The Lenkurt Demodulator

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MICROELECTRONICS

The physical size of electronics equipment was reduced drastically and dramatically by the invention of the transistor a number of years ago. Now another size-reducing revolution — microcircuitry — is producing a similar impact on the industry. Like the transistor microelectronics promises more than mere size reduction. It also offers the potential for increased reliability, lower manufacturing costs, and lower power consumption. But microcircuitry is still in its infancy, and major problems remain to be solved. This article presents a survey of microelectronics and considers its impact on the future of the telecommunications industry.

Powerful factors are accelerating the improvement of electronic packaging. One of the strongest influences, of course, is the aerospace industry. This gigantic industry uses some of the most complex electronic devices ever developed. Furthermore, reliability, size, and weight are of the utmost importance. Every extra pound of load placed in a rocket adds many extra pounds to the gross weight, in such things as additional structural material and more fuel required for lift off — and the failure of a single component worth only a few cents may mean that millions of dollars and months of effort have been wasted. The field of aircraft electronics is only slightly less demanding than the space industry in its size and weight requirements.

Some of the same factors that are so vitally important to the aerospace industry are also the ones that have traditionally concerned telephone companies and other operators of communications equipment: reliability, cost, maintainability. Size also is important to the earth-bound communications industry, although often it is overlooked or outweighed by other factors. The actual cost of a square foot of floor space in a telephone office building, for example, would astonish many people. In addition to the original cost of the building, several other things such as light, heat, insurance, and maintenance for a period of perhaps thirty or more years must be considered.

Thus, it is evident that the whole electronics industry benefits by better and smaller circuit packages. Initial efforts in re-packaging were directed primarily toward improving vacuum tubes. Then along came the transistor, which virtually revolutionized the field. And now, barely fifteen years after the transistor, microelectronics may make "conventional" concepts of electronics obsolete.

Before discussing the advantages and the disadvantages of the various approaches to microelectronics, it is necessary to clarify and define some terminology to provide a common meeting ground. Over the past year some terminology has come to be quite generally accepted. Agreement is by no means unanimous, but the terms used here are those enjoying fairly general usage.

The field of microcircuitry is in its infancy, so naturally the terminology changes almost from day to day. Even the term "microelectronics" does not have a precise meaning. It is a loosely defined term which covers several methods of achieving smaller circuit packages than have heretofore been possible. These approaches to microelectronics range from the use of conventional components in a very high-density packaging arrangement to actual integrated circuitry where discrete components do not exist, and the circuit can be identified only by the function it performs.

High-Density Packaging

As might be expected, the earlier approaches to microelectronics have been extensions of conventional packaging techniques. One method is to take a conventional circuit package and simply shrink its size by reducing both the size of the discrete components and the space between them. This approach is simple in concept — the problems are primarily mechanical.

Component manufacturers are constantly striving to reduce the size of their discrete components; but even so, the space required for mounting and for the interconnecting wiring eventually approaches a certain irreducible minimum. Thus, there are limits to how far this approach can go toward miniaturization. Efforts so far have indicated that perhaps a two-to-one or three-to-one reduction in size is possible.

Furthermore, this approach contributes nothing to reliability. There are just as many components as there ever were, and should one fail the problems of replacing it are complicated by the lack of working space. Nor does the high-density method offer much reduction in

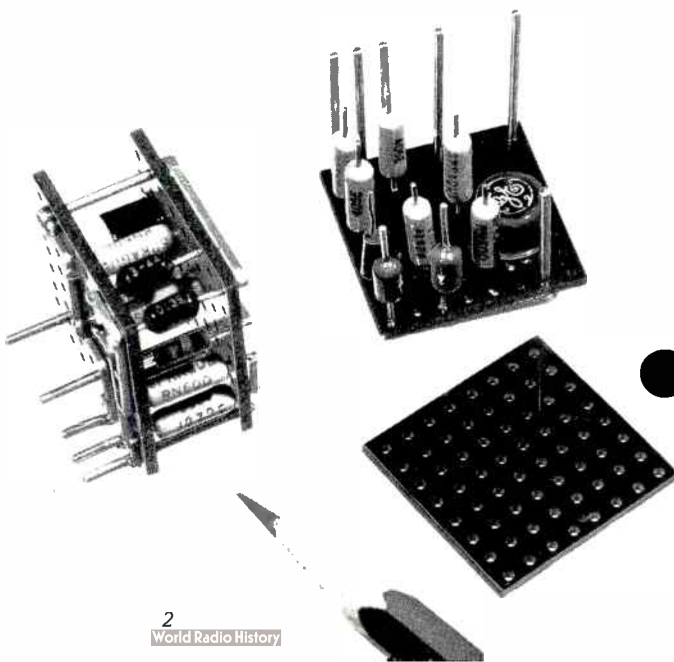


Figure 1. "Cordwood" construction is one method of high-density packaging using discrete components. It reduces size but does not improve reliability or maintainability.

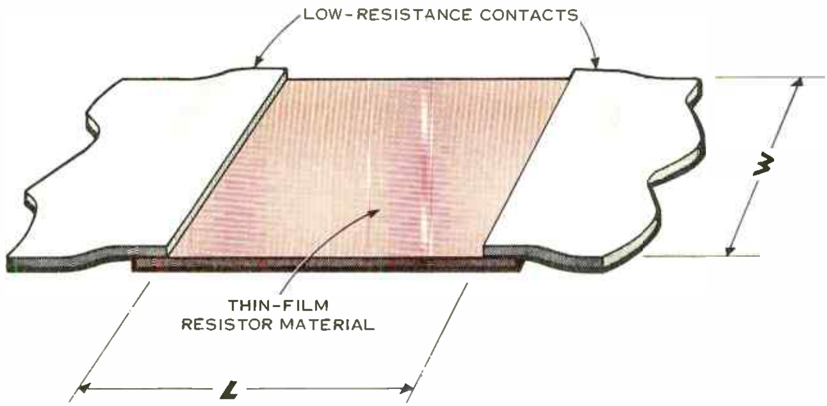


Figure 2. Since the resistance of a thin-film resistor depends only on shape, not on size, such resistors can be considered in terms of sheet resistance, measured in ohms per square.

power consumption. This in itself is a problem because essentially the same amount of power is dissipated in perhaps one-half or one-third of the space of conventional packaging. Heat dissipation may therefore become the limiting factor on this type of packaging.

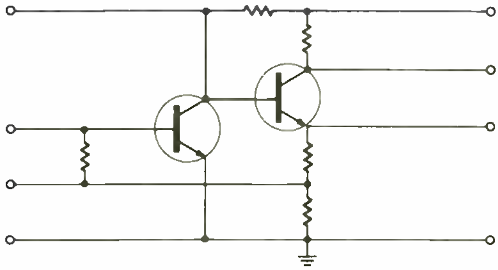
The next logical step in miniaturization is to form a complete circuit, consisting of several elements, on or in a single block of material to provide an *integrated circuit*.

Thin-film Techniques

One method which shows considerable promise in integrated-circuit design is that of thin-film deposition. In this technique circuits are made by depositing passive elements such as resistors and capacitors and their associated wiring on inert or passive "substrates." These substrates, usually made of glass or ceramic, simply provide a foundation for the circuitry. The thin-film method can be viewed as merely another way of making and interconnecting components which are electrically similar to conventional components. One of the chief advantages of this technique is the close control of tolerances. Since the thickness of the film can be controlled quite precisely, a good portion of the manufacturing problem is two dimensional. Five-percent resistor tolerances are achieved routinely, and one percent or better can be achieved. Capacitor tolerances are somewhat more difficult, with 15 to 20 percent being common values.

As an example of the thin-film technique, Figure 2 indicates the method of forming a resistor. When two opposite sides of a square section of the thin-film material are connected to low-resistance contacts, the value of the resistor depends only on its shape, not on its size. A long narrow film provides more resistance than a short wide one in the same way that a long thin wire has a higher resistance. Thus, a resistor consisting of 10 squares in a row has 10 times the resistance of a single square — if the contacts are at the ends. If, however, the contacts are along the sides, the resistance is only 1/10 that of a single square.

While it is not particularly difficult to deposit resistors, capacitors, and wiring by thin-film techniques, inductors and transformers present an entirely different problem. The thin-film method simply does not lend itself well to dupli-



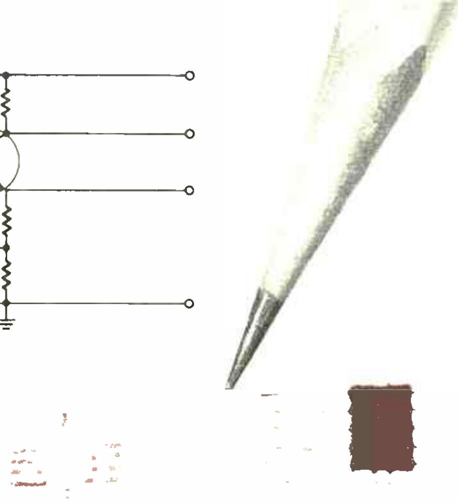


Figure 3. One solid-state circuit may perform the functions of many discrete components. Small disk at left provides performance equal to that of the two-transistor amplifier shown in the inset.

cating the effect of the traditional inductor. However, considerable research effort is being expended in attempts to find a satisfactory method of depositing inductors as spirals of thin-film material. These efforts have met with some success, but much more work remains to be done in this field. For the communications industry this is perhaps one of the most serious drawbacks to the use of thin-film techniques. Inductors are a vital part of the filters used in modern telecommunications systems. Furthermore, in terms of physical size, inductors often form the largest part of the electronic equipment. Hence, this is the area of the largest potential savings in size and weight.

Another major drawback to the use of thin-film techniques is the difficulty encountered in attempting to deposit active devices such as transistors and diodes. The usual method, at present, is to add conventional active devices to a completed thin-film circuit. However, progress is being made in this area. A field-effect device called a thin-film transistor has been developed. In this device, current flows through a channel in a semiconductor between two electrodes called the "source" and the "drain." The voltage applied to an insulated gate controls the current flow through this channel. This is one of several approaches which show satisfactory performance in the laboratory. Quantity production, however, presents a different situation because of the mechanical fabrication problems involved. In spite of these problems, however, the thin-film technique does show considerable promise.

Solid-State Circuits

Another form of integrated circuit is the "solid-state circuit," which refers to a fabrication method in which a single semi-conductor block contains all of the circuit elements: transistors, diodes, resistors, capacitors, etc. In this technique, different portions of the semiconductor block represent various circuit elements. In other words, all the elements are constructed from the same block and are physically inseparable.

For example, each of the single semiconductor chips shown in Figure 3 performs the same functions as a two-stage transistor amplifier. Input and output parameters can be measured, gain can be calculated, and even a feedback loop can be connected, but the transistors or other components cannot be identified individually. The circuit must be considered as a whole, identifiable only by its function.

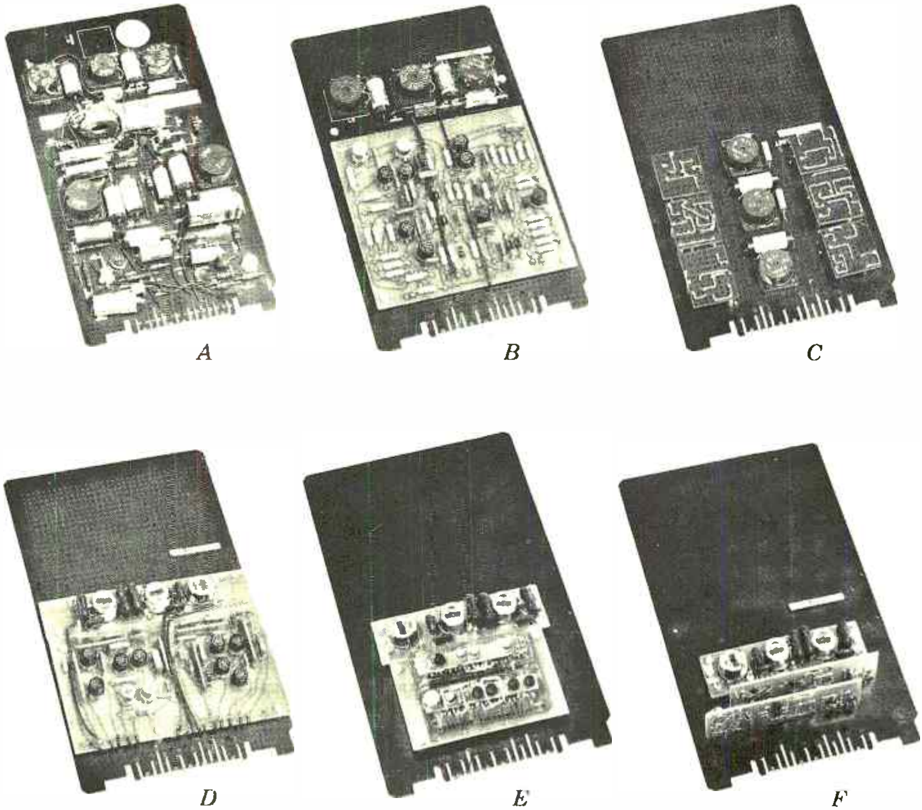


Figure 4. Several approaches to miniaturization are illustrated by the same circuit constructed by six different methods: (A) conventional components and wiring, (B) miniature components, (C) cordwood, (D) thin film-discrete component hybrid, (E) pellet pack, (F) Swiss cheese. Production of such circuits is primarily an economic problem, since (F), for example, costs several times as much as (A).

While solid-state circuits provide perhaps the most dramatic example of space-saving in the microelectronic field, they do have their disadvantages. One of the chief disadvantages is the lack of close control over component tolerances. While tolerances of 5% and even 1% are quite readily attainable in thin films, solid-state circuits typically have tolerances of 20%.

Another disadvantage of solid-state circuits is their high susceptibility to parasitic capacitance between the components. This parasitic capacitance may amount to several picofarads, whereas a comparable thin-film circuit would have virtually none. Because of this capacitance, considerable care is necessary in designing solid-state circuitry.

Hybrids

Often two or more approaches to microelectronics can be combined in a so-called "hybrid" circuit. As an example, such a hybrid circuit might be constructed by using individual active components in combination with thin-film passive components and wiring. A good example of this approach occurs in Lenkurt's recently introduced four-wire terminating set. This unit includes strappable loss pads which require a total of 40 one-percent resistors. By using thin-film resistors deposited on a substrate and encapsulated in ceramic material, reliability was improved, size was reduced, and component tolerances were easily met. The rest of the four-wire terminating unit consists of conventional circuitry attached to the thin-film pads by means of several leads projecting through the ceramic material.

Another hybrid design is to combine the thin-film and solid-state circuit approaches. Thus, the components which are better formed by semiconductor technologies can be "built in" to the substrate. The substrate is then either insulated or rendered passive, and other components are deposited on its surface by thin-film techniques. Thus, the active components are in the block, the passive components are on the surface, and the whole circuit is fabricated by the most effective techniques.

The so-called "pellet" method offers a technique which is easily adaptable to automation. Each circuit element is manufactured in a standard component size. These uniform-size pellets are then placed in rows built around a structure of interconnecting wires. The wires are cut anywhere an interconnection is not desired. Figure 4(E) shows an experimental circuit which uses conventional transistors connected to pellet-type passive components to form a discrete-component circuit. However, active components and integrated circuits can also be formed as pellets, permitting a hybrid arrangement.

Another manufacturing technique using pellet components is the "Swiss cheese" approach. In this method, the pellets are set in holes drilled in a circuit board as shown in Figure 5. Interconnections are then made in much the same manner as in conventional circuitry. The chief disadvantage to either pellet approach is that the cost is several times that of conventional circuitry.

Pros and Cons

The goal of all these approaches to microelectronics can be stated quite simply. It is to improve reliability and increase maintainability while reducing cost, size and weight. (Of course there may also be secondary benefits, such as reduced power consumption.) Therefore, any particular miniaturization technique must be judged by how well it meets these established goals. For example, high-density packaging of con-

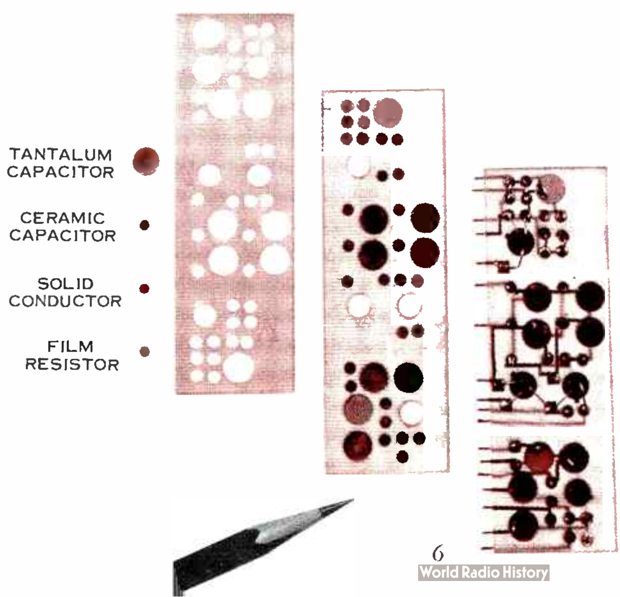


Figure 5. "Swiss cheese" approach uses discrete components in high-density packaging. Unlike some other techniques, such as "cordwood," it improves reliability as well as reducing size.

ventional components does reduce size somewhat and it may reduce weight. But it does not increase reliability, because there are as many components and as many connections as there were before. Furthermore, maintenance and heat dissipation are both complicated by the reduced space. Therefore, this "interim" approach to miniaturization could have applications where there is an immediate need for small size — if the requirement is urgent enough to warrant sacrificing the other qualities.

When a way is found to eliminate inductors from circuits, the thin-film approach will show even greater promise. One possibility is the use of active filters composed of capacitors, resistors, and transistors. This would eliminate or drastically reduce the need for the space-consuming inductors required by conventional passive filter networks.

Many people feel that integrated circuits will provide the "ultimate" in microelectronics. Certainly they provide one of the most dramatic size reductions. Furthermore, because there are no interconnections and no separable circuit elements, the potential for reliability approaches that of a single component. But integrated circuits do have disadvantages. The difficulty in achieving close tolerances in solid-state circuits is one of these. Also, the limited power-handling capacity of integrated circuits is much more restrictive than that of other types of microcircuits.

The Future of Microelectronics

The microelectronics industry has grown tremendously since its start only about three years ago — and its rate of growth is increasing. Conservative estimates indicate annual sales of perhaps 500 million dollars by 1970.

But such figures can be deceptive without interpretation. For example, by far the largest segment of the microelectronics market is in digital circuitry. Computers, of course, are in the forefront because they probably have the most to gain from size reduction. Microelectronic logic circuits are much easier to build than are linear circuits, and often these logic circuits are used in greater quantity, which helps to offset the high tooling cost for each circuit. Furthermore, the reductions in power consumption are much greater for logic circuitry than for linear circuits.

Thus, analog applications are lagging behind digital applications both in technology and in cost. These two factors, of course, are inextricably intertwined. As the solutions to technical problems are found, the cost will come down, allowing microelectronics to compete with conventional components in more and more applications.

In addition to the economic and technical problems which must be overcome, new equipment must be compatible with existing conventional equipment. Microcircuitry generally requires low voltages and low power. This may seriously reduce the advantages of microelectronics by requiring conventional components for interfaces with existing equipment.

Thus, although the trend toward microcircuitry is clear, it is equally clear that the telecommunications industry will not be "revolutionized." The change-over will take years, gradually coming about as a dynamic and growing industry finds ways to adapt the latest technological advances to its needs. •

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