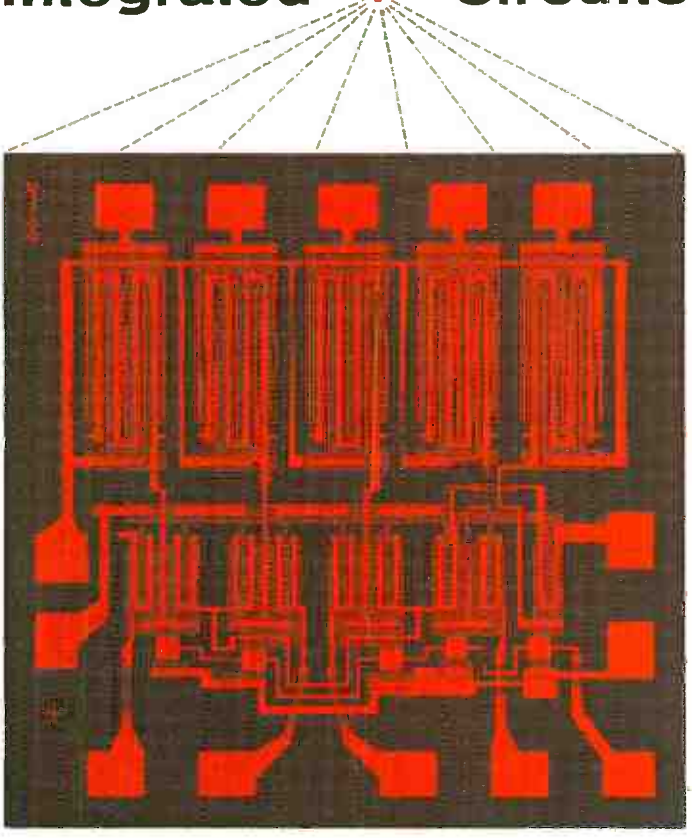
DECEMBER, 1967
VOL. 16, No. 12

The Lenkurt DEMODULATOR

Integrated Circuits



LENKURT ELECTRIC . . . *specialists in* VOICE, VIDEO & DATA *transmission*

Integrated circuits promise increased reliability and lower cost in addition to minute size.

Microelectronics, until very recently, was mainly concerned with packaging discrete components in as small a space as possible. First electron tubes and then transistors were packed tightly with diodes, resistors, coils, and capacitors to make miniaturized circuits. With vacuum tube technology, engineers were proud to get something like 6000 components into a cubic foot of space. Transistors replaced tubes, and upped the packing density to about 100,000 parts per cubic foot. And now, while it may seem like a lot of room, 10-million components might fit into that same cubic foot through the use of integrated circuits.

While all of this space saving is impressive, it is not size alone that makes integrated circuits attractive—in fact imperative—to the future of electronics design. The real savings come in manufacturing cost and reliability.

Reliability vs. Interconnection

In all microelectronics the basic motivation is to control complexity. More sophisticated needs bring more complex devices and gigantic growth in the number of parts. So great is this increase in individual items in the machines of todays electronics world that design engineers are faced with what they term the "tyranny of numbers".

The problem is one of reducing the number of components that must be individually manufactured, tested, interconnected, packaged and finally retested. Circuit reliability is inversely related to the number of individual devices and the necessary interconnection.

Early electron tube and transistor attempts at microelectronics solved many of the space problems, but did not substantially improve reliability. The number of interconnections remained the same. Integrated circuits, by their very nature, go to the root of the interconnection/reliability relationship.

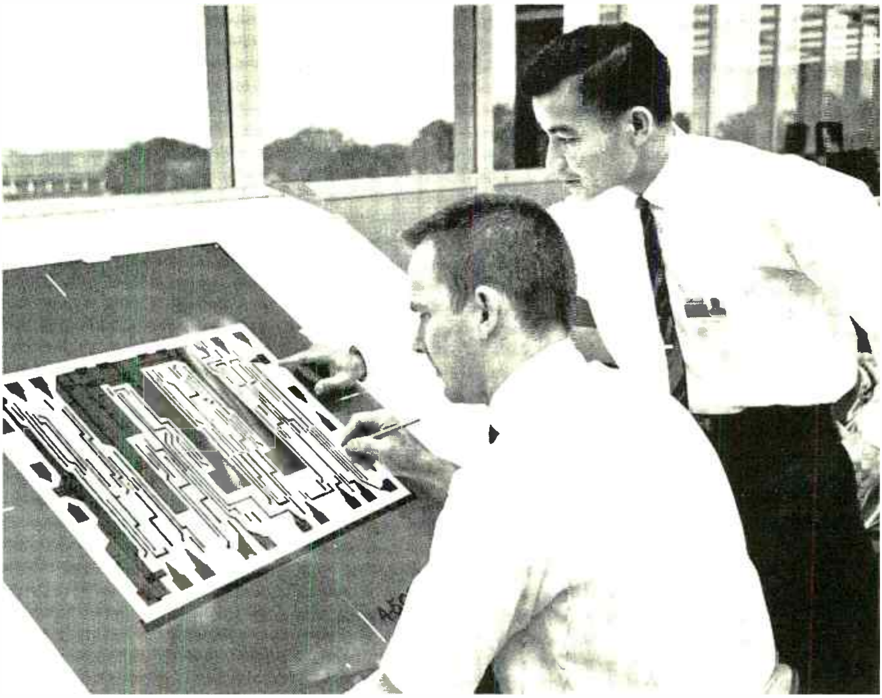
An integrated circuit contains a number of inseparably associated active and passive devices. In a monolithic integrated circuit, all of the circuit parts are fabricated within a single block of material; hybrid circuits include some discrete active devices attached to the integrated circuit components such as resistors and capacitors.

A Circuit on a Chip

Whatever the type of IC, connections, as such, are not used but are "built in" to the device itself. Instead of making a number of separate components and then joining them together to form functioning circuits, the monolithic IC approach is to construct all components at the same time on one "chip".

No new physical principles are involved in integrated circuits, but rather the innovation of mass fabrication techniques. Silicon integrated circuits are really just an extension of transistor technology. But with IC's, hundreds or thousands of circuits, each involving many transistors and other components, are produced at one time.

The creation of a monolithic integrated circuit begins with the basic circuit design. A breadboard model may even be constructed with discrete components to test circuit operation. Then



Courtesy Fairchild Semiconductor

Figure 1. Original art work for an integrated circuit must be prepared in exacting detail. Reduced, it will control fabricating process.

the IC equivalent is drawn representing all of the components and necessary interconnections in the circuit (Figure 1). A separate piece of art work, usually about 30 by 30 inches, is made to represent each of the many steps in the manufacturing process.

The circuit is reduced photographically about 500 times, and then is stepped and exposed repeatedly across a small glass plate. The image on the plate or mask can later be transferred to the surface of a silicon wafer for the fabrication of integrated circuits. In this way as many as 1500 identical circuits may be placed on one wafer—all produced at the same time, all with the same characteristics (Figure 2).

From the finished wafer each circuit or chip is separated, connecting wires are attached, and the IC is packaged in a convenient form.

Manufacturing Process

The raw material from which IC's are fabricated begins as a large ingot of carefully grown silicon. It is between 1 and 2 inches in diameter and about a foot long. The silicon is "doped" with very small but accurately controlled quantities of impurities which change the electrical properties of the material (the basis of all semiconductors).

Glass-like and very brittle, the ingot is cut with a diamond carborundum saw into wafers 12 mils (0.012 in.) thick. After additional processing and polishing, the finished wafer is no thicker than 6 mils.

This wafer will serve as a mechanical

base or substrate for future operations. Onto this substrate another layer of silicon is added by a process called epitaxial growth. The epitaxial layer, about 2 mils thick, has the same crystal structure as the substrate, but is different electrically because of different doping.

Now a series of steps is taken to carefully change the properties of the epitaxial layer in selectively masked areas (Figure 3). In this way the circuit, first drawn in an area almost a yard square in order to obtain good dimensional accuracy and now only slightly larger than a period, can be transferred to the wafer.

The wafer is first exposed to oxygen at high temperature, resulting in a layer of silicon dioxide, called the passivating layer. This layer is coated with a photosensitive resin and with the first mask in place is exposed to light. The exposed areas become hardened, but those under the mask can be rinsed clean of resin. Next the wafer is subjected to an acid which etches away the silicon dioxide layer not protected by the hardened resin.

Courtesy Sylvania Electric Products

Figure 2. Integrated circuit wafer is compared to half dollar. Each square is an entire circuit.

Diffusion of Impurities

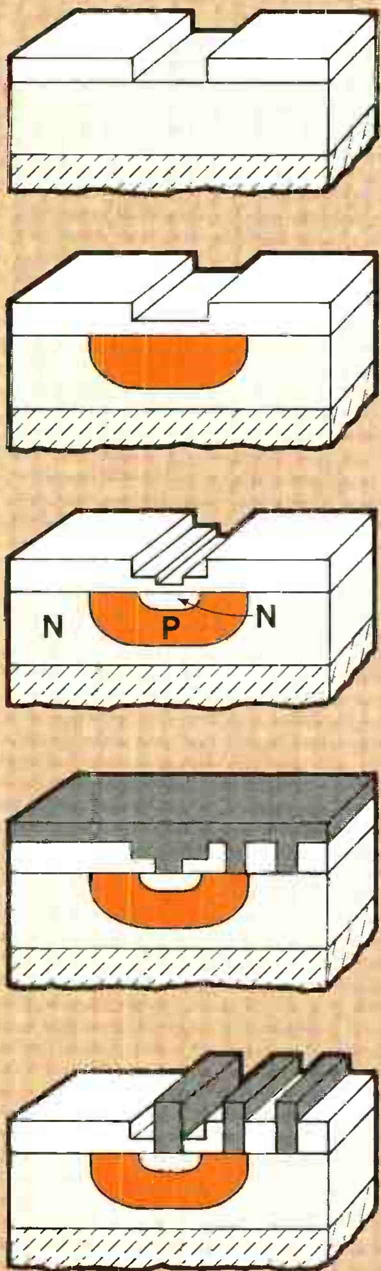
The result of the photo etching is a window through which selective parts of the chip may be exposed to a diffusion process. Diffusion is accomplished by "soaking" the wafer in a furnace with an impurity-rich atmosphere. These impurities will diffuse into the silicon only in the areas not protected by the silicon dioxide layer.

The routine is repeated over and over—photo resistive coating, masking, exposure, rinsing, etching and diffusion. With each step another function is added—a transistor emitter or collector, a resistor or capacitor.

The type of semiconductor produced is determined by controlling the types and amounts of impurities introduced to the silicon. One form of impurity will result in an excess of conduction electrons. This is called N-type silicon. Another impurity will leave a deficiency of conduction electrons, resulting in P-type silicon.

To create a diode, a junction is formed between P-type and N-type material—a PN junction. A transistor requires two junctions, and may be PNP or NPN.

While some values of resistance and capacitance can be diffused into the epitaxial layer, in many cases it is more practical and exacting to add these functions *on top* of the finished active devices. This may be done by a thin or thick film process. Minute quantities of metal are laid down through sputtering or evaporation for thin films or by a silk screen process for thick films. A very thin and narrow piece of metal makes an accurate resistor and can even be trimmed later to touch up the value for more critical tolerances. Capacitors likewise can be made with thin film. It is possible to use the silicon substrate



Window etched through silicon dioxide to expose epitaxial layer to diffusion.

Impurity is diffused into silicon. In the process, new oxide layer forms over entire surface.

Repeated etching and diffusion create other parts of device. NPN areas now form a transistor.

New windows are cut for placement of leads. Surface is covered with metal, typically aluminum.

Metal is etched away leaving leads to each part of device.

Figure 3. Simplified illustration of integrated circuit manufacture shows steps of etching, diffusion and metalization.

as one plate, and the thin-film layer as the other.

Economy of Duplication

All of these processes take place at the same time on *all* circuits on the wafer. It is here that the reduced cost of manufacturing is realized. What can be done to one circuit can be done to hundreds at the same time.

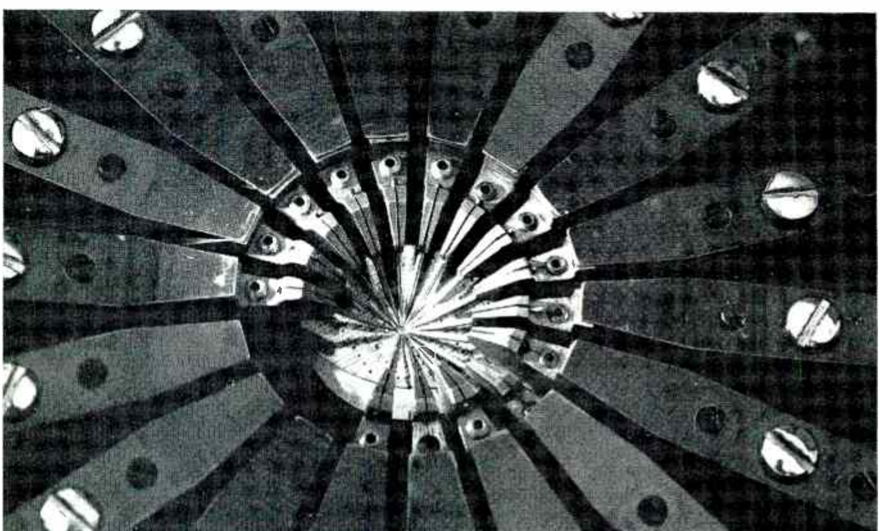
But not every circuit or chip on a wafer is going to be perfect. Seemingly minor defects caused by dust particles and other imperfections can be fatal to such small units. Manufacturing techniques are constantly being improved, but still the yield from a wafer is not 100 percent. And the percentage goes down with more complex circuits.

After all diffusion processes have been completed, but while the wafer is still intact, each circuit is automatically tested. The wafer is stepped through a computer-controlled device where probes determine whether each circuit is acceptable or not (Figure 4). If the circuit does not come up to specification, it is marked, fished out later and destroyed.

The chips, measuring about 0.04 inches on a side, are then separated using a diamond scribing point. They are now ready for packaging—one of the most expensive steps on the assembly line. Until now all manufacturing processes were carried out at the same time for all circuits on a wafer. In fact, many wafers are treated together as a group. At the packaging stage circuits must receive individual manual attention for the first time.

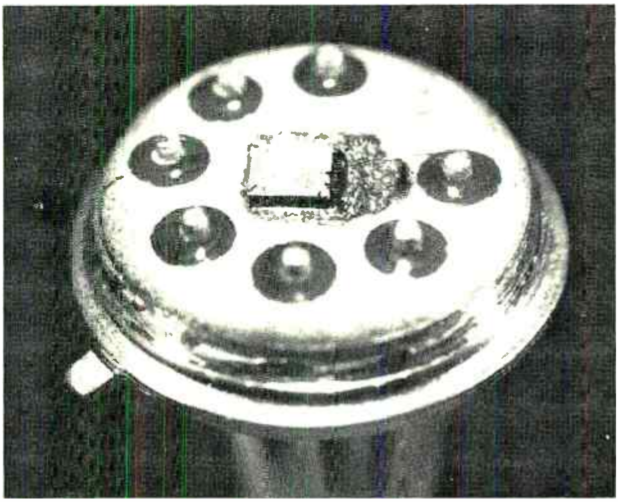
Packaging Methods

Before the chip can be sealed in one of the more than 250 types of packages, a means of connecting it to other component parts must be accomplished. One technique uses the bonding of tiny gold wires to the connection "pads" on the chip (Figure 5). These wires are



Courtesy Fairchild Semiconductor

Figure 4. Computer-controlled probes reach down to test individual circuits while still on the wafer. Imperfections in crystal structure, dust, and failure to meet mechanical and electrical tests all affect the yield from a wafer.



Courtesy Fairchild Semiconductor

Figure 5. Small gold wires connect IC to terminals of standard TO-5 package.

then attached to larger terminals for easy access.

Another scheme — generally called the "flip-chip" method — involves the building of small humps of metal on the pads. The chip can then be turned face down on a larger substrate or frame and bonded by soldering, thermocompression or ultrasonics (Figure 6). This process lends itself to automation and physical durability.

A method of building up heavier metal leads coming directly from the circuit is also being developed. These "beam leads" make external contact easier and also add structural strength to the entire device.

Once the IC has been packaged it must again be tested. Special tests are made for frequency response in linear devices and switching speeds for digital circuits. They are also subjected to a variety of mechanical tests, shock, vibration, acceleration and temperature changes to ensure dependability.

Operating Speed

When fast switching times are required—always a consideration in digital equipment—an interesting dependency on size makes integrated circuits valuable.

The ultimate factor limiting the operating speed of any electronic device is the velocity of electromagnetic propagation (the speed of light). In space this rate is approximately 186,000 miles per second, or about one foot in 10^{-9} seconds (one nanosecond). Electric current flowing through a conductor will have a speed somewhat slower than this, depending on the characteristics of the conductor.

If a switching circuit is to operate in the nanosecond range, the distance between circuit components must be measured in fractions of an inch. Integrated circuits make this possible.

Typical applications of the digital integrated circuit include many associated with computers: flip-flops, adders, gates, buffers, and memory cells.

The linear integrated circuit, as the name implies, is applicable to most amplifying chores and may be the building block for anything from a simple audio amplifier to a complex communications network. Linear IC's are found in analog computers, communications equipment and even hi-fi systems.

Again, it is not so much the major breakthrough in technology that is seen in the final equipment, as it is the ingenuity of the designer effectively using available tools. For example, Lenkurt engineers are currently investigating ways of using digital integrated circuits to perform analog functions—especially desirable for economic reasons as well as reliability.

A typical monolithic integrated circuit contains a number of transistors and associated passive components interconnected to provide a functional circuit. After packaging, the integrated circuit becomes a unit of some larger design—interconnected to perform the functions of an entire system or piece of equipment. And so numbers of integrated circuits are stacked in smaller and smaller spaces just as tube and transistor circuits were before them.

$(IC's)^2$

The next logical jump in technology is to combine a number of circuits onto a single chip, with the same advantage of reduced interconnections and manufacturing ease. Several such devices, using a technique known as medium or large scale integration (LSI), are now on the market (Figure 7).

Large scale integration is particularly applicable to computer and other digital technology, where the same type logic circuit may be used hundreds or thousands of times. LSI is capable of offering 100 logic gates on a single chip. This tends to reduce manufacturing and packaging costs. However, increasing the number of components on a chip results in decreasing cost only to a point. Beyond a certain level, circuit complexity tends to reduce the yield of usable chips on a wafer—a chip is only as good as any of its parts—and cost per component begins to rise.

LSI is having a definite effect on the circuit designer who has always had

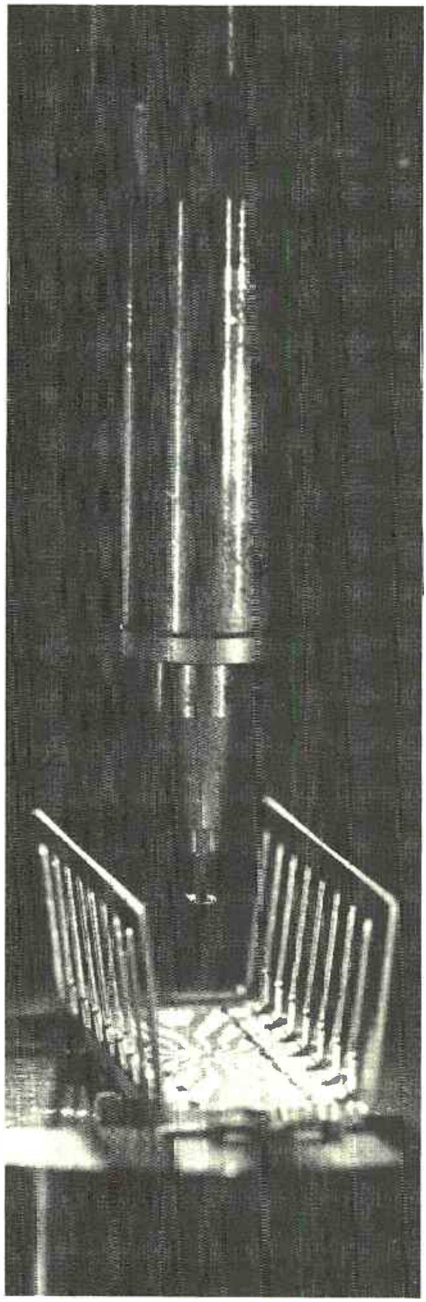


Figure 6. Recently developed technique shows Fairchild integrated circuit about to be mounted face down on frame. All contacts are made at one time.

freedom to choose components according to his own specifications. As entire circuits, and beyond that entire functions, become standardized in manufacture, the design engineer's ingenuity may have to be applied to the use of standard circuits instead of to the design of original units.

At least three types of LSI packages will probably be offered:

1. Stock items ready for use (mainly logic and memory units).

2. Basic units, such as gate circuits, which require final metalization. Interconnection will be provided according to the buyers specifications.

3. Custom units, where specifications demand original design.

LSI circuits at present are more appropriate for digital than linear systems because of the repetitive nature of the elements used. And because components on an LSI chip are closer together than discrete IC's, operating speeds of digital systems are further increased.

IC's and Communications

Miniaturization of electronic systems has been an obvious product of integrated circuits, even though it must be remembered that the more basic value of IC's is in cost and reliability. Com-

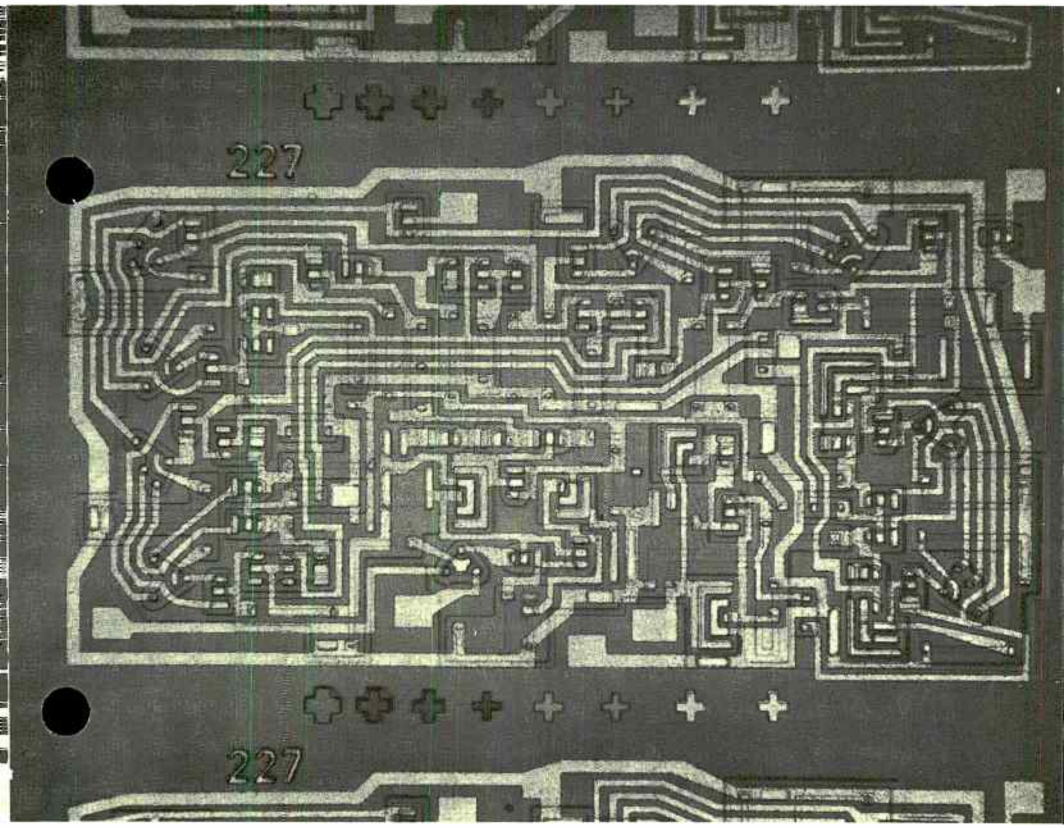
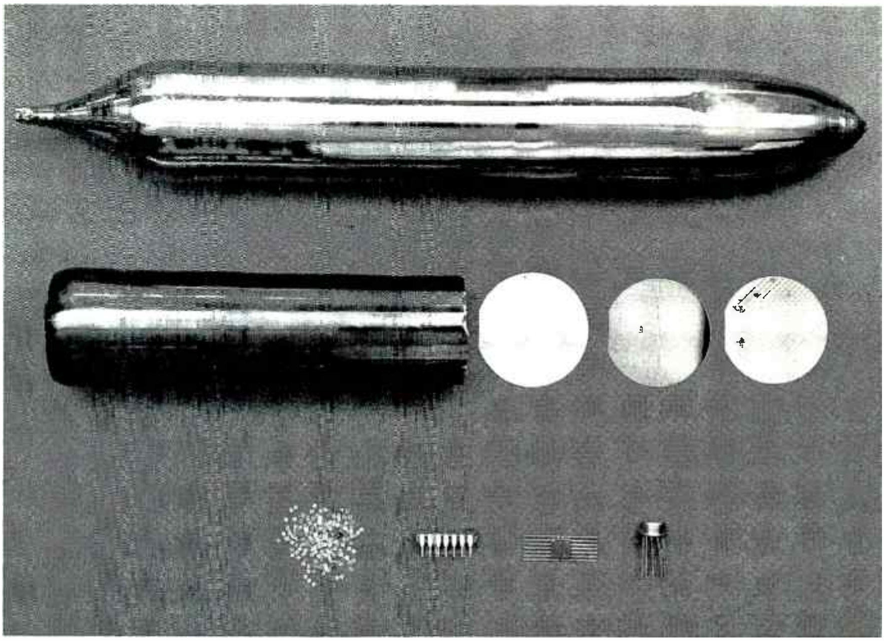


Figure 7. Sylvania IC contains 116 transistors, resistors and diodes to produce 40 gate circuits on each chip. Used in computers or digital communications equipment.



Courtesy Fairchild Semiconductor

Figure 8. Silicon ingot (top) is sliced, and then polished before integrated circuits are fabricated. From the finished wafer (middle, right) come hundreds of chips (bottom, left) ready for packaging. Shown are Fairchild's Dual In-Line, a flatpack, and a TO-5 can.

puters that would have filled rooms by previous technology now stand in the corner or even on a desk top. And the size advantage is now being applied effectively to the designs of new communications systems, especially as linear devices become more practical.

IC's, including transistors, diodes, resistors and capacitors, are so small that the manufacturer's assembly line is now characterized by rows of microscopes. But filter circuits—so important to the telecommunications industry—have remained a problem. These filters require very high quality inductors, large coils of wire that are heavy, bulky and relatively expensive.

A solution in constructing inductorless filters using integrated circuit technology has been proposed by Lenkurt engineers. While still in the experimental stage, the technique exhibits a great deal of promise for the future in keeping communications systems economical, reliable and small.

Simply stated, the method replaces each inductor in a complex filter network with a circuit that behaves electrically like an inductor. This circuit consists of one capacitor and a circuit called a gyrator. Low-sensitivity, high-Q circuits have been produced in a package roughly a quarter of an inch square. This compares in size to a coil of about 1.5 inches in diameter and 1 inch thick.

Data and PCM

The first area of telecommunications to be significantly affected by integrated circuits will be where digital techniques are used. Here, the extensive developmental effort placed in digital IC's for computers can be easily transferred to data transmission and its cousin pulse code modulation (PCM).

For data and for PCM, circuits are needed to deal strictly with digital pulses—signals that are either *on* or *off*. In PCM transmission, for example, binary digits are used to represent discrete values of a voice signal. In the first generation PCM system, bit rates of 1.5 Mb/s are used, requiring very fast sampling and switching. Digital integrated circuits are almost a must. And in future systems, with rates approaching 300 Mb/s, the need is even more pronounced.

Integrated circuits also provide a means of manufacturing extremely stable resistors as part of the miniature circuit. Because all resistors are made at the same time, and with their close proximity will be subjected to identical changes in environment, they are excellent components in critical communications applications.

Hybrids Sometimes Appropriate

Much of this discussion has centered around monolithic integrated circuits. Hundreds of circuits, including all active and passive components, are processed as a unit on one wafer. And the wafer is repeated hundreds and thousands of times. Obviously this is advantageous whenever great quantities of the same circuit are needed.

Many telecommunications equipment designs will use "off the shelf" IC's both of digital and analog variety. But some specific applications will not require the large quantities needed to justify monolithic integration.

In these cases hybrid IC's may be more appropriate. The equipment manufacturer could produce much of the circuit using in-plant thin or thick film capability. Other components—including active devices—would be added as separate units. Single transistors, or standard integrated circuits could be bonded to a unique circuit of the manufacturer's design. Bell Laboratories, for example, has used this approach for a tone-generating circuit in some Touch-Tone telephones.

Integrated circuits may also affect the design of future microwave radio equipment. With their fixed component relationships and close spacing, IC's may solve the problem of manufacturing circuits with uniform performance to operate at microwave frequencies.

The IC Promise

The entire electronics industry is facing a change of great magnitude—a physicist might call it a technological quantum jump. Integrated circuits as they stand promise price savings and reliability. Large scale integration will open roads to miniaturization still hard to visualize accurately. A hundred transistors on a chip, or a hundred-thousand on a wafer are foreseeable in the next five years.

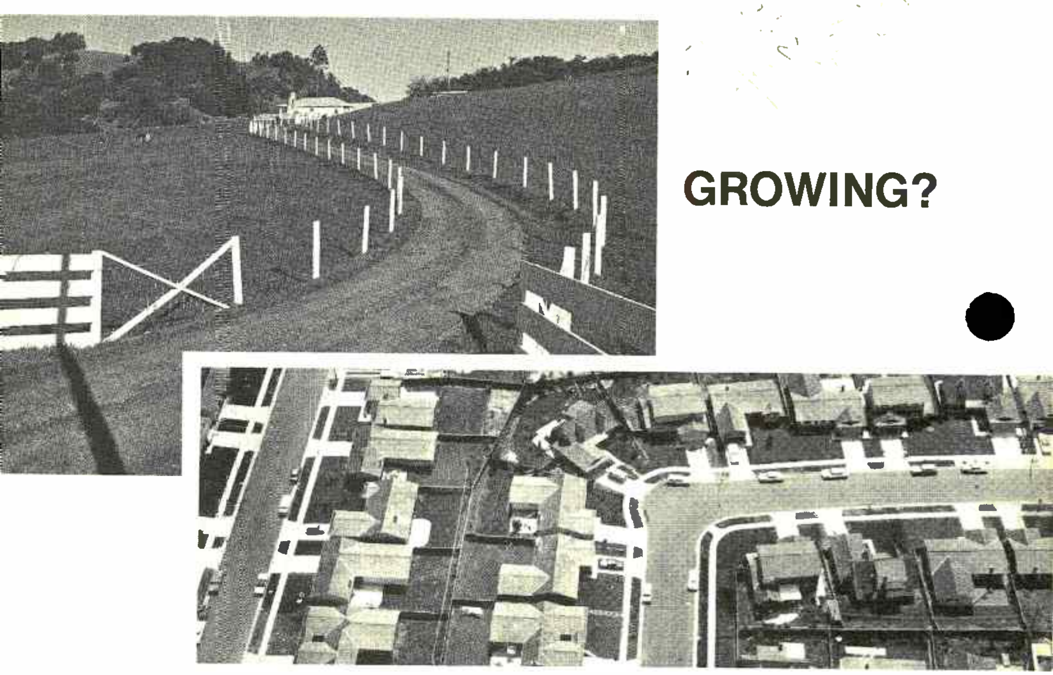
Whether it's a shoe-box size computer, a carrier system inside a telephone handset, or even wrist watch television—the integrated circuit is the gadget dreams are made of.

Lenkurt Electric Co., Inc.
San Carlos, California

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

MR. E. A. GARCIA
CHIEF OPERATOR
MILWAUKEE ROAD DEPOT
SAVANNA, ILL. 61074
R-24948 6B

RETURN REQUESTED



GROWING?

The Lenkurt XU subscriber carrier system extends service up to 30 miles—20 channels on two cable pairs. Easily converts to exchange carrier to meet continuing growth. Write Dept. B720.

LENKURT ELECTRIC San Carlos, California, U.S.A.

Subsidiary of
GENERAL TELEPHONE & ELECTRONICS

Lenkurt Offices

San Carlos | Stamford, Conn.
Atlanta | Washington, D. C.
Dallas | Chicago

THE LENKURT DEMODULATOR is a monthly periodical circulated to technicians, engineers, and managers employed by companies or government agencies who *use and operate* communications systems, and to educational institutions. Job title, company affiliation, and nature of business must be indicated on subscription requests. Each issue features an instructive article on a subject dealing with the science of telecommunications. Permission to reprint articles may be obtained by writing THE EDITOR.