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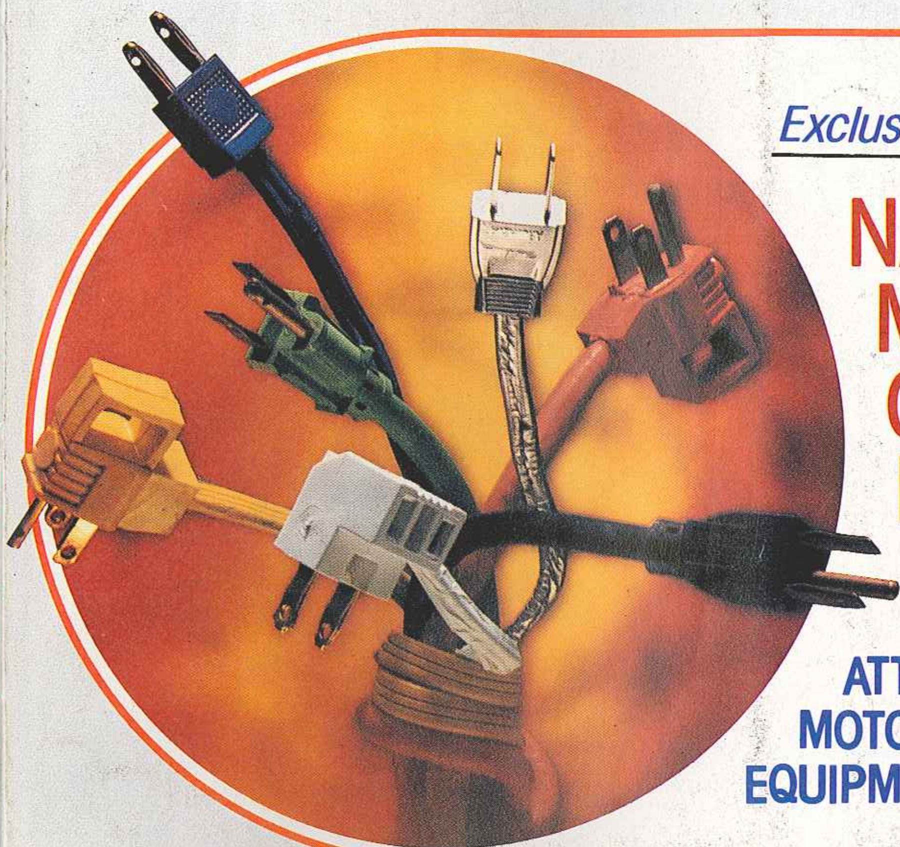
25th ANNIVERSARY ISSUE

Special Focus on the Electronics Revolution



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25TH ANNIVERSARY ISSUE

It was only a few short years ago that engineers became increasingly interested in what might well become the most significant advance in semiconductor technology since the invention of the transistor—the single-chip microcomputer. It has stimulated interest in electronics to levels seldom before experienced.

Yet relatively few people truly understand the impact of the "computer-on-a-chip." Microelectronic technology moves so rapidly that it becomes impossible for even those intimately involved with a new development to grasp its full significance. Something new to divert the attention always seems to evolve. But without some understanding of the depth and scope of these technological changes, potential users too often perceive them as added confusion rather than practical innovations.

Webster defines the word *evolution* as the "art of unfolding or unrolling . . . a process of development, formation or growth." *Revolution* is defined as a "complete and drastic change of any kind." Understanding the "evolution" of these "revolutions" will help place future development possibilities into a more readily discernible perspective.

The MICROCOMPUTER

An Evolving Revolution in Consumer Electronics

BY JAMES T. VAN TASSEL

Texas Instruments Inc.

It's November 1, 1954, fully 25 years ago. A remarkable new invention has just been announced that will lead innumerable people—young and old alike—to seemingly plug their ears with a small, handheld device. This "earplug" isn't designed to solve auditory problems, but it will start a revolution in personal communications and help make "solid-state" a household word.

The First Revolution. The innocuous hand-held device alluded to was the first transistor radio. Blaring out such hits as "Rock Around the Clock" or Elvis in his "Blue Suede Shoes," this transistor radio represented the first volume application of the germanium transistor invented six years earlier by Bell Labs. Transistor prices had dropped from $16.00 to $2.50.

Another major breakthrough in transistor technology had been announced six months earlier. At a meeting of the National Conference of Airborne Electronics in May, Gordon Teal of Texas Instruments was next to last on the agenda. The title of his presentation was "Some New and Recent Developments in Germanium and Silicon." Not sensing the impact of the subject, one speaker after another predicted that the technology for producing silicon crystals of sufficient purity for semiconductor manufacture was years away. Teal said, stunning his audience: "Contrary to popular belief about the prospects for the silicon transistor, I happen to have a few here in my pocket." The last speaker of the day lost his audience as they clamored en masse to the rear of the hall for literature on the new devices.

These two seemingly different events heralded the first revolution in solid-state electronics. Not only had the transistor

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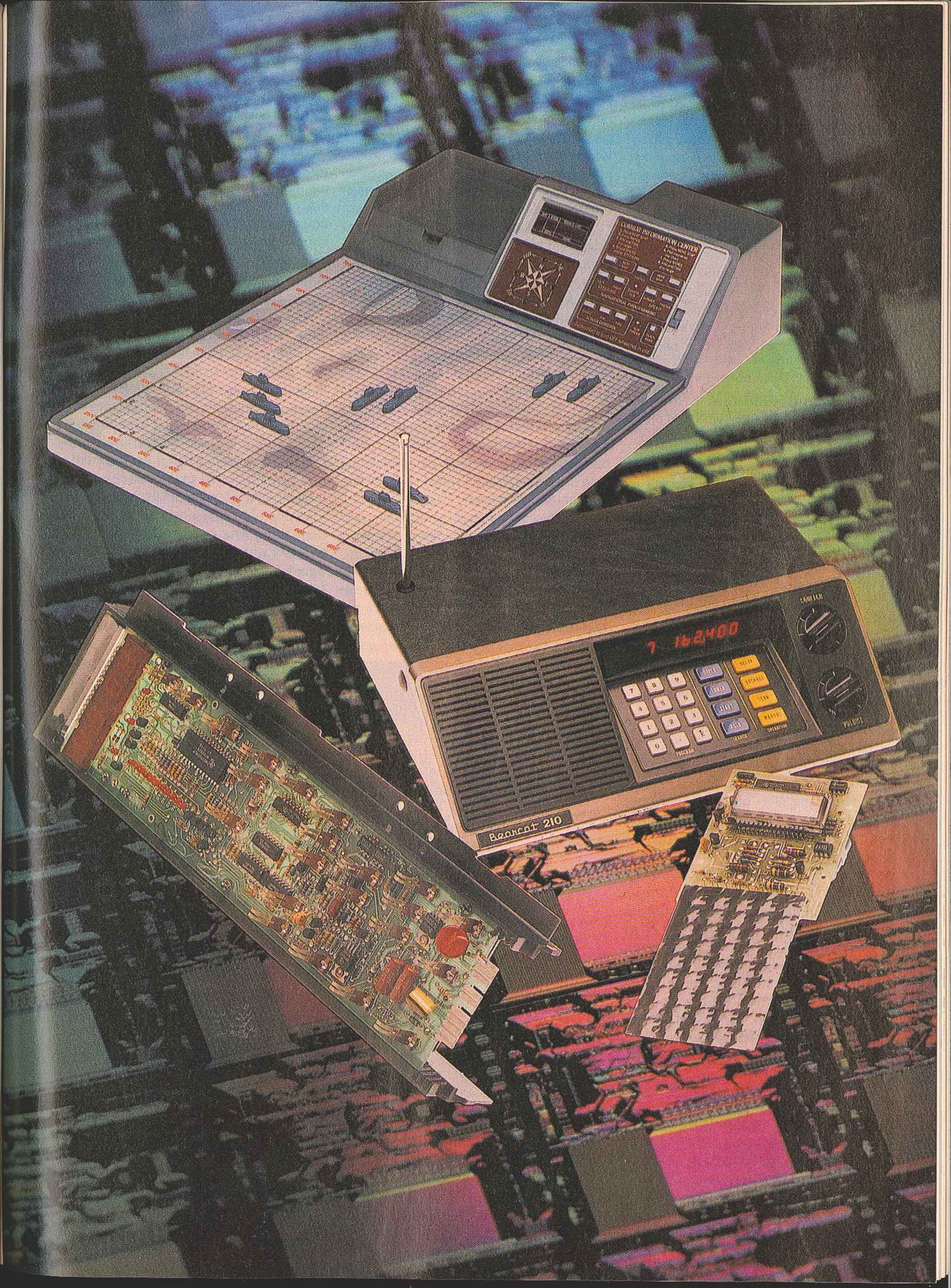


Development of the single-chip microcomputer, such as the TMS1000, has led to the establishment of entire new product areas such as electronic toys and games, a variety of programmable appliances, and sophisticated automatic scanners.

Evolving Revolution

continued

been mass-produced, the temperature problems inherent in germanium had been solved through the use of silicon. This opened the way for the fledgling aerospace industry to explore alternatives to the large, overly expensive and unreliable vacuum-tube systems that had encumbered aircraft since before World War II.

The Second Revolution. In November of 1958 Jack S. Kilby, who had only joined TI about six months earlier, demonstrated a unique semiconductor that for the first time incorporated more than one transistor, resistor and capacitor on a single chip of silicon. The integrated circuit eliminated the need for masses of separate discrete devices and the multitude of electromechanical interconnections they required. It has thus paved the way for a host of consumer products that were less costly and more reliable.

The first production integrated circuits delivered to the Air Force in 1962 were simple devices with two to four Active Elements Groups (AEGs) per package, priced at $100 each in small quantities. An AEG is a measure of circuit complexity defined as one digital logic gate, a single bit of memory or a single stage of amplification.

Commercialization of this revolutionary technology led to an increasing number of AEGs being packed into a rapidly shrinking area. For comparison, a vacuum-tube AEG of the mid-1950's occupied about four square inches. The transistor AEG of the early 1960's occupied only three-fourths of a square inch. Progressing from Small-Scale Integration (SSI) through Medium-Scale Integration (MSI) with over 100 AEGs per chip to Large-Scale Integration (LSI) with over 1000 AEGs per chip, the typical active element group was reduced to two and one-half millionths of an inch. Cost dropped also from $7.00 per AEG in 1960 to less than $0.001 currently.

One of the major developments that contributed to the development of LSI technology was the change from a concentration of bipolar devices to a unipolar configuration called the Metal-Oxide-Semiconductor, or MOS. With bipolar devices, high component densities were very difficult and chip sizes were limited because of problems with heat dissipation and low product yields. MOS technology, where only one type of current carrier is used as opposed to two, offered the higher packing densities, lower power consumption and fewer machine steps. However, it did so at the expense of throughput speed.

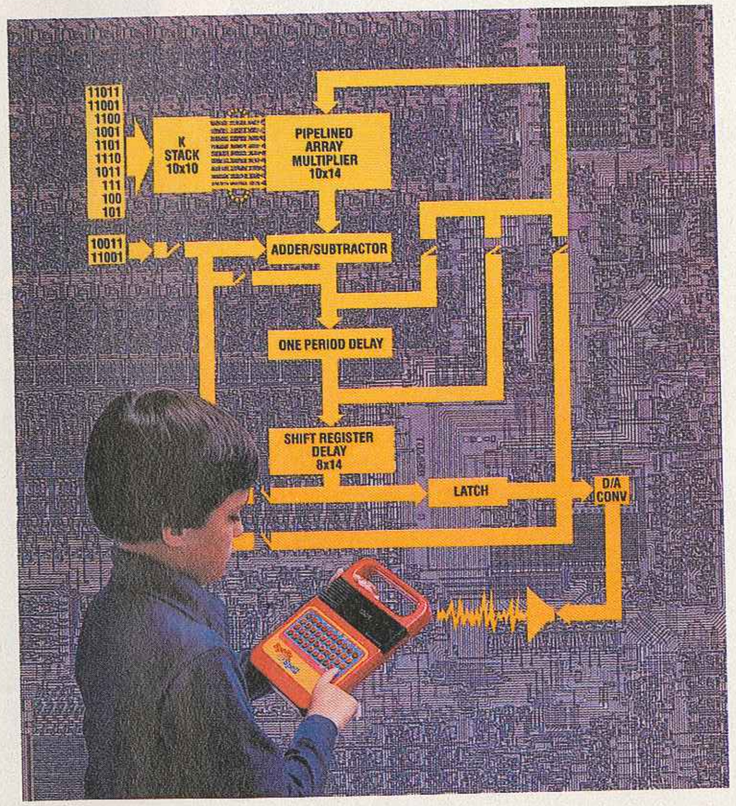
Among the outgrowths of this advanced MOS/LSI technology was the hand-held calculator invented in 1967 by Jack Kilby, Jerry Merryman and the author. Measuring only 4¼ × 6⅛ × 1¾ inches, this first miniature calculator had as its working heart an integrated-circuit array that contained all of the necessary electronics for performing addition, subtraction, multiplication and division.

PMOS (Positive-channel MOS) technology and demand for low-cost calculators led a number of companies to undertake development of a calculator chip. Intel Corporation was among those that chose to design a versatile, programmable single-chip microprocessor, one element of a multi-chip microcomputer system. Introduced in 1972, the Intel 4004 processed data blocks of 4 bits each. Less than a year later, National Semiconductor, Rockwell International, and Fairchild Semiconductor also entered the marketplace with microprocessors capable of processing 8 bits and containing anywhere from 5000 to 10,000 transistors.

For the purposes of definition, the microprocessor is the basic CPU—Central Processing Unit—of a computer. When memory, clock and input/output circuits are added, the system becomes a microcomputer. With software, a power supply, interface devices, control and a display capability, the configuration becomes a microcomputer system that operates like a true computer.

The Third Revolution. The next revolutionary step in microelectronic technology was taken in early 1971 when Michael Cochran and Gary Boone of Texas Instruments developed the single-chip microcomputer. There were over 20,000 transistors and other components comprising all of the elements of a computer on a chip of silicon a few thousandths of an inch thick and less than one-fifth of an inch square. Component count was reduced from about 10 to only 1 with system costs reduced from about $150 or $200 for a comparable microprocessor or custom LSI system to less than $5.00 currently.

This tiny computer-on-a-chip offered



Superimposed over the photomicrograph of the TMC0280 Speech Synthesis chip is block diagram of linear predictive coding-based system used in TI's Speak and Spell.

4-bit computational power to help execute automatically a wide array of complex operations. On board the chip there are: (1) the arithmetic and logic unit (ALU) that performs basic decision-making and data processing, (2) memory for storing both computer software instructions and input data that the computer manipulates or processes, (3) control and clock circuitry for retrieval of instructions from memory and directing the rest of the system to execute these instructions in proper sequence and timing, and (4) input/output subsystems that allow the computer to productively communicate with the outside world.

During the processing of the silicon slice, the software program generated from the end system's functional specifications is imbedded in memory by a single-level mask technique that programs three parts of the microcomputer—the ROM, the instruction decoder and output encoder. These programmed parts control data input to the central processing unit, the processing of the data, and the encoding of the output to meet the needs of the system. Electronic elements in the microcomputer are reduced to micron dimensions so that an enormous amount of task-performing power is packed into an area of 1/20 of a square inch. What is truly significant is not so much that such a high degree of miniaturization is achieved, but that substantial economies of manufacture have been realized both for the electronics and the end-systems, along with substantial increases in reliability. For example, a current family of four series of 4-bit devices that have evolved from the original microcomputer offers a reliability of more than 0.05% per 1000 hours. This equates to less than one failure per 210 years. And the cost is $1.75 or less in high-volume production quantities.

With a cost and reliability impact of more than 15 to 1 over microprocessor and hard-wired LSI systems, the microcomputer is revolutionizing digital electronic control. The most obvious impact has been in consumer electronics, where entirely new product lines are technically and economically feasible.

The transistor radio of the 70's now offers automated frequency scanning coupled with digital readout.

The calculator now performs a full array of scientific and engineering functions at a retail price more than 90% less than it was just a few years ago.

Microwave ovens have been made programmable through the use of the microcomputer, as have washing machines, blenders, food processors, automotive systems, TV tuners, security systems, and even children's toys.

In a very real sense, the microcomputer has brought what has long been perceived as science fiction into the realm of science fact. The microcomputer, the microprocessor and custom LSI logic are all the result of extremely rapid technological progress that continues to be made within the semiconductor industry. And there is every reason to believe that this is just the beginning; that the complexity will increase in direct proportion to the reduction in cost.

Where Do We Go From Here? If the past decade can be any indication, the future possibilities are virtually unlimited. They're difficult to predict in specific terms, however, because technology is snowballing in a way that few people could have foreseen only a few short years ago.

The toy industry is a good example. The microelectronics revolution has hit the toy business harder than anything since batteries replaced wind-up mechanisms a generation ago. In the beginning, manufacturers were somewhat timid about getting into the area of electronic playthings. Toys are a big, serious business, and overnight failures and fortunes are common. However, when a few toy companies cautiously came out with their first electronic games in 1977, the market subsequently exploded.

Not even the most optimistic of industry observers could have foreseen the blockbuster success of the electronic toy and game products of 1978, which were sold out virtually overnight. In just three years, the market has jumped from $21 million in 1977 to $152 million in 1978 with a projected $225 million in 1979, according to the Toy Manufacturers of America. Some predict the market will hit $500 million in 1980 and that eventually most games will become electronic.

As with the toy business, the speed with which innovation spreads makes it virtually impossible to predict accurately the impact of the microcomputer on other consumer products and services. However, certain trends are beginning to emerge which give a generalized indication of coming developments.

Much of what has happened over the past few years represents a relatively simple adaptation of calculator technology, the addition of touch-panel or keyboard-based electronic control to existing products. Recently, however, entirely new concepts have been developed; new consumer and commercial products are available that would not be practical or even possible, in some cases, without the microcomputer.

The digital thermometer is one such product. A very simple semiconductor, the thermistor, is used to measure the change in resistance caused by the change in temperature. However, the change in resistance for either negative or positive temperature coefficient thermistors follows a complex curve that can be almost logarithmic in shape. It is possible to select a narrow range for health-care applications, as an example, and then add various shunt resistors to linearize the curve. The linear signals can then be converted to a digital readout, but this limits the application of the thermometer and tends to price it out of the commercial market.

A far more cost-effective answer is being carried out by Electro-medics, Inc. of Denver, Colorado. There, designers put the algorithm that defines the temperature-resistance curve into the microcomputer and then use it to solve analog-to-digital computations. The result is a broad-range thermometer that can serve a multitude of applications with an accuracy of 0.1 degree. So because of the microcomputer, it is possible to take a patient's temperature in one-tenth the time, with greater accuracy, without the cost of breakage, and without the human error that was always inherent in a technician's attempting to read a glass thermometer.

A new toy organ recently introduced by Kenner Products of Cincinnati, Ohio, exemplifies another type of product made possible by the microcomputer. Using a TMS1000 4-bit single-chip microcomputer, the Play 'N Playback organ allows preschoolers to hear any of eight songs programmed into memory played out, to play songs of their own composition, and to record and then play back those songs or others from the accompanying songbook in proper sequence and rhythm.

For those that have long been associated with mechanical and electromechanical buzzers, bells and whistles, the concept of a tiny piece of silicon talking back or making music seems incomprehensible. In the past, where sound effects have been essential, discrete semiconductors have provided a limited variety of sounds. The products, however, suffered from the variations between individual discrete components and the high costs involved in development, assembly and packaging.

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Evolving Revolution

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Custom integrated circuits to generate sound effects were not an attractive alternative because of the lack of external programming capability. If the sound was not correct or even quite accurate, the circuit had to be redesigned. The original was simply a wasted effort. Another major problem with custom sound circuits was that they were limited to only one application, thus necessitating large-volume orders to amortize development costs.

The microcomputer was the technological breakthrough that opened the door to the low-end sound generator market. It can be used independently or to control a variety of sound generator circuits. By itself, the microcomputer can only produce square waves by holding an output ON for a short period and then holding if OFF for an equal period. This creates a square-wave cycle which, for most low-end applications, is of acceptable sound quality. For purer tones, as in musical instruments, the square waves can be shaped outside of the microcomputer quite simply by adding a resistor and capacitor to the output.

Musical tones are not the only type of sound that can be generated through the microcomputer. The new Marx Electronic 300 Bowling Game™ is a microcomputer-controlled table-top game that creates the sights and sounds of a real bowling alley. The 4-bit microcomputer brain of the game drives incandescent lamps to represent bowling pins and LED displays to indicate the score. In addition, it receives inputs from fourteen switches strategically placed in the alley surface and controls outputs to a sound circuit to imitate the sound of pins falling. This is achieved by generating a low-frequency tone and then decaying the sound through external components. The falling-pins effect is made by stringing several of these sounds together to represent a number of pins being hit.

For applications requiring more complex sounds or those of higher frequencies, the microcomputer can be used to provide the control signals for a complex sound-generator chip to produce sirens, whistling missiles, explosions, chirping birds, and a host of other sound effects. More advanced chips can produce truly complex sounds composed of up to three tones, random noise, or various mixtures of the two with independent attack and decay envelopes.

Using the speed and processing power of a 16-bit microcomputer, such as the TMS9940, it may well be possible to even teach the soon-to-be-available SN76489 complex sound generator to talk. The vocabulary of such a circuit would, of course, be quite limited, but perfectly adequate for a variety of annunciator circuits. It may prove feasible to expand some of the aircraft collision-avoidance systems to include an auditory response. Thus, rather than alarms or flashing lights which the pilot of an aircraft must interpret, a voice may well shout out, "Pull up. The aircraft is 100 feet below glidepath." Farther out in the future, voice recognition ability built into this flight-control system may well react to human vocal commands.

Microcomputer applications in the home have generally been limited to the kitchen, but this can be expected to change in the near future with more being accomplished in the areas of convenience and communications products.

Automatic telephone dialing, repertory dialing and automated phone-answering systems will become reasonably priced for the average homeowner through application of the microcomputer. It's likely that this will become popular in much the same way as the pushbutton phone has been replacing the circular dial. Uses of the phone can be expected to expand, allowing the homeowner to do his banking, pay bills, and send and receive printed information over the phone lines.

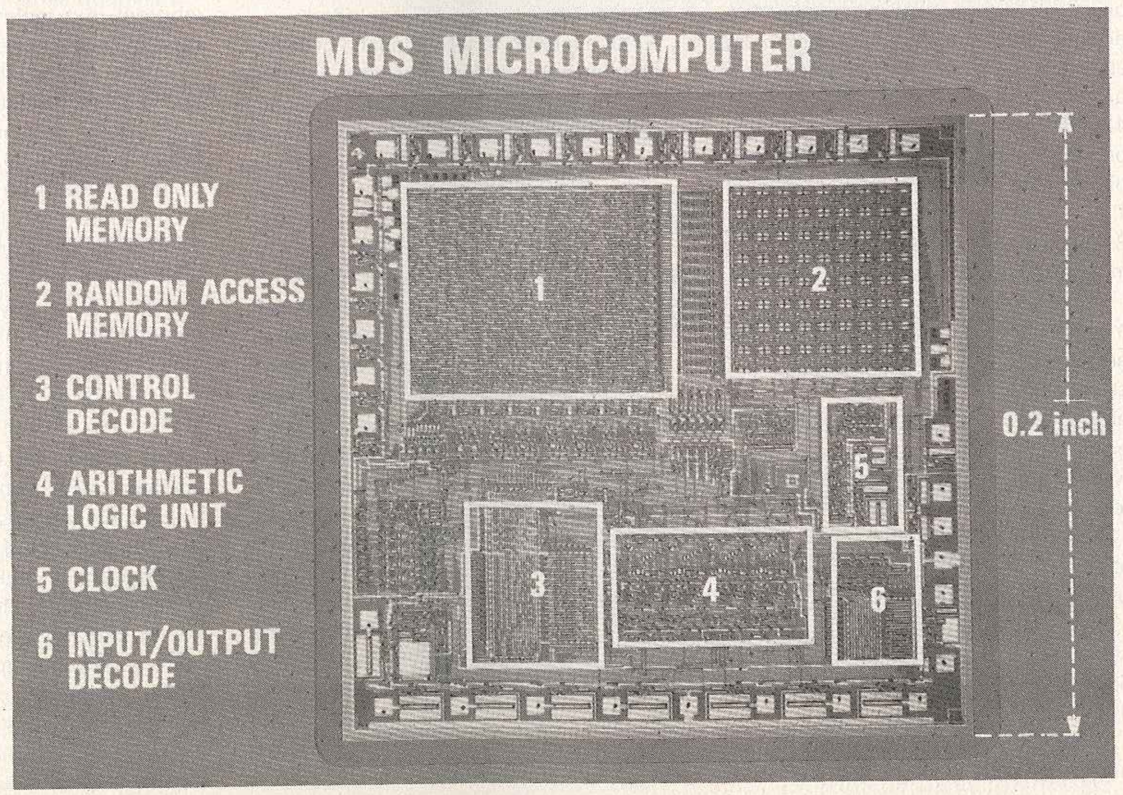

Photo of a microcomputer chip with important functional areas identified.

The key to this expanded use will be mass-acceptance of the personal or home computer.

In the 1960's, electronics hobbyists busied themselves with the design and construction of that "perfect" sound system. The spreading popularity of the hobby led to the commercialization and mass-production of those sophisticated systems to where they became readily available for a palatable cost.

In the 1970's, the hobbyist has also turned his attention to the computer. Developing games and other programs for the professional calculator once was a favorite diversion for computer specialists and mathematicians. As microcomputer modules became more readily available, the experimentor turned the calculator-based hobby into a microcomputer-based hobby. As happened with high-fidelity and stereo systems, electronics manufacturers have taken note of this spreading interest, developing first a series of personal computers specifically for the enthusiast and now products for even broader markets. Home computers are now available that require no computer-expertise or knowledge of programming. Software comes in pre-programmed ROM packages that simply plug into the computer much like the video game cassettes plug into the video games introduced in the mid-70's.

It's anticipated that the day will come in the future when a home computer will be another appliance designed to simplify and expand communications capabilities within the home. Through standard modern interfacing, it will connect to the telephone to provide the advantages of automated audio and visual communications. Electronic mail, electronic newspapers and automated communications will become commonplace. With an interface to the home electrical system, energy management and automated electrical control of any kind will be made possible.

The microcomputer will also make complex fire and security control systems practical realities for the consumer. Security systems will detect the presence of an intruder, and indicate the point of entry. This information will be displayed to both the homeowner and police via video monitors. Fire alarms will sense the location of a fire, calculate intensity and speed of growth, signal the occupants, indicate the safest route out of the house, and also alert the local fire department—again providing details of the fire via a video monitor.

Wouldn't it be convenient to have a microcomputer-controlled lawnmower that, once it was run through the mowing sequence, would automatically follow that sequence time-and-time again? With the simple addition of radio-control, it might even be programmed to back itself out of the tool shed and start the mowing job.

The family car will not escape microcomputer control. In some of the luxury models, it is there now! A microcomputer will control brakes to equalize application of pressure to minimize skidding. The same microcomputer will control engine operation to minimize exhaust emissions and maximize economy. With recent advances in speech synthesis, the day will come when the family car will *tell* the driver when the fuel is low, oil pressure is approaching a danger point or it's time to buckle up.

The microcomputer has just begun to tap the immense potential that exists in the field of education. Learning aids such as TI's Little Professor™ and Speak & Spell™, with other products, have found wide acceptance as simple, low-cost handheld devices that help make learning fun. Calculators and computers are being adapted to classroom work to help teach not only the fundamentals of arithmetic but also the use of math as a pure, universal language.

Teacher and student response to calculator-oriented mathematic learning aids has been so enthusiastic that studies are now being conducted in ways to utilize the technology in other subjects. The time is not far off when students will be using calculator or computer-extended materials to learn reading, writing, spelling, geography, history and foreign languages. The science is still in its infancy, but is already perceived as a positive educational influence on many levels. Computer simulators, for example, of the kind most readily associated with driver education and flight training, will eventually be available in smaller, maybe even portable, units to provide specialized instruction in a number of diversified fields—from shop training to first aid, from bridge lessons to computer maintenance.

Among all of the new features, one to evolve will be the most important—ease of programming. Simplified programmability will lead to ease of use in applications undreamed of today. An exciting new area of development is synthetic speech and voice recognition. The technology to enable appliances to "talk" is not only here, but economically practical, as is evident in TI's "talking" learning aid, Speak & Spell. And some electronic experts predict that speech recognition will be cost-effective within another three to five years. By the mid-1980's, appliances may be intelligent enough to carry on simple conversations with consumers. One of man's fondest dreams—the interactive machine that listens, responds and talks back to him—is the next big challenge.

In the not-too-distant future, a homemaker may well put a frozen roast in a microwave oven before leaving for a day's shopping. After lunch she (or he) calls home and accesses the oven through the home computer, telling it to turn on at 4:00 p.m. The oven responds, "What temperature, please?" A few hours later, the homemaker arrives home and tells the door to open. The electronic lock recognizes the voice as authentic and opens the door. As the person enters the house, lights turn on as the room is entered and off as it is left—automatically! The oven will eventually announce over the home intercom, "The roast is ready."

Is this science fiction? Not at all! The technology to produce such a system is already at hand. Mass production for the consumer will have to wait a while, however. And behind it all is the evolution of the microcomputer revolution.

In the mid-Sixties, Margaret Meade described society as being in the midst of an information explosion, a situation where technology has provided the capability of gathering, organizing, storing and disseminating far more information much faster than ever believed possible; but man has yet to learn to synthesize this information. This is the problem facing the consumer electronics industry today. There is a wealth of information, products and capabilities available now through microelectronics. The "problem" is for creative manufacturers to synthesize this information into more efficient and useful appliances.

The nature of the consumer electronics industry is changing, as is the nature of the job functions within it. Individual product designers now work together as systems designers. Engineers who once rarely left their drawing boards are now active in consumer research. And manufacturers cannot afford to ignore human factors in product and control design or the potential of newly developed microelectronics. If they do, along with designers of the wringer washing machine, the horsedrawn buggy, and the ice box, they'll wonder what ever happened to the good old days. ◇