Computers: First the Maxi, Then the Mini, Now It's the Micro

While ever larger and more powerful supercomputers may constitute the glamor segment of the computer industry, recent developments at the opposite end of the computer spectrum may in the end have a larger impact on society. The much heralded microelectronics revolution—heretofore largely confined to the aerospace and computer business—has affected the man on the street only marginally so far, one example being the boom in hand-held calculators. Now, under the egis of low-cost computing power in the form of microprocessors, the full impact of such electronics is near.

Microprocessors are already widely used in programmable electronic calculators. They are beginning to appear in controllers for factory machinery, automated materials handling systems, phototypesetting systems, traffic control systems, telecommunications terminals, and computerized, electronic cash registers. Peripheral devices associated with large computing systems, such as "intelligent" terminals with video displays, are being built around microprocessors. The invasion of the home by computers is under way in the form of microprocessor-based electronic controls for appliances. Onboard computers in automobiles are not far off. And the potential of microprocessors for automating instrumentation for scientific research and medical care is just beginning to be exploited.

A microprocessor is a general purpose, programmable integrated circuit that is equivalent to the central processor unit (CPU) of a conventional computer. Unlike the heart of the conventional computer, however, the microprocessor occupies only a single chip (or at most a few chips) of silicon, packing several thousand transistors in an area only a few millimeters on a side (Fig. 1). Even a minicomputer CPU, in contrast, might consist of several hundred much less densely packed integrated circuits.

A fully operational computer called a microcomputer can be built around a microprocessor by adding some memory and additional circuitry to connect the computer to the outside world. The memory usually comes in two forms. The first type has a fixed content and is called a read-only memory. The second type has a variable content and is called a read-write or random access memory. A read-only memory (ROM) is used to store the microcomputer's operating program. A programmable read-only memory (PROM) is a ROM that is programmed by the user in the field. Some PROM's are reprogrammable. The reliance on ROM's marks one important difference between microcomputers and larger, more general purpose computers. While the microprocessor is general purpose, the microcomputer built around it usually is highly dedicated, that is, it performs one specific function exclusively. A random access memory (RAM) is usually used for storing the data upon which the microcomputer is to act, since the data are continually changing, but can also be used for storing frequently changed programs.

Communicating with Other Devices

The microcomputer can be connected to a variety of external devices, such as sensors (for example, voltmeters, thermocouples, and strain gauges), teletype terminals, paper tape readers and punches, magnetic tape cassette units, keyboard terminals, and displays. In addition, the microcomputer can communicate with telecommunications devices (including telephones), other microcomputers, or other large computers.

If the history of electronics has any themes, miniaturization surely must be one of them. From vacuum tubes to discrete transistors to integrated circuits, putting more circuitry in a smaller space for less money has been a major goal. At present, the most densely packed integrated circuits, containing from a thousand to more than 10,000 transistors, are termed large-scale integrated (LSI) circuits.

In the 1960's, a type of unipolar transistor (only one type of current carrier, either electrons or holes) known as the field affect transistor (FET) made with silicon and silicon dioxide was experimented with. Researchers found that much higher packing densities were possible, less power was consumed, and fewer processing steps were needed with FET's than with the then dominant bipolar transistors (in which both electrons and holes contribute to the current), when a particular configuration called metal oxide semiconductor (MOS) was used. Various forms of MOS technology have since dominated such LSI devices as electronic calculator circuits and high density RAM's for computers.

However, the great cost reductions inherent in integrated circuits occur only when large numbers of devices are sold (in the hundreds of thousands for LSI circuits), because of the lengthy and expensive development process. Thus, so-called custom LSI circuits designed only for limited or specialized uses were seen to be unprofitable by the semiconductor industry very early. But since the microprocessor is a general purpose LSI circuit that can be customized by programming it to carry out a specific function, costly design changes are not required for different applications.

General purpose microprocessors (as opposed to custom versions available even earlier) became commercially available at the end of 1971. Engineers agree that it is the control over the fabrication process that is crucial to making LSI circuits, particularly complex ones of the type found in microprocessors. The principal problem is that of obtaining yields (that is, the fraction of the total circuits produced that are free of defects) high enough to be economically viable. Because of such difficulties, there have been a number of premature microprocessor announcements. More than two dozen makers of integrated circuits are now planning to have microprocessors available in 1975; but for the present, reliable sources are limited to only a few companies.

The first microprocessors were derived from electronic calculator circuits and thus had a computer word length of 4 bits, because 4 bits is a convenient length for decimal arithmetic. (In this context a word is the number of binary bits that are processed simultaneously. Such parallel processing distinguishes microprocessors from calculators that process serially or 1 bit at a time.) Later versions increased the word length to 8 bits for easier character and symbol manipulation and were oriented toward keyboard terminal applications. Some microprocessors now have 16-bit word lengths.

These relatively short word lengths mark another distinction between most microcomputers and larger computers, at least at the present time. Typically, minicomputers might have a 16-bit word length (they range from 8 to 32 bits), and full-size, general purpose computers have a 32- or 64-bit word length. The short word length of many microprocessors also tends to limit their performance somewhat. For example, the number of instructions the microprocessor can carry out directly (as opposed to operations constructed from a sequence of instructions) has been small, and very high precision computation has not been possible. In addition, as compared to larger computers, memories (of which the largest part is usually in the form of a ROM) have been smaller in microcomputers, and higher level programming languages, such as Fortran, have not been widely available.

The speed of microprocessor execution is limited both by the small word length (since fewer bits are processed in a given time interval) and by the MOS technology used up to now. Typically, several microseconds are required to execute an instruction, as compared with one or a few microseconds with the faster, bipolar medium-scale integrated (MSI) circuit technology used in larger computers. These features pretty well point out where microcomputers are useful and where they are not. Researchers are nearly unanimous in agreeing that microcomputers are not now directly competitive with minicomputers. However, advances in technology (bipolar LSI microprocessor circuits are now becoming available) will tend to lessen the distinction between the two.

Instead, the microcomputer is a strong competitor in a number of control and automation functions that are currently carried out by digital logic circuits (known in the trade as random logic). These circuits are termed "hard-wired" because they must be explicitly rewired each time it is necessary to alter their function. If the logical task to be performed is sufficiently complicated, then it becomes economically viable to replace hard-wired circuits with microcomputers, both because of initial costs and the flexibility inherent in the programmability of microprocessors.

There are also a number of applications requiring a decision-making or

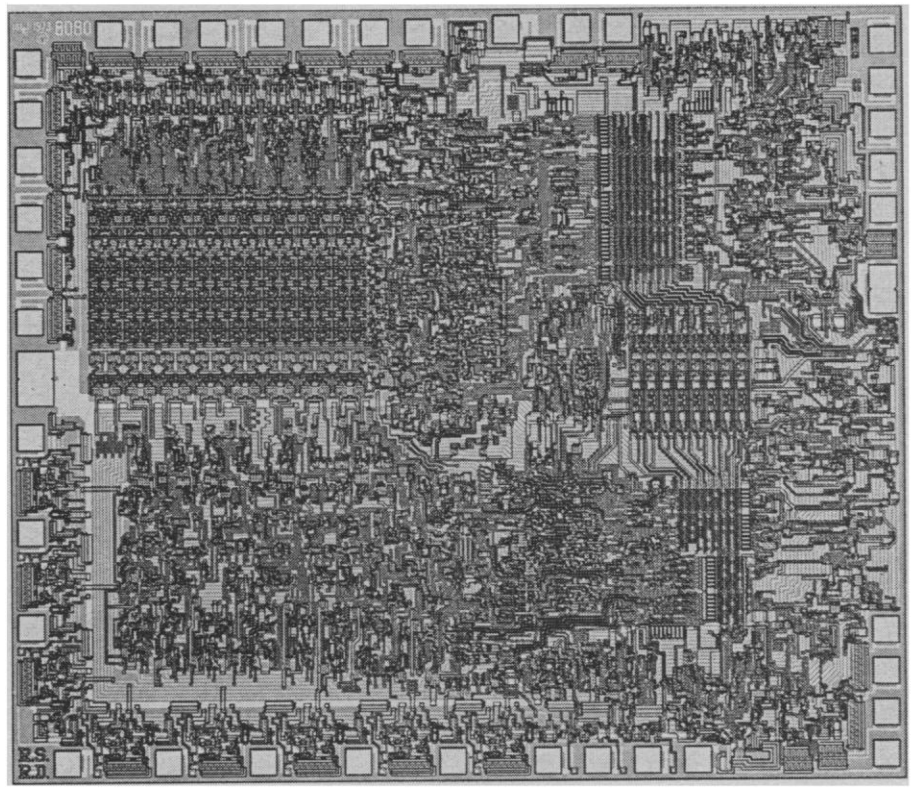

Fig 1. Photomicrograph of an 8-bit microprocessor integrated circuit. There are more than 4500 transistors in an area 4.2 by 4.8 millimeters. [Source: Intel Corporation, Santa Clara, California]

computational capability beyond that of hard-wired random logic but which cannot justify the expense of a minicomputer (the cheapest being a few thousand dollars). Microprocessors are currently priced between about $50 and $350 (in small quantities); but this price could drop by a factor of 10 when, as expected, sales volumes increase. Memories range from $5 to $60 apiece. Thus, a customized microcomputer designed for a specific function can be quite inexpensive. Moreover, some companies are buying components from the microprocessor makers and packaging complete microcomputer systems. (The semiconductor companies also sell packaged systems, which are oriented toward prototyping and program development, rather than being microcomputers for use in the end product.) The principal customers of such companies include both low volume buyers, such as research laboratories, who cannot afford the appreciable time and expense involved in assembling systems from components and developing applications programs for them, and manufacturers with no background or interest in developing an expertise in computer technology.

However, the major user of microcomputers likely will be original equipment manufacturers (OEM's) who will design their own microcomputer around microprocessors and memories and bury it deep with a final product. For example, computerized, electronic cash registers are remote computer terminals (point of sale terminals), each of which is linked to a central computer located in the store or at a distant site. The computer carries out such functions as authorization of personal checks, credit checking, automatic price look-up, and inventory control.

Point of sale terminals for general merchandise (department) stores and for supermarkets have somewhat different requirements; but in either case, microcomputers can be used to provide a "stand alone" capability to each individual terminal—that is, the terminal functions even when the computer is not running. In the supermarket, for example, each terminal can keep track of taxable items, coupons, returned bottles, food stamps, sale items, and make change, all the while printing an itemized receipt for the customer. In the department store, terminals are programmed to lead the salesperson through the sequence of operations required for complicated sales, such as charge-account sales, so that a sale cannot be closed if an incorrect procedure is attempted. In both cases, optical or magnetic scanners can read codes imprinted on items and automatically enter them into the terminal, thus relieving the cashier of much keyboard operation. Complete sales records for later processing by the central computer are also maintained.

Automobiles represent the largest single potential market for microprocessors, in part because of the increasingly stringent emissions control regulations faced by auto makers and the possibility of fuel economy rules in the future. For example, timing of the spark firing could be controlled by a microcomputer receiving inputs from sensors that measure such variables as the number of revolutions per minute of the engine, crankshaft position, engine coolant temperature, ambient temperature, and intake manifold pressure. Similarly, the ratio of fuel to air could be optimized. And the amount of exhaust gas recirculation, in which exhaust gas which is depleted of hydrocarbons and oxygen relative to the not yet combusted fuel-air mixture is used as a diluent in order to reduce the combustion temperature and thus reduce nitrogen oxides, could be adjusted.

The major car companies are all negotiating with microprocessor manufacturers over what will be, in effect, custom microprocessors tailored to automotive requirements, and are now testing systems in the laboratory and on the road. According to automotive engineers, getting the price of microprocessors reduced still further is one obstacle to be overcome before computerized cars will be sold. But obtaining reliable solid state sensors to provide information to the on-board computer is the major problem.

An as yet largely untouched area in which microcomputers could have a large impact is instrumentation for scientific research and medical care. There are innumerable instances in which automated control or some amount of data manipulation is needed, but in which the expense of a minicomputer, or in some cases the physical bulk of a mini, cannot be tolerated.

To take one example in the field of medical instrumentation, Philips Medical Systems, Shelton, Connecticut, is working on a line of instruments that will be designed to eliminate all controls of an essentially nonmedical nature, such as balancing pens on recorders or zeroing meters, and to produce directly usable, numerical data. Such instruments will be self-calibrating, do a certain amount of self-checking, and do a fair amount of computation. Because microcomputers are small and inexpensive, several of them, each doing a separate task, could be used in one instrument. Philips has recently announced the first of such instruments, in which a microcomputer is used as the processing unit, an automatic cardiac catheterization laboratory system for use during diagnostic procedures. The microcomputer receives information from one or more blood pressure electromanometers, scales and otherwise processes the measurements, and provides visual and hard copy display of the results.

Automating Research

A similar philosophy is taking hold among makers of laboratory instruments. For example, the Hewlett-Packard Company, Palo Alto, California, has begun to incorporate microprocessors into what will be known as "smart" instruments. Although Hewlett-Packard has for sometime been using microprocessors to do rather mundane tasks such as autoranging in digital voltmeters, the smart instruments will have sufficient intelligence to do a number of altogether new operations, such as monitoring their own operation, checking for procedural errors (such as ascertaining that the controls are set correctly), and carrying out computation needed to produce desired answers. At present, Hewlett-Packard is selling three such instruments: a high-speed, general purpose oscilloscope, a gas chromatograph, and a distance measuring system.

Perhaps surprisingly, the large research establishments, including the National Institutes of Health, the National Bureau of Standards, and many of the AEC's National Laboratories, are still in the early stages of incorporating microcomputers into their research instrumentation. Only the Lawrence Livermore Laboratory, Livermore, California, has taken real advantage of the potential of microcomputers for automating research.

At Livermore, a group headed by E. R. Fisher saw very early that, for microcomputers to be useful in the Livermore environment, they would have to have a modular design—with microprocessor, memory, and interface chips all on separate circuit boards so that, for example, memory could be extended simply by adding another board. A design was worked out and software was developed to the point that now, at Livermore, microcomputers can be obtained from the shelf from a stockroom. It is the basic Livermore design, incidentally, that one microcomputer company has been marketing as a complete microcomputer.

To cite one application, at Livermore the microcomputer is being used as an automatic batch monitor. Programs submitted at remote terminals in the laboratories are run on central computers according to a priority system. The microcomputer, attached to a remote terminal, monitors the progress of the program submitted to the central computer. If the program is stalled because of an improper priority assignment, for example, the microcomputer can reassign a priority sufficient to get the program run without any intervention by an operator. Similarly, the microcomputer can make sure that all information needed to run a program is available, as, for example, when the central computer is restarted after it has been shut down.

In the microelectronics industry, microcomputers are the current "wave of the future." A recent issue of a newspaper for electrical engineers carried at least six announcements for seminars and short courses on microprocessors. Digital design with microprocessors is becoming a part of many electrical engineering department undergraduate curricula. Projections of future sales of micro- and minicomputers indicate that the value of microcomputers sold will surpass that of minicomputers by 1977 and will become a significant portion of the entire semiconductor market. Semiconductor memories have approximately doubled in density (bits per chip) every year since 1962. Similarly, the 1974 microprocessors are 100 times faster than the 1972 versions. Anticipating this continued growth in performance, computer scientists are already planning to connect up to 100 microprocessors in parallel to produce a supercomputer for specific types of applications. For the same reasons, a minicomputer on a few chips is likewise forecast for the near future.

—ARTHUR L. ROBINSON

Additional Readings

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2. H. Falk, *IEEE (Inst. Electr Electron Eng.) Spectrum* **11**, No. 9, 59 (1974); *ibid*, No 10, p 78; *ibid*, No. 11, p. 46
3. See also articles on various aspects of microprocessors and their applications in *Electronics* **47**, No 8, 81 (1974); *ibid*. No. 14, p 81