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Microcomputer anatomy and the way it communicates to the outside world is described this month.

PETER RONY, JOHN TITUS, and DAVID LARSEN*

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IN THIS COLUMN WE WILL DISCUSS THE "anatomy" of a typical microcomputer system. (See Fig. 1, page 24.) This system is based upon the 40-pin 8080 microprocessor chip and possesses all of the minimum requirements for a computer.

- It can input and output data.
- It contains an arithmetic/logic unit (ALU), located within the 8080 chip, that performs the arithmetic and logical operations.
- It contains "fast" memory (speed is an important requirement for a functional computer these days).
- It is programmable, with the data and program instructions capable of being arranged in any sequence desired.
- It is digital.

Memory

Lets first consider the data communication between the 8080 central processing unit (CPU) and memory. The following definitions[1,2] will be useful in the ensuing discussion:

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

memory cell—A single storage element of memory.

memory word—A group of bits occupying one storage location in a computer. This group is treated by the computer circuits as an entity, by the control unit as an instruction, and by the arithmetic unit as a quantity. Each bit is stored in a single memory cell.

memory address—The storage location of a memory word.

memory data—The memory word occupying a specific storage location in memory, or the memory words collectively located in memory.

random access memory—A memory into which bits can be written (stored) and then read out again (retrieved).

read-only memory—A memory that can be repeatedly read out, but cannot be written into.

programmable read-only memory—A read-only memory that is field programmable by the user.

volatile memory—In computers, any memory that can store information only as

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long as power is applied to the memory.

read—To transmit data from a memory to some other device.

write—To transmit data into a memory from some other device. A synonym is *store*.

The 8080 microprocessor uses 8-bit words that are stored in memory by a 16-bit memory address bus. The memory address bus determines a specific storage location in memory. Therefore, 2^{16} = 65,536 different memory locations can be accessed by the microprocessor. This memory access is direct, which means that you don't have to engage in any special tricks or digital electronic gimmicks to access any given memory location within the 65,536 possible locations. Forty-pin integrated circuit chips do have their advantages, and this is one of them. The total memory capacity of the 8080 microprocessor is known in the trade as "64K." This is far more memory than you will ever need for most applications, but it is nice to know that you have such power in reserve.

Data is transferred between the 8080 CPU and the memory via 8-bit input and output buses, both of which are shown in Fig. 1. By "input," we mean "input into the CPU." The term "output" is defined in a similar fashion. Our point of reference is always the CPU. Data leaving the CPU is always considered to be "output data;" data entering the CPU is always considered "input data." In the figure, we have indicated that the input and output data is transferred between the *accumulator* and memory. This is frequently the case, but in a more detailed look at the 8080 chip, you will discover that data stored in memory is transferred to other internal *registers* within the 8080 chip as well. The most obvious such register is the *instruction register*, from which the decoding of the instruction occurs. Other registers, known as *general purpose registers*, are classified by the letters B, C, D, E, H, and L.

The accumulator register is the heart of the entire microcomputer. Arithmetic and logic operations are always performed to or on the eight bits of data present in the accumulator. All input and output data passes through the accumulator with the aid of two computer instructions called IN and OUT.

Between the 8080 CPU and memory there is a single output line called memory READ/WRITE. When this line is at a logic 1 level, you are able to read data into the CPU either from memory or from an external device. When this line is at a logic 0 level, you are able to write data from the CPU into memory or an external output device.

As a final point, you can use any type of "fast," digital electronic memory device, including random access memory (RAM), read-only memory (ROM), and programmable read-only memory (PROM). What do we mean by "fast" memory? Simply that the memory can perform either a read or write operation during a single microcomputer instruc-

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tion. A typical 8080 microcomputer system operates at a clock rate of 2-MHz and a read or write operation takes only 3.5 μs. Thus, RAM, ROM and PROM all need an access time of about one to two microseconds to allow you to take full advantage of the maximum clock speed. Slower semiconductor memories can be used, but the microcomputer will have to "wait" while a read or write operation is completed.

Data output

The 8-bit output bus between the 8080 CPU and memory also serves as the output data bus to an external output device. When you provide output to an external device, there are several important points that you must remember:

- You must select the specific output device that will receive 8-bits of data from the CPU.
- You must indicate to this device when output data is available on the output data bus.
- The device must capture this output data in a very short period of time, typically 1.5 μs.

The third point is perhaps the most important. Keep in mind that the microcomputer is operating at a clock rate of 2 MHz. Each computer instruction is executed in a very short period of time, which ranges from 2 μs to 9 μs. Thus, accumulator data designated as "output data" to an external device is not available for very long. You must capture it while it is available. We will discuss the techniques that you should use in a subsequent column; this topic is certainly among the most interesting topics that can be discussed in the area of computer interfacing.

Data input

The basic considerations that apply to data output also apply to data input to the CPU from an external device. Thus:

- You must select the specific device that will transmit 8-bits of data to the CPU.
- You must indicate to this device when the CPU is ready to acquire the input data.
- You must insure that the CPU acquires this data in a very short period of time, typically 1.5 μs.

Input/output device addressing

The 16-bit memory address bus is time shared so that it can provide, at certain times, an 8-bit device identification number called a *device code*. Eight bits of information allow you to decode $2^8 = 256$ different devices. When used in conjunction with 2 output-function pulses called IN and OUT, the microcomputer system can address 256 different input devices and 256 different output devices. We might point out here that a "device" can be a complex machine such as a teletype, a CRT display, or a simple device such as a single integrated circuit chip. This is another interesting topic for discussion that we shall reserve for a subsequent column.

Microcomputer interrupt

Not shown in Fig. 1 is a single input line to the microcomputer that generates

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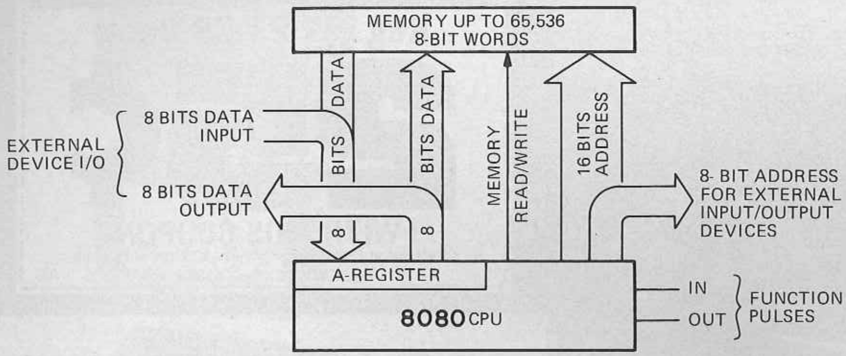

FIG. 1

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a program *interrupt* during microcomputer operation. Such an interrupt would be generated by an external device that wishes to transfer data to or from the computer. This particular topic is quite complex and it will be a number of months before we tackle it in this column.

The above is about the best that we can do to describe the general "anatomy of a microcomputer in one thousand words or less. Microcomputers are fascinating machines. They are small and relatively inexpensive, so one is less likely to be intimidated by them. They are far simpler than their minicomputer and computer counterparts and can be readily repaired by the simple process of chip substitution. **R-E**

References

1. Graf, R. F., *Modern Dictionary of Electronics,* Howard W. Sams & Co., Inc., Indianapolis, IN, 1972.
2. Blukis, J. and Baker, M., *Practical Digital Electronics,* Hewlett-Packard Co., Santa Clara, CA, 1974.

Computer calls to computer via amateur radio satellite

Two North American radio amateurs have made the first claimed remote access of a computer, not only through a two-way radio link but also via an amateur communications relay satellite.

An "execute program" command was transmitted by WB4BWK, W. Franklin Mitchell, Jr., Due West, SC, to VE2BYG/3, Randall S. Smith, Barrie, Ontario, via the AMSAT/OSCAR 7 satellite. On reception, it executed the stored program which consisted of a message from VE2BYG/3 to WB4BWK. The data was transmitted in ASCII code at a rate of 110 baud (110 units per second). The FCC has granted a waiver to hams interested in computers and radioteletype, permitting them to transmit ASCII-coded information by way of the satellite.

Calculators good for kids say mathematics teachers

The little hand-held electronic calculator, which formerly aroused some doubts in the minds of educators, is now acclaimed as a "valuable instruction aid" by the National Council of Teachers of Mathematics. "In the classroom," reads the Council's policy statement, "the calculator should be used in imaginative ways to reinforce learning and to motivate the learner as he becomes proficient in mathematics."

According to articles in *Arithmetic Teacher* and *Mathematics Teacher,* organs of the Council, important teaching uses of the calculator are to encourage inquisitiveness and creativity, to promote independent problem solving, to solve problems that would be impractical to attempt with pencil and paper, and to decrease the time needed to handle difficult computations. The little computers can also be used more prosaically to solve consumer problems and to verify the results of pencil-and-paper calculations. **R-E**