and each output device.

o Synchronize the transfer of 8 bits of data between each input device and the microcomputer.

o Generate the appropriate input and output data transfer synchronization pulses, which are called *device select pulses*. For an 8080A-based microcomputer, you can generate 256 different input synchronization pulses and 256 different output synchronization pulses.

o Service interrupt signals that enter the microcomputer from external I/O devices.

o Program the microcomputer to perform all input-output and interrupt servicing operations.

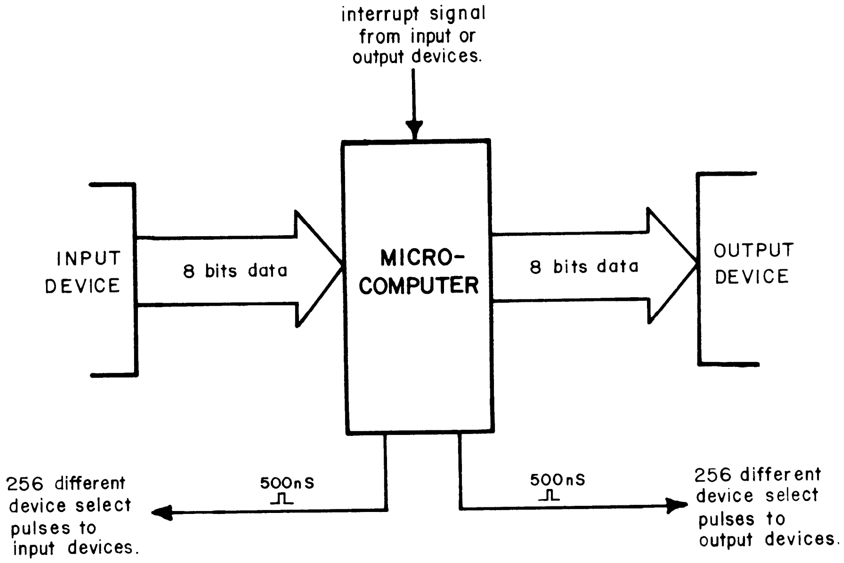
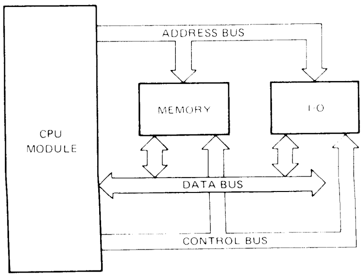


Figure 16-4. The four principle tasks of interfacing: input, output, device select pulse generation, and interrupt servicing.

A better way of viewing three of the four tasks of interfacing is given in the diagram below:



The transfer of 8 bits of data between the CPU and an I/O device occurs over the 8-bit bidirectional data bus. The specific I/O device that is involved in the data transfer is selected via the use of 8 bits on the address bus. The precise timing of the data transfer is determined by the presence of an IN or OUT pulse on the control bus. Therefore, during the transfer of data between the CPU and an I/O device, *all three busses participate!*

There is much more to say about computer interfacing, but we will save it for subsequent units.

WHAT IS AN I/O DEVICE?

Two useful definitions include:

input-output, input/output, I/O General term for the equipment used to communicate with a computer and the data involved in the communication.

I/O device Any digital device, including a single integrated circuit chip, that transmits data to or receives data or strobe pulses from a computer.

The traditional view of an I/O device is that it is somewhat large or complex. Card readers, magnetic tape units, CRT displays, and teletypes fit such a description. However, a single integrated circuit chip, such as a latch, three-state buffer, shift register, counter, or small memory, can be considered to be an I/O device as well. If it is digital, it usually can be an I/O device.

We have indicated previously that you must synchronize the transfer of data between a computer and an I/O device, and that this synchronization is accomplished with the aid of pulses called *device select pulses*. An important point is that several device select pulses may be required for a single I/O device. For example, the 74198 shift register has a pair of control inputs that determine whether the register shifts left, shifts right, or parallel loads eight bits of data. The chip also contains clock and clear inputs. Thus, a single 74198 chip may require three or four unique device select pulses. The fact that you can generate 256 different input device select pulses and 256 different output device select pulses does not mean that you can address 512 different "devices." A more reasonable number is of the order of 50 to 100 devices. Rarely will you require so many device select pulses. If you do, there are other tricks that you can use to generate still more such pulses.

In the following Unit, you will learn how to generate device select pulses. also provided is a discussion of the various uses for device select pulses.

REVIEW

The following questions will help you review a few of the important concepts of microcomputer interfacing.

1. Which of the following constitute hardware and which constitute software?

   a. cross-assembler

   b. editor

   c. integrated circuit chip

   d. wire

   e. printed circuit board

   f. capacitors and resistors

   g. FORTRAN program

   h. turbo-alternating grundle flusher

   i. thermistor (temperature transducer)

2. What are the three important busses in a microcomputer?

3. Why is it useful for the data bus to be bidirectional?

4. List five important control signal lines in an 8080A-based microcomputer.

ANSWERS

1. a. software
   b. software
   c. hardware
   d. hardware
   e. hardware
   f. hardware
   g. software
   h. hardware, whatever it is
   i. hardware

2. The bidirectional data bus, the control bus, and the address bus

3. For an 8-bit microprocessor chip, it reduces the number of pins required by eight. For a 16-bit microprocessor chip, it reduces the number of pins required by sixteen.

4. $\overline{\text{OUT}}$, $\overline{\text{IN}}$, $\overline{\text{MEMR}}$, $\overline{\text{MEMW}}$, and $\overline{\text{IACK}}$