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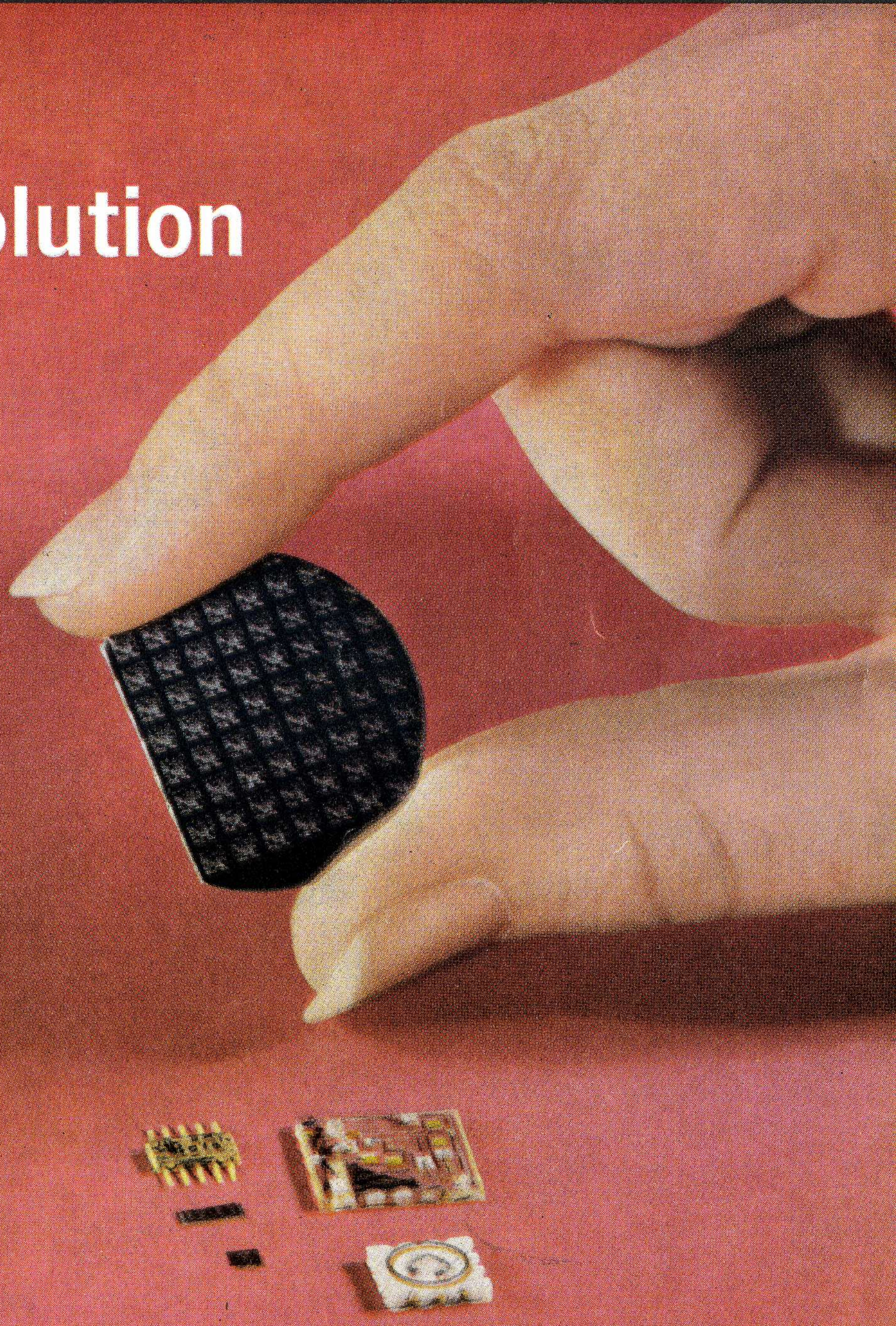
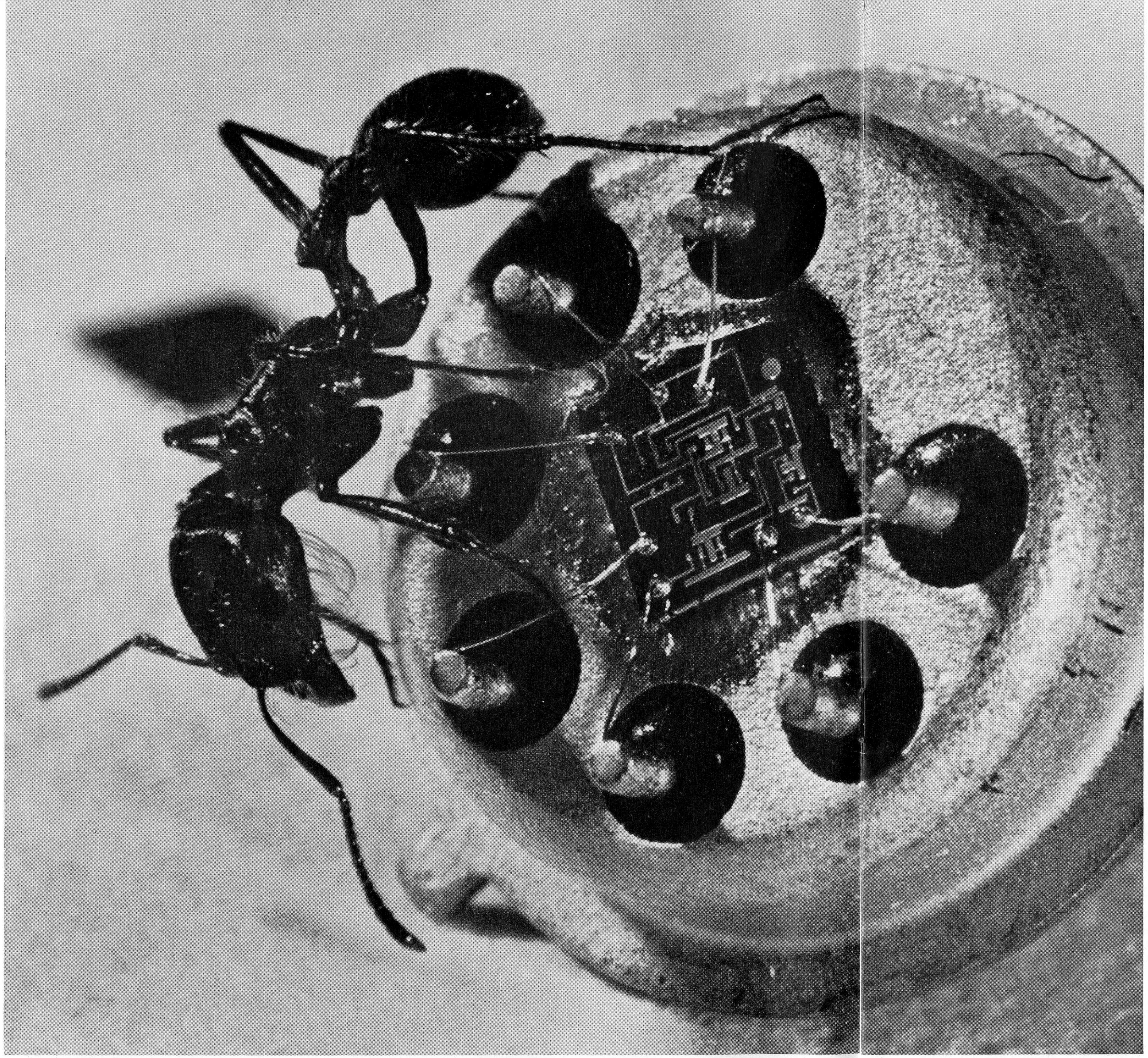
The next revolution in electronics



New technologies are forcing drastic changes on the fastest growing U.S. industry – with smaller-than-ever devices tackling bigger jobs

Special report



Medium-sized ant dwarfs a Fairchild integrated semiconductor circuit (black square) that contains eight transistors and 12 resistors in a solid block

Special Report

The new shape of electronics

Radically new techniques that swallow up components in ever-tinier package devices with multiplied powers promise to put industry through its severest shake-up yet

It's an industry like no other.

On the technological side, it has burst the bounds of electronics to become applied science. And this is technology growing at a rate that makes your head spin.

Unlike most industries, which started as crafts, this one started as theory. Perhaps more than any other, the industry is dependent on an intangible—ideas. While boasting a private language, it still has trouble defining its own terms.

To add to the confusion, you can't quite call it an industry in the usual, economic sense. For it is diffuse, spreading far beyond its original role in communications and broadcasting and becoming a part of manufacturers' operations in a host of industries. And it is in constant flux, with companies reorganizing, expanding, merging to adjust to ever-changing technology and markets.

New shape. But—for want of a better word—call it electronics, for that was the starting point for this new industry.

If the transistor and its brothers and sisters shook up the electronics industry, the tiny devices (cover and pictures) now under development will turn it upside down, reshaping the industry along new, unpredictable lines. It's as if someone were to present the transportation industry—all at once—with a motor that cost a tenth as much, ran 10 times as long between overhauls with one-tenth the fuel consumption, weighed 5 lb. instead of 500 lb., required little labor to produce, and still developed 300 hp.

At the heart of this "revolution" is integration—the disappearance of individual components, from transistors and resistors to coils and wires, into an ever-smaller whole that swallows up their separate roles. This is what happens in a so-called circuit function package. In one unit, it handles the sub-activities of electronics such as amplification, frequency conversion, and electronic switching.

Predictions. For the transistor and other semiconductor devices, Bell Telephone Laboratories, Inc., provided a cookbook of formulas to lead the way. In the new industry upheaval, there's no such recipe book. The approaches take many forms and many different names—molectronics, molecular electronics, circuit function development, integrated circuitry.

Whatever paths the industry may follow, there's no doubt about profound changes ahead. The electronics technology lab of the Air Force Systems Command predicts:

- A tenfold increase in reliability of electronic devices.
- A significant decrease in costs, as much as tenfold in some cases.
- A hundredfold decrease in size and in bulk material requirements.
- A tenfold decrease in power consumption.

The history of the electronics industry, of course, has been one of constant change. You can see that in what happened after scientists at Bell Labs first demonstrated the transistor in 1947.

Transistor boom. Since then, solid state devices have changed the industry's whole product mix. They have bred whole families of new companies and products, and created a new kind of technologically based competitive atmosphere. What was impossible to do with tube technology became possible with transistors and other semiconductor devices.

The transistor has been the star of the show. In 1961, transistor sales of $300-million almost overtook the $311-million of its older rival, the receiving tube—and more than half the tube sales were for replacement. Actually, the transistor outsold the vacuum tube by two to one for use in new equipment.

Deeper still. Even so, the transistor revolution was just a beginning. Most of the changes so far in electronics have been skin-deep, not basic. A transistorized electronic device looks and acts like a smaller version of its tube counterpart.

The new products now in or nearing mass production are much more than transistor-type components. And their uniqueness stems not just from their minute size, for miniaturization and microminiaturization of components is an old story.

The difference comes from basically new approaches to the problem of designing electronic systems. Study of the basic nature of materials helped produce the new devices, as it also did with transistors. But this time the changes will affect the systems makers as much as components makers.

Rough road. Not that the new devices will have a complete walkover. Despite the industry's predilection for the new and different, the ledgers of electronics companies are deeply stained with the red ink of wrong or premature guesses [BW Mar.31'62,p62]. So there's natural hesitation to reshape companies around these new devices.

Yet, the industry has come so far in purely technical solutions that it can hardly resist the wave of change. It is beginning to grapple with reorganization problems—and these will make the tube-transistor battle look like a minor skirmish.

Turmoil. Signs of the turmoil are already appearing. If the big companies can't or don't reorganize to meet the challenge, they may be outmaneuvered by smaller, more flexible companies—just as Texas Instruments, Inc., outflanked the giants in early stages of the semiconductor battle [BW Mar.26'60,p74].

The systems makers are coming up against a hard decision. They will have to integrate effectively from raw materials through the finished system, or turn over much more responsibility for making their products to component suppliers. Neither course is an easy one.

The new electronics

I. What the transistor left undone

You get an idea how far the new technology has developed by looking at the disc of silicon metal held in the girl's fingers on the cover. It was plucked right from a production line at Fairchild Semiconductor Corp. in Palo Alto, Calif.

The disc, about as thick as several pages of this magazine, contains some 60 very small squares. Each square is a portion of a logic circuit of a computer. And in each square are eight transistors, plus resistors, plus the wiring necessary to interconnect them. The circuit weighs less, and takes up less space, than a soldered joint between two wires.

To finish the electronic circuit, or functional block, the individual squares will be cut out, tested, mounted inside a standard transistor case. Fine gold wire leads will be bonded to eight connection points on the tiny square, from the leads of the transistor case. The pea-sized result looks like a transistor.

Yet it is the equivalent of a whole boardful of components.

Answer to a prayer. This talented, pea-sized midget, and its brothers and cousins, already coming off other production lines, provide an answer to a dilemma posed for the industry by the triumph of the transistor. For the transistor has played the role both of hero and villain.

It's the hero because it proved far more reliable than the vacuum tube and so made it possible to build larger and larger electronic systems. But, at the same time, transistorized electronic products tend to have more parts, more interconnections than their vacuum-tube equivalents —until the number of parts threatens to become almost fantastic.

Jack A. Morton, vice-president of Bell Laboratories, calls this "the tyranny of numbers." Herein lies the dilemma. For, in the last 20 years the number of components in electronic systems has increased from less than 100 to more than 200,000 in a single device—and without a change in technology the numbers could go on multiplying endlessly.

If electronics is to take full advantage of its capabilities in large systems, the number of parts—and the cost—has to come down. Some of the new methods eliminate most of the direct labor, up to an almost incredible 99% of the bulk, and do away with more than 90% of the interconnecting wires and soldered connections.

Transistor's feat

A look at how far electronics has come in the last two decades throws some light on what's involved in its "tyranny of numbers" dilemma, and in the new technological tricks aimed at throwing off that yoke. If they're such an obvious answer to the industry's prayer, why didn't they come along sooner, before the numbers problem became so acute? And why are they coming along now in such a rush?

It's a story of fast growth, and the complications that come with it.

Up from behind. Only 20 years ago, electronics was devoted in the

Amplifier shrinks from tubes (left) to transistors to microminiature to integrated circuit held by Lear's David Moore

main to products associated with radio broadcasting; it ranked about 40th in dollar volume among manufacturing industries. Now it ranks about fifth.

According to Electronics magazine, the McGraw-Hill publication that gave the industry its name in 1930, electronics products account today for better than $16-billion in sales, and promise to pass the $20-billion mark sometime in the mid-1960s.

Already, electronics has spread all over the map—into data processing, machine tool controls, industrial instruments, and incredibly complex weapons systems. Within a decade, say such industry leaders as Morton of Bell Labs and Daniel E. Noble, executive vice-president of Motorola, Inc., the electronics industry will be the biggest of all.

Change of heart. But electronics didn't put on this fast spurt, with its promise of future eminence, without changing its original ways.

Until fairly recently, electronic techniques were used only where nothing but electronics could do the job. It was, so to speak, a last resort technology. It was used where extreme high speed was necessary, as in generating high frequency signals used in radio transmission, or stepping up the power of almost immeasurably faint electric signals gathered by radio antennas. Until recently, Western Electric Co., Inc. —for example—tried to avoid using electronic techniques, except where absolutely necessary, because of their inherent unreliability and high maintenance cost.

In the last few years, however, the transistor and electronics of the solid state have wrought a tremendous change. In solid state electronics, nothing moves except electric current—electrons. There is nothing to wear out or get used up. Theoretically, component lifetime should be nearly infinite, and first cost should approach final cost.

That this isn't yet quite true is exactly what is spurring the scientists to further research. They are making rapid progress in finding out more about basic materials and their behavior, in order to be able to turn the theoretical promise of infinite life into a physical, producible, and reproducible reality.

The transistor also introduced a new, higher order of reliability. A high quality transistor is likely to be even more reliable than the soldered joint that connects its leads to the rest of the circuit. And, once you know how, a transistor is very easy to make.

New hurdle

Technological progress brings its own complications, however. Semiconductors, a brainpower intense business as contrasted with the capital and labor intense business of making tubes, resistors, wires, and coils, moved component development ahead incredibly fast. But by the mid-1950s, it became apparent that another hurdle was developing. Engineers recognized that what was holding back electronics circuitry was not the active components such as tubes and transistors, but the passive components—the wiring, the resistors, the soldered connections.

Network. Essentially, any electronic device takes an electrical signal and changes it in a distinct and deliberate way, or routes it to a particular place. Thus, a radio receiver takes very weak high frequency signals from the air, sorts out a particular one, amplifies it, changes it from alternating to direct current, feeds the varying direct current to a coil of wire on the speaker. And the coil moves the speaker to produce sound.

A computer circuit handles pulses of current—the order and timing of the pulses cause different types of switching circuits to react, much as pushing certain buttons on a typewriter puts selected mechanical linkage into action. Of course, a computer does it much faster—speeds are heading toward tens of billions of pulses per second.

But to perform a single electronic function such as amplification or electronic switching—what engineers call a circuit function—traditionally requires a small network of components. There's usually one so-called active component, such as a tube or transistor, that does the work of amplifying or switching. Then there's a batch of passive components—resistors, capacitors, coils, and wires—that feed the tube or transistor the right amount of signal and power so it can do its job, and adjust the output for presentation to the next circuit function.

Leading the attack. With transistors and other semiconductor devices taking care of the problem of the active components, the industry turned its guns on the interconnections and passive components.

Birth of an idea

The problem of how to simplify the passive components, the soldered interconnections, and the myriad parts in larger, solid state systems is terribly complex. It almost forces the industry to turn to some form of standardized circuit function packages. It would be possible, some researchers claim, to make up almost all known electronic devices from a limited number—perhaps less than 200—types of standard circuit functions.

But a logical concept may not be immediately practicable. The industry has not been able even to standardize simple components very well. The industry's organization—with systems designers or device manufacturers who determine circuit design in one group, component suppliers in another—stands as a roadblock to circuit function standardization. And worse, there's the question of who will make the circuit function package, the systems manufacturer or the component supplier?

The circuit function package is something in between—a sort of subassembly of components. Traditionally, the circuit designer has demanded full control over every tiny component in the entire circuit. That's the only way he can get optimum efficiency, produce slightly better performance, cut costs, satisfy his creative urge, or get around a patented design.

Pressure for change. So there's inherent resistance in the industry to standard circuit function packages made by component manufacturers. But as electronic devices get more complicated, the forces multiply that are pushing the industry into the circuit function pattern.

The push comes not so much in the relatively simpler consumer electronic goods as in the dollar-fertile military market and the lush computer field. It comes from use of repetitive circuitry in large computers, the need to simplify maintenance, the use of electronic devices so miniaturized that they can't be repaired in the field.

A large-scale digital computer, for example, may use thousands of identical circuit boards, usually called modules, that plug into the main frame. It may pay a large manufacturer to mechanize production of these boards on a circuit function basis, even though each board is made of a collection of traditional components.

In military electronics, it's necessary to simplify field maintenance to the point where men with no more mechanical experience than changing a light bulb can repair a defective unit in a hurry. The only way to do that is to use interchangeable, or modular, plug-in units—and the convenient module is a circuit function package.

Rebuff. With such pressures, it's hardly surprising that growth-minded components manufacturers have tried to develop and market "packages" or subassemblies of components. But systems manufacturers—the companies turning out the end products—usually have rebuffed these attempts.

The trouble was that component makers tied their efforts to make circuit packages to traditional components. Thus, the advantages they offered were largely variations in packaging—and this often proved more expensive or less flexible than standard techniques.

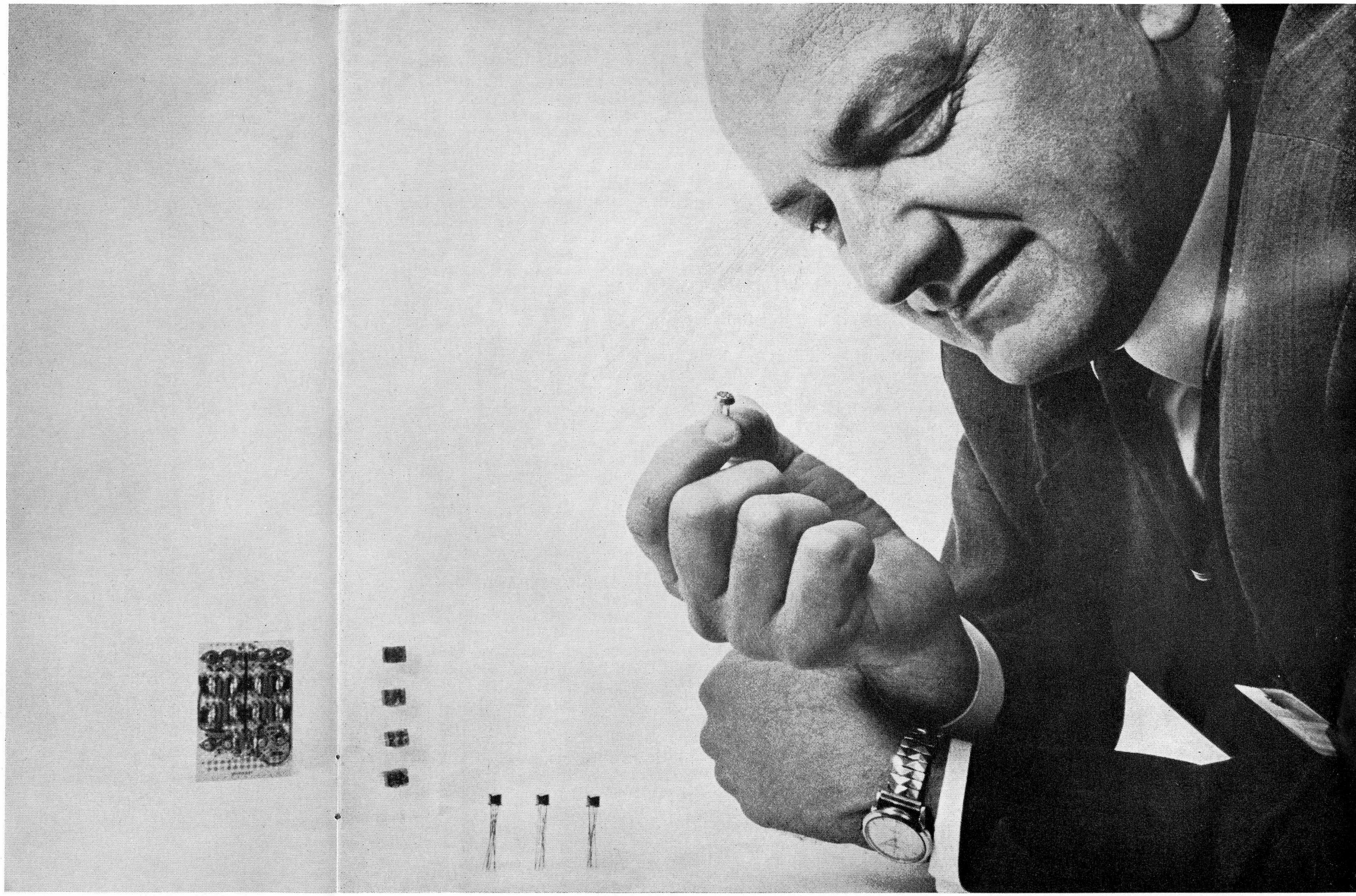
Final push

But the complexities of manufacture and multiplication of components—Morton's "tyranny of numbers"—know no end. With the number of components in large computers reaching 200,000, William Webster, director of Radio Corp. of America's electronics research, predicts that future electronic systems may use as many as 10-million components.

But with such a number, unless the components are almost incredibly reliable, the system won't work.

One way to solve the numbers problem is to make components with special care, and follow up with complex sampling tests and aging tests. The Minuteman missile is built just that way. Every component that goes into the Minuteman has a pedigree on its own punched card, recording when and where it was made, tested, and retested.

But testing and proving out these components costs much more than making them in the first place. It's an inside joke in the industry that if all components had to be made the way Minuteman components are made, the military electronics bill would be higher than the gross national product. And it might well be.



Chmn. H. Q. North of TRW Electronics holds its latest integrated circuit; it and three below are equivalent to transistorized and microminiaturized circuits (left)

II. Three roads to a new technology

The only real solution to the industry's dilemma is to change drastically the methods of making electronic devices.

This is why such new methods as semiconductor integrated circuits, thin film techniques, and molectronics offer such an alluring prospect. It's also why they pose such deep problems for the industry.

To the nanosecond. One big problem is that there's no single path to follow, and each method is costly to develop. Everyone has about the same goal: greater reliability, lower unit cost, better performance (which usually means the ability to operate at higher speeds).

Size reduction is no longer the prime requisite, since microminiature standard components are small enough to meet almost any conceivable problem of compaction. But size reduction is nice if you can get it, because in the future some systems will operate at such high frequencies that the speed of light puts distinct limits on their physical size.

For example, some computers now on the drawing boards will operate at switching speeds measured in a unit of time called a nanosecond—one-billionth of a second. Light or electricity can travel less than a foot in that time. So a computer 10 ft. long might perform 10 switching operations at one end before the first signal from the switching action could get to the other end of the machine.

Triple play. In its search for more reliability, lower costs, and better integrated components, the industry is focusing on three main approaches. Various branches of the military are spending millions of dollars in support funds for research and development on these three approaches: microminiaturized modular circuits, thin film techniques, and semiconductor networks.

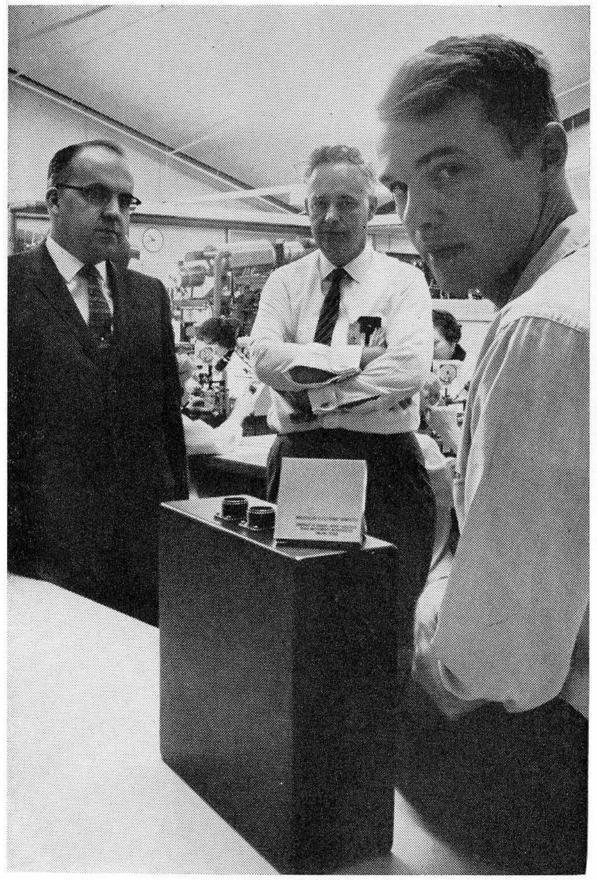
Modular circuits

Packaging microminiaturized components in standard-sized modules, using more reliable interconnection techniques such as welding instead of soldering, can yield greater reliability as well as a very satisfactory reduction in size.

This is essentially a present-state-of-the-art approach, and offers maximum flexibility for the circuit designer. It also fits the traditional industry pattern.

It offers little in the way of cost reduction, however. And in the opinion of the Air Force, Bell Laboratories, Texas Instruments, and many others, it does little to solve the tyranny of numbers problem.

It's likely, though, that methods making use of more or less standard techniques will always have a good share of the market, because of the flexibility that they offer and the minimum cost in low production volume.



First molectronic device, Texas Instruments' tiny computer, sits like jewel box atop airborne computer it duplicates. TI's Dr. W. Adcock, Pres. Patrick Haggerty, and Harvey Cragon look on.

Thin film techniques

Thin film techniques have already proved economically competitive with standard circuitry in miniaturized electronics. They may well be able to compete successfully with consumer product components as methods of mass-producing them are perfected.

Simple. The most common thin film techniques are relatively simple. Metal, vaporized in a vacuum, is deposited through a mask onto a glass plate. The pattern this makes forms the electrical leads and passive components in the circuit. Fine lines in the pattern act as resistors. In subsequent operations, insulating layers can be put on the plate, and these covered by more conducting film patterns, so as to provide an interconnected resistor and capacitor network. Active devices, such as transistors and diodes, are attached later. The glass square on the cover picture is a thin film circuit made by Lear, Inc.

This type of circuitry cuts down significantly the number of materials used and the number of interconnections needed.

Promise. Research on a variety of materials that can be used in thin film circuits shows tremendous promise. Magnetic thin films look like a best bet for low-cost, high-speed computer memories.

Sperry Rand Corp. is now making a computer with a small thin film memory. Burroughs Corp. both uses and sells thin film memory devices. International Business Machines Corp. and others have demonstrated thin film memories about 100 times as fast as the standard high-speed memories using ferrite cores that most present-day computers use.

Servomechanisms, Inc., has a magnetic thin film device that converts a voltage into a pulsed readout that a digital computer can use. It's a very good example of a one-piece circuit function device that performs the function of a whole array of standard components.

On the horizon. Further in the future, some believe, are active thin film devices of another sort. These depend on unusual phenomena that occur when insulating layers get so thin they can be pierced by electrons at low voltages. These phenomena provide a function that's capable of amplifying a signal. But there's still some question whether it will be possible to control the fabrication process closely enough to make reproducible devices.

RCA has demonstrated some experimental thin film transistors. Other companies are working on methods to lay down single-crystal semiconductor materials on insulating substrates—the glass or ceramic bases used in building the devices. However, this is still far from commercial production.

Semiconductor networks

Semiconductor networks have been the industry's big surprise, in the speed with which they have developed into practical units. A long list of companies that have demonstrated working semiconductor networks includes Texas Instruments, Fairchild Semiconductor, TRW Electronics, Inc. (formerly Pacific Semiconductors, Inc., a subsidiary of Thompson Ramo Wooldridge, Inc.), Motorola, Inc., International Rectifier Corp., Westinghouse Electric Corp., Philco Corp., and Sperry Semiconductor Div. of Sperry Rand.

Two new companies have also joined the parade—Teledyne, Inc., in Los Angeles, and Signetics Corp. in Sunnyvale, Calif. Many others are working feverishly and will be announcing product lines this year.

Attraction. The primary attraction of solid semiconductor networks is that they are potentially cheap, reliable, and small. They contain both active and passive components in a single-crystal structure that is essentially the same as a diffused transistor—one, that is, made by introducing impurities into the surface of a pure crystal by heat treatment. They eliminate component interconnections in the usual sense, except for input and output leads.

In addition, the whole circuit is exposed to a very limited number of processing steps—very few more than it takes to make a modern-type diffused transistor. That's important from a reliability standpoint.

Thorough control. In making a semiconductor network, everything that happens to the material is controlled thoroughly. The starting material is a thin slice of super pure single-crystal silicon—one of the purest, and therefore most controllable, basic materials any industry has ever used.

One of the first processing steps is to grow an oxide layer on the polished surface of the silicon slice. This acts in the handy double role of protective covering and masking material for subsequent steps.

Transistors, resistors, and diodes (which can also act as capacitors) are produced by etching away areas of the oxide coating, then allowing controlled amounts of impurities to diffuse into the silicon. In some processes, the oxide layer builds up again during the diffusion process, providing further protection from unwanted impurities.

After a few diffusions, all that's needed to complete the circuit is an etching step to uncover the spots where external connections are needed. A metallizing operation deposits a thin film—usually aluminum—that interconnects these exposed spots.

That completes the circuit except for input, output, and power connections. These are usually made by gold wires attached by a cold welding process known as thermocompression bonding.

Other processes can be brought in if necessary, such as a method of growing layers of semiconductor single crystal on the original wafer by gas deposition. This method, called epitaxial growth, produces very sharply defined boundaries between different impurity levels in the semiconductor. Epitaxially grown layers can be laid down much faster than the usual impurity layers can be diffused.

Researchers at Motorola's Semiconductor Products Div. are particularly optimistic about this technique in solid semiconductor circuits.

Computer promise. Presently, integrated semiconductor circuits look most promising for the electronic jobs performed in computers—largely very fast on-off switching operations. Such circuitry doesn't require the close tolerances essential in so-called analog circuits, which are used in such continuous signal devices as radios and television sets.

However, Westinghouse has developed a number of analog circuits by such methods; the first ones went on the market earlier this year, with sampling prices starting at $100 each. Air Force scientists believe the method is promising for low-power radio circuits, except for a few functions where extreme stability is necessary.

What's molectronics?

A source of some confusion and much bickering in the industry is the concept of "molectronic" circuits or molecular electronics.

As defined by the Air Force—which has supported large projects at Westinghouse, Texas Instruments, and Motorola—the molectronic objective is to find ways to perform circuit functions more reliably and at less cost by utilizing the inherent electrical characteristics of materials, rather than by soldering together a bunch of separate components to do the job.

From this point of view, semiconductor integrated networks are one form of the molectronic approach. But many other materials such as crystals and magnetic substances are being vigorously examined for their electronic properties.

Strangely, the electronics industry hasn't taken kindly to the concept—or the word molectronics itself. "We don't deal with molecular phenomena," a physicist told Business Week. "We're more concerned with the behavior of electrons, and that's on the subatomic and quantum levels, not the molecular level."

Whether it's the right word or not, molectronics has certainly helped get the industry off to a burst of technical activity. The concept has started scientists and engineers looking at products in a different light. Many scientists feel such a new look is long overdue, because the industry has just about exhausted the combinations and permutations of standard components.

Westinghouse bet. Westinghouse likes both the word and the concept, and has established a molectronics department in its components division. It has been actively analyzing its end product lines to search out possible applications for semiconductor network techniques. As early as last summer, the heads of the department were confident that molectronic techniques could compete in price with standard circuitry, even in some consumer product lines.

Last month, Westinghouse quietly

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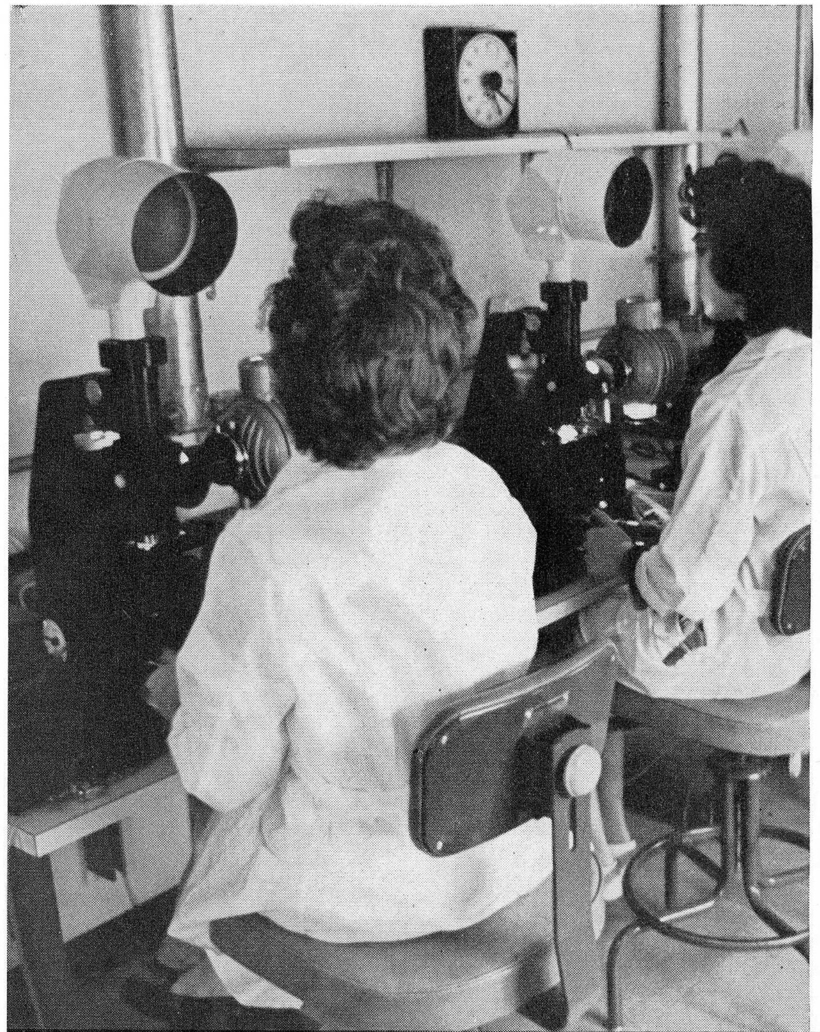
released details of a radio receiver it had delivered to the Air Force as part of a contract in connection with the Air Force molectronic program [BW Mar.10'62,p140]. The receiver was only partially "molecularized," but represents a considerable step forward in the art of solid state electronics. According to Harrell V. Noble, director of the Air Force electronics technology laboratory, it is the most complex device yet demonstrated showing semiconductor networks for radio circuitry.

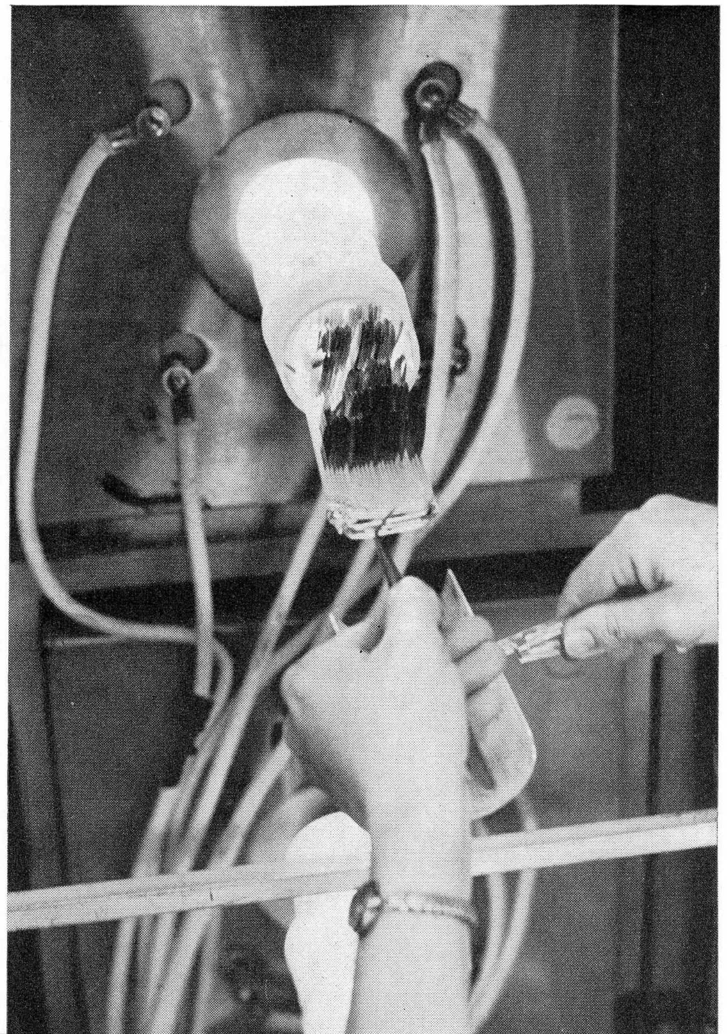
Battle of methods

No one in the industry expects thin films or semiconductor networks or any single method to take over all electronics. Researchers are merely trying to set goals and establish cost figures in order to select the right techniques. All of the new technologies require a sizable amount of capital equipment and a huge investment in research and engineering. Large-scale production means commitment of millions of dollars.

There's a lot of intra- and inter-company rivalry over which technique is likely to be the best bet. There's even interservice rivalry between the Air Force, which has been supporting research in molectronics, and the Army's Signal Corps, which has backed RCA's micromodule program.

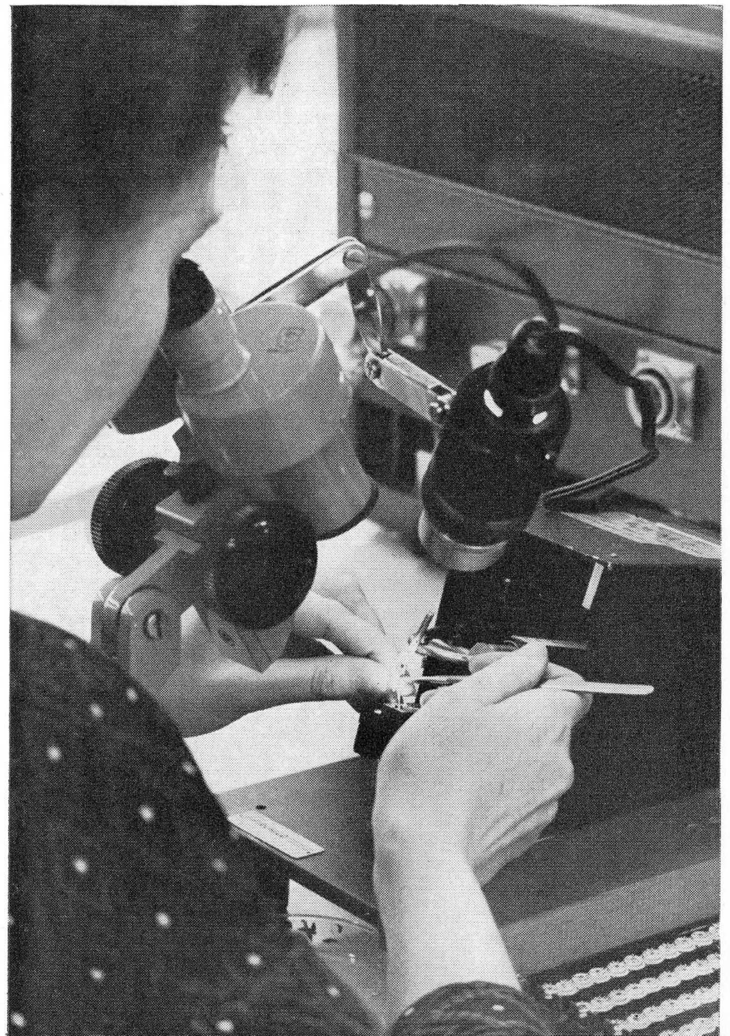
Some big markets are at stake, and every large maker of systems and components is trying to foresee which way the main stream will go—and still hedge his bets by keeping up with other techniques, too. This leads to tremendous duplication of effort; it's probable, indeed, that as much as 90% of the industry's R&D effort is mere duplication of work. And competition will be reflected in price cutting just as rough as the battle for transistor markets. It may be rougher, since survival is at stake for some companies.





Making an integrated circuit

Steps at Fairchild for semiconductor circuits resemble those for transistors. Girls (above) in yellow-lighted room use photoprinting technique to put masks on polished slices of silicon. Then dozens of slices containing up to 60 circuits each are put into muffle furnace (above), where impurities are diffused into wafers to form transistors, diodes, resistors.



After several masking and diffusion steps, the wafers are tested; then the 60 or so complete networks on each wafer are cut apart and mounted on bases similar to transistor cases. Such cases are used primarily for convenience.

Final step, after still more testing, is to put the cap on the transistor case. This is done in an inert-atmosphere dry box to minimize chances of contamination; girl uses gloves like those in foreground, projecting inside the box.

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III. Shaking up to do the new job

When an industry revolutionizes the way it makes products—as has been happening in electronics—it is bound to go through a shakeup. In the case of the electronics industry, the repercussions run even deeper. For it is an industry that translates scientific knowledge into products faster, more effectively, and at lower capital cost than any other.

And, with the industry's traditional organization and economics thrown out of kilter, the problems for management pile high.

Strange economics. The process of making semiconductor circuits and other package devices may look simple to the outsider. But it's one of the trickiest ever devised. It demands remarkable engineering skill and knowledge of materials almost unrivaled by other industries.

That's what makes the economics of it so strange. The materials cost is insignificant. The labor content is practically nil—a few minutes direct labor per device, at most. The capital equipment needed to turn these devices out by the thousands per week is not particularly costly by other industry standards. Custom tooling costs for specific devices aren't particularly high, either; for a single device, special tooling might cost from $500 to $5,000.

But research and engineering costs are preposterous by the standards of any other industry. There is no way to isolate them: The semiconductor industry, if it has discovered anything about management, has found that there must be no barriers between research, engineering, and production.

In this business, a production problem is infrequently solved by a clever mechanic. A solution may require the efforts of a team of chemists, physicists, and mathematicians. It often involves breaking into new areas of knowledge of the basic nature of materials. Texas Instruments, one of the leading companies in the new art, estimates the total cost of its technical effort last year at $39-million, on net sales of $233-million.

Tougher nut. Even with high-level scientific support, just knowing how to make a device is only part of the battle. Knowing what to make is an even harder problem for an electronic company's management—because that question, unlike production problems, has no orderly physical laws to guide the answer.

Take the case of two components in the earlier stages of semiconductor development [BW Mar.26'60,p74] —the four-layer diode, a very fast switching device invented by William B. Shockley, and the Esaki, or tunnel, diode developed by Leo Esaki. Both are marvels of simplicity, economy, and performance.

Undoubtedly both will eventually find markets. But, so far, circuit designers have generally preferred to use other, more familiar techniques to do the job. Even in electronics, the need to change old habits must be clear and indisputable.

New industry shape

Nevertheless, the fantastic promise of the new thin film and semiconductor network devices exerts a tremendous, almost irresistible pressure on manufacturers to get the jump on competitors. It's this that's shaping the organization of the industry into new, unforeseen patterns.

The appearance of the more complex circuit function devices, falling in the middle ground between sys-

Progressive shrinkage in computer circuits: From right, Chuan Chu, Univac Div., holds electron tube module; Burke H. Horton, Univac, a transistorized version and a subminiaturized digital device for an airborne computer now in production; and W. R. Sittner, Sperry Semiconductor, a tiny integrated semiconductor circuit.

tems and components, is forcing companies to integrate vertically—from basic materials through final systems.

Large and small companies alike are responding to the pressure with organizational changes, mergers, acquisitions. It's getting hard to find an electronics-based corporation that isn't reorganizing or hunting for mergers.

IBM's move. Perhaps the most outstanding recent move is International Business Machines Corp.'s almost crash program to set up a components division after years of depending almost entirely on outside sources. Next to the U. S. government, IBM is the nation's largest buyer of semiconductor devices.

Though IBM has kept the electronics components industry on tenter-hooks by not defining its specific intentions, no one doubts the size or seriousness of its effort. It already had a powerful scientific and engineering crew in semiconductor research development and production engineering. Indeed, IBM built some of the automatic transistor assembly machines used by Texas Instruments, with which it has for years had a joint research and development program.

Now IBM is adding to its components string such topnotch experts as W. J. Pietenpol, who recently came to IBM as manager of component development. Pietenpol, widely respected in the industry as a semiconductor pioneer, was with Bell Laboratories, then became vice-president and general manager of the Semiconductor Div. at Sylvania Electric Products, Inc.

IBM would hardly be hiring men of this caliber—and salary—if it were not serious about making its own components. Its prime aim is to recapture control of the most critical components, which in essence are responsible for the ultimate performance of its products.

Bandwagon. Smaller companies are following giant IBM's lead, though not on the same scale. For most of them, the potential internal market for components is too small to soak up a full-scale production, so they sell outside, too.

One typical move is the setting up of HP Associates as an offshoot of Hewlett-Packard Co., Palo Alto, Calif., a maker of scientific instruments. HP Associates began as a semiconductor facility of the parent company, to make special components that Hewlett-Packard found it could not buy.

Lear, Inc.—recently merged with Siegler Corp. [BW Feb.24'62,p82]—also decided that an internal component development and manufacturing facility was necessary. It spent thousands of dollars developing a method to make thin film circuits for use in its own products—hoping also to license others to use the equipment it developed.

Recentralizing. Of course, vertical integration in electronics is nothing new. The older and larger companies in the industry—such as RCA, Westinghouse, General Electric Co., Raytheon Co., and Sylvania—began as integrated companies. But they decentralized long ago, finding the task of making both components and end products too different to keep under the same roof.

Now, most of these companies are reexamining their organizational structure to make components manufacturing more sensitive to the special needs of other product divisions.

These are not merely belt-tightening maneuvers after a year of bad profits in the semiconductor components industry—though there's no doubt the business situation helped the trend along.

Westinghouse recently brought its semiconductor and other component divisions under one organization. So did Thompson Ramo Wooldridge, which melded several divisions with its semiconductor subsidiary, Pacific Semiconductors, Inc., to make TRW Electronics, Inc.

Another big company, Motorola, Inc.—which didn't get into the component-making business until it started to make transistors in the late 1930s—has recently set up a brand-new group to make solid state circuitry of various types. Motorola hopes the new group will grow into a major segment of its corporate family.

New competition

For the established electronics companies, there's also the threat of being outmaneuvered by new, smaller companies with greater flexibility. So far, though, the new technology of semiconductor networks and integrated circuits hasn't brought a great proliferation of new companies on the scale of the semiconductor revolution.

Part of the reason is that money is tighter, and capital is not so easily come by. Besides, this new technology takes considerably more knowhow—it's at least 10 times as difficult as making transistors alone. Marketing is a problem, too.

Nevertheless, some new companies are plunging bravely into this untried field. Two outstanding ex-

amples are Signetics Corp., of Sunnyvale, Calif., and Amelco, Inc., a division of Teledyne, Inc. of Los Angeles, Calif.

Systems maker. Teledyne was formed by its president, Dr. Henry E. Singleton, former vice-president of Litton Industries, Inc., and its executive vice-president, George Kozmetsky, also from Litton. They were joined recently by Jay T. Last and Jean A. Hoerni, two of the founders of Fairchild Semiconductor—and considered two of the most knowledgeable men in the field.

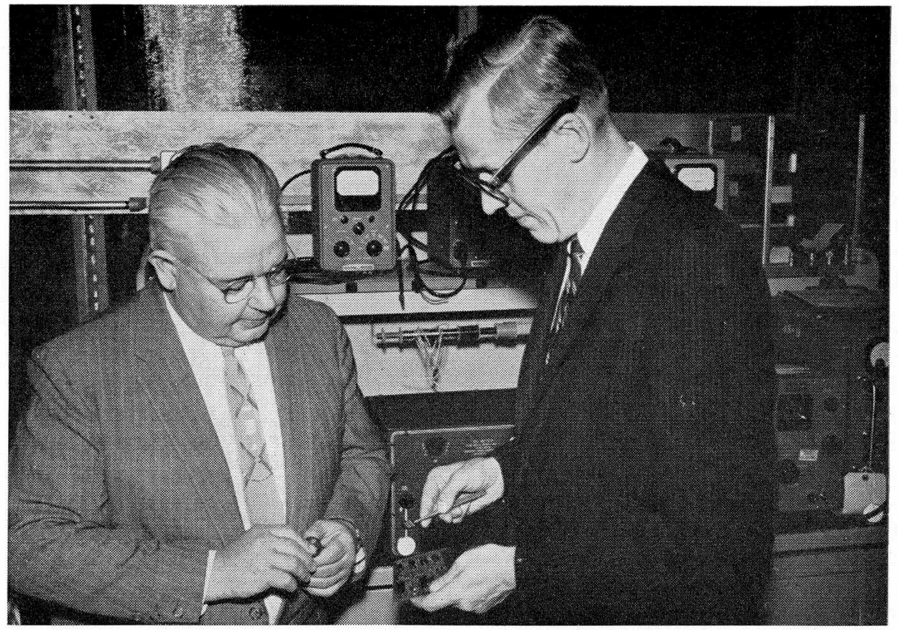
Teledyne is going after systems business, basing strategy partly on its capacity to manufacture integrated circuits. It may also sell the semiconductor networks that it is building into its own systems.

The company started in October, 1960, with the two founders, now has 650 employees. It chalked up sales of $4.5-million last year, and Singleton says he expects to double this in 1962.

Custom job shop. Signetics Corp. has rather different ideas. This company was formed last year by a group of engineer-scientists from Fairchild Semiconductor headed by Dr. B. David James, now Signetics president. It will make semiconductor networks on a custom basis.

"We intend to be a job shop," says James, "and we don't think we will have too much trouble getting people to come to us early in the design stage of equipment development, once we prove that we can produce."

Signetics' engineer-scientist team is convinced that within a year it will be able to turn out circuits to customer specifications in approximately the same lead time required by standard circuitry. Dr. James predicts that the cost of semiconductor networks will be competitive with standard circuits within a year.



Directing Air Force molectronics program are Harrell V. Noble and Richard Alberts of Electronics Technology Laboratory at Wright-Patterson Air Force Base.

Two answers

These two new companies, Teledyne and Signetics, represent opposite approaches to the basic question: Who is to make the new integrated circuit packages? Teledyne's Amelco is tackling them primarily as part of a systems-making setup, Signetics as an independent supplier. But most companies still are undecided on the make-or-buy question—and don't agree as to which way the scales will tip.

Pres. Patrick E. Haggerty of Texas Instruments points out that many of TI's best customers now have their own manufacturing divisions for making semiconductor components but, nevertheless, continue to buy TI components. He's convinced the same thing will be true for integrated circuitry: Even if the customers develop their own facilities for producing integrated circuitry, he thinks, they will continue to buy integrated circuits TI can make better and more cheaply.

Many in the industry disagree. The device manufacturers—from giant RCA and GE down to the little job shops—take great pride in their circuit innovations, and there will be great resistance to standard integrated circuitry that can be bought from a supplier. Some systems makers argue, too, that it would put too much responsibility for the system on the component supplier, and reduce the end product manufacturer to a final packager.

Sell-or-not sell. Dr. H. W. Welch, heading the Solid State Systems Div. at Motorola, points to another face of the same problem.

"When you make integrated circuitry," he says, "there's not only a tougher make-or-buy decision to be made, but management has to make some important sell-or-not-sell decisions. If we come up with a really good integrated circuit, should we sell it as a component, or keep it inside the family as a proprietary product that gives us a significant lead in producing a system?"

Motorola has a very large semiconductor team, and a small but effective force at work on thin films and magnetic materials. Welch's division is turning out the first thin film circuit package for a consumer product—a circuit for a very small hearing aid, the Dahlberg Miracle Ear. So far, Motorola has not seen fit to offer the circuit package to other hearing aid manufacturers.

Explosive patterns

The answers depend in part, of course, on how the markets for the new integrated devices shape up. So far, the market for semiconductor networks and other packaged circuits has not been defined even in the broadest terms. But the experience of pioneer manufacturers indicates an explosive growth pattern—a fast climb from a jerky take-off.

In sharp steps. Fairchild Semiconductor has had its Micrologic semiconductor networks on the market for more than a year, and thinks it shares a significant lead in the field with Texas Instruments. But it's still feeling its way.

T. H. Bay, Fairchild's marketing manager, describes the initial sales pattern as a series of sharp, upward steps. When Fairchild introduced its first Micrologic networks a year ago, industry reaction was sluggish.

Bay thinks people just "wanted to get hold of them and put them on an oscilloscope to see what they were like."

Another, more complex Micrologic circuit, introduced last May, did no better. But the announcement of another circuit at the Western Electronics Conference in August seemed to spark a real change.

"In the latter part of August—I can almost pin down the exact day," says Bay, "we started getting orders for hundreds of units." Fairchild isn't sure just what happened. But Bay thinks people wanted to build an operating device to try out, and needed hundreds of micrologic elements for a system with enough complexity for a real checkout.

At any rate, the sudden demand put the company in a different kind of bind. The slow sampling start had convinced Fairchild executives they had most of 1962 before they would need production volumes of, say, 10,000 a week. The spurt of orders called for immediate production. By the end of 1961, Fairchild had sold close to $1-million worth of Micrologic. As for 1962 sales of Micrologic, Bay shrugs: "Maybe $4-million, maybe $40-million. More likely, in between."

Steady growth. Haggerty of Texas Instruments reports much the same pattern in initial sales of his company's Solid Circuits, introduced last October. TI sees a steady growth pattern for integrated circuitry, with industrywide sales climbing to a point between $150-million and $200-million by 1968.

Enthusiasm for integrated circuits runs very high at TI's Apparatus Div., which is primarily engaged in producing sub-systems for military electronics. The division turned out a tiny molectronic computer for the Air Force in only nine months. Since then, its Solid Circuits have improved considerably.

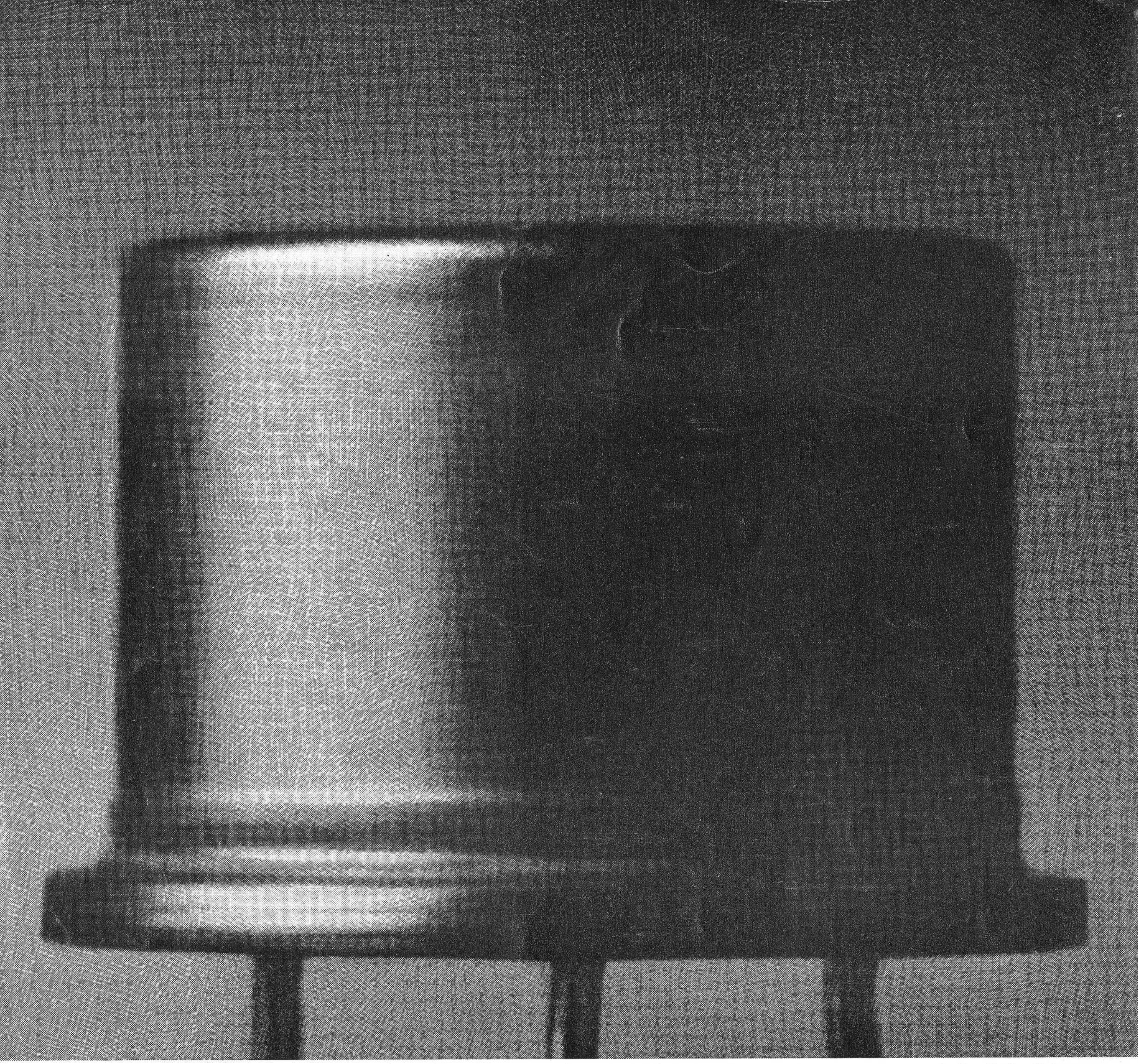
The division manager, pointing to a microminiaturized airborne computer about 1 ft. in diameter and 6 in. thick, says confidently: "We'll be able to cut the cost of stuff like this by a third, and it won't be any bigger than your fist."

Outlook. As the industry reorganizes, TI will remain primarily a component supplier, according to Haggerty and most of his executive group. Haggerty points out the component suppliers have always supplied the stepping stones the circuit designers need to produce better end products. But the sales end now will have to work even more closely with customers' engineering. Moreover, TI does not intend to turn away business in the systems field.

But to support the expensive research in basic sciences and technology, production volume has to be fairly high for any device. Thus, the knotty question facing TI and every component maker is whether highly specialized circuit-function devices—which will never match the more general purpose tube or transistor in volume—will pay their way, enough to cover much higher development costs.

Most companies are convinced they will.

The new electronics



Magnification: 20 times

Old hat

Six months ago this Fairchild transistor was the newest thing on the market. Now there's a better one. Made by Fairchild. Meeting the challenge of your own products is a criterion of leadership in this fast-moving, fast-changing industry. That's why the search to make it (1) work better, (2) do more and (3) cost less—goes on 24-hours a day at Fairchild.

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