evolution of MICROELECTRONIC PACKAGING

The past decade has witnessed a truly remarkable development in electronics. The "Dick Tracy Wristwatch" radio has passed from the absurd to the here and now. Electronic engineering has been overtaken by microelectronic engineering. Emphasis has been placed on shaping instruments to do the job in situ. Few times in history have technological developments had such a direct and widespread effect on the man-in-the-street as the microelectronics evolution.

Among the more commonplace applications are the electronic wristwatch, personal size TV, pocket FM-AM radios, miniature tape recorders and record players, and electronic exposure control in 35-mm cameras. In the medical field, we have an array of implantable electronic devices, such as the pacemaker and pressure and flow gauges; in the industrial field, miniature closed-loop TV, portable special-purpose computers and control systems that are built into the machines they control; in the military field, numerous applications including light-amplifying infrared devices and highly sophisticated communication systems.

The reason for the sudden onrush of electronic devices was a combination of factors including: low cost, high reliability, small size, ruggedness, and low power consumption. Although electronics has always had the potential to achieve all the tasks that it is now performing, it was not until these factors changed that the avalanche started.

History

Miniaturization of electronics has resulted from a sequence of size-reduction developments. Components and vacuum tubes were reduced in size to miniature, then to subminiature. Transistors replaced vacuum tubes. Wiring emerged as a printed circuit board, which also supported the components. Then two significant developments occurred which accelerated and revolutionized the growth of electronics; thin-film circuits became a reality and, at about the same time, the semiconductor industry gave birth to the integrated circuit (IC). The combined influence of these new techniques completely changed the role of the electronic packaging engineer. New concepts were needed to handle and assemble these tiny circuits. The packaging job now starts with the design of the integrated circuit and with the processing of the thin-film circuit. The packaging engineer had to add design and process engineering to his capabilities. The hybrid microcircuit became one of the most important products of this new electronic packaging world.

Today's Technology

The popularity of the printed circuit board is evidenced by its widespread use in consumer electronics. It will continue to be used in many applications where economy demands are urgent.

Microelectronic technology is changing rapidly as it finds increasing applications in a variety of fields. Through these developments, electronic devices have been reduced so much in size that new methods of handling and packaging have had to be invented. This paper reviews the evolution of microelectronic packaging showing the development of today's packaging concepts. The influence of new capabilities on electronic designs now emerging in the packaging field is also discussed.

D. D. Zimmerman

Commercial and military applications continue to set the pace for new developments. The typical printed circuit board assembly shown in Fig. 1 was eventually superseded by a packaging concept called cordwood. Here the components are literally bundled together, in an orderly fashion, and the component leads welded together to make the proper circuit connections.[1] The active components, i.e. transistors and diodes, were packaged in sealed metal cans and included in the cordwood assembly as shown in Fig. 2.

Integrated circuits are semiconductor chips like transistors, but about four or five times larger. They perform a more complex function than do transistors because, as their name implies, they contain many transistors, diodes, resistors, and capacitors all wired and integrated together on a single piece of semiconductor material. Each integrated circuit requires 10 to 14 electrical connections and a clean sealed environment.

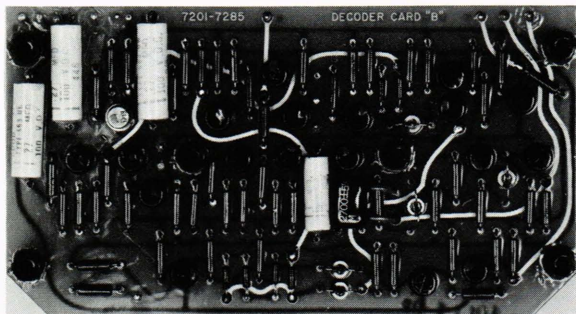
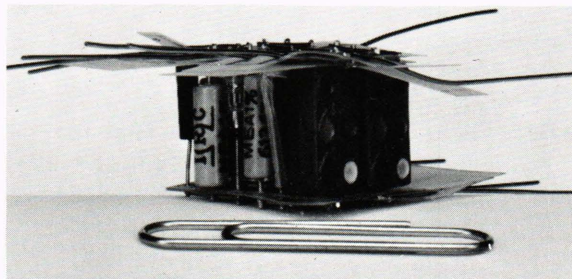


Fig. 1—Typical printed circuit board.

Electronic designers found many uses for integrated circuits, particularly for digital logic circuits in computer applications. However, IC's have limitations and are not as useful for analog or linear electronic circuit applications as they are for digital circuits.



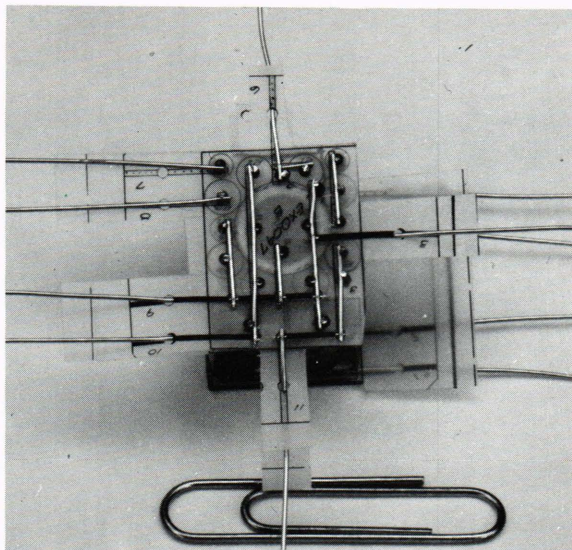


Fig. 2—Typical cordwood assembly.

The next concept in packaging, called the flatpack, emerged to provide a sealed package for the integrated circuit (see Fig. 3). Flatpacks are assembled in various ways to form an electronic system. One such assembly technique developed at APL is called Ministick.[2]

Variations in size of these tiny flatpacks with multiple leads yielded to another assembly of components known as the hybrid microcircuit. A typi-

[1] "Welded Cordwood—Last Step in Conventional Circuits?" *APL Technical Digest* **1**, 1, Sept.-Oct. 1961, 20.

[2] C. F. Noyes, "Ministick Packaging—A Further Aid to Satellite Reliability," *APL Technical Digest* **5**, 3, Jan.-Feb. 1966, 2-10.

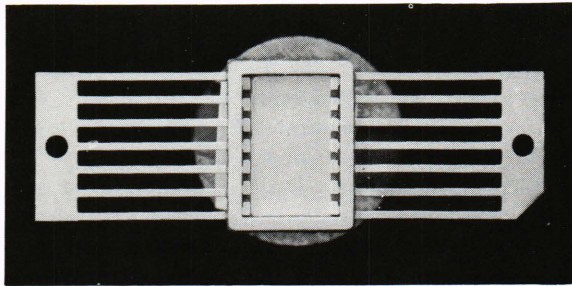


Fig. 3—Typical flatpack.

cal thin-film hybrid circuit, developed by the Microelectronics Laboratory at APL, is the source sink driver. A photograph of this hybrid (shown in Fig. 4), was taken before the lid was sealed in place. Six silicon transistors and four thin-film chromium resistors can be seen with the interconnecting thin-film aluminum wiring. The interconnecting wires, which are only one thousandth of an inch in diameter, complete the internal wiring. The flatpack case is one-quarter of an inch square. The assembly technique of hybrid microcircuits, like the source sink driver example, is known as the chip and wire method.

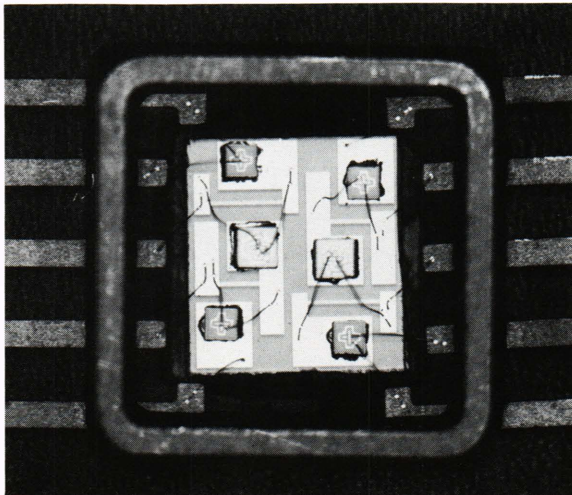


Fig. 4—APL source sink driver thin-film hybrid microcircuit.

The thick-film approach is another concept used in making hybrid microcircuits. It should be pointed out that the distinction between thick films and thin films is really not the film thickness as one may be led to assume from the terminology, but rather the method of preparation of the film. Thin films are usually made by a vacuum evaporation process. Thick films are printed from conducting inks and pastes through a silkscreen type printer and then subsequently fired at high temperature in a furnace. This converts the printed paste material into a glass-like vitreous substance called thick film. Thick-film conductors can be solder-coated by tin-lead solder. This provides a capability of solder attachment of add-on components such as ceramic sealed transistors, resistors, tiny chokes and transformers, and capacitors to complete the hybrid assemblies. An example of a thick film is shown in Fig. 5.

Solderable thin films have been developed in the Microelectronics Laboratory which provide the same component add-on capability discussed above for thick films. A number of frequency multiplier circuits have been fabricated using this technique. The frequency multiplier assembly is protected from handling and environmental damage by a molded silicon rubber encapsulation (see Fig. 6).

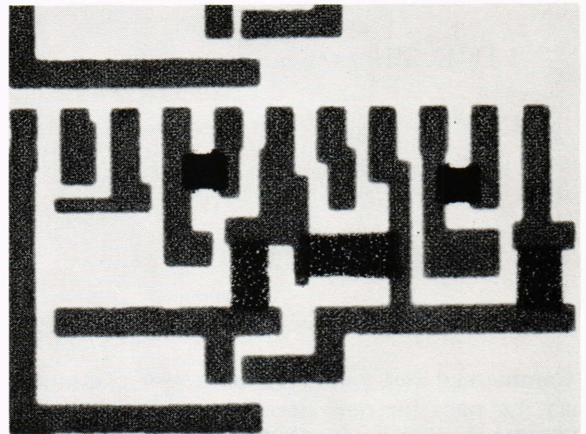


Fig. 5—Thick-film circuit.

Recent packaging developments have been stimulated by the most pressing problem of packaging—that of interconnections between packages. The number of connections from the flatpack to the outside world defines an interconnection problem of significant magnitude. A complex technique such as Ministick is required to

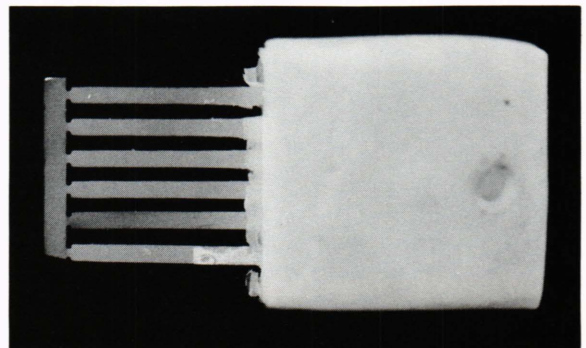


Fig. 6—Molded thick-film assembly.

complete all of the connections between the many flatpacks in an electronic system.

A first order simplification of this problem can be achieved if the amount of circuitry inside a package is increased. The large-scale array (LSA) approach to packaging is an attempt at solving this problem. The interconnections for a complete subsystem are made on a single substrate with thin-film conductors for wiring. Insulated thin-film crossovers are used to complete all of the connections in a single plane. Thin-film resistors and capacitors are an integral part of this substrate design. Transistors and integrated circuits are mounted face down on top of the substrate by ultrasonic bonding directly to conductor pads. This is known as flip-chip assembly. The actual connection between the semiconductor chip and the substrate conductor is a metallurgical bond. The chips are provided with a raised metal bump for each wiring connection. The bumps are registered to the corresponding thin-film conductor on the substrate as they are bonded in place. The chips are mounted and wired into the circuit simultaneously. As many as fifty chips can be mounted by this technique on one square inch of substrate area and still allow sufficient area for the interconnecting thin-film wires.

Packaging large-scale array substrates is an extension of the flatpack approach using larger packages with more leads per package, but with fewer packages per system. As an example, 52 source sink driver packages (1/4-inch x 1/4-inch flatpacks) would reduce to about four or five large-scale array packages, each of which is about 1-1/2 x 3/4 x 1/8 inch.

Progress in Review

The review of the evolution of electronic packaging presented thus far is useful for determining what common trends in design have occurred. Starting with the use of the printed circuit board, the structure or electronic chassis used to hold components and the insulated wires connecting the components have been eliminated. The printed circuit board provided both the structure for the components and the interconnecting wiring for the circuit. Taking the next step, the cordwood module eliminated the printed circuit board. More structure and wiring disappeared from the packaging design. Thin-film resistors, capacitors, and conductors used in the source sink driver example in Fig. 4 demonstrate these same trends again. Structure and wires now disappear from these circuit elements including the transistors, which were packaged before in separate sealed cans. A few interconnecting wires still remain as does some structure, i.e., the flatpack.

Developments in microelectronic packaging have followed a specific course, i.e., the progressive elimination of structure and wires in each new design. Since this trend has been established throughout almost a decade of electronic history, it is reasonable to assume that it will continue.

A Look at the Future

The key to the future of microelectronic capability is the combined utilization of substrates with thin-film crossovers, ultrasonic bonding of semiconductor devices directly to the substrates, and simplicity of multipackage assemblies eliminating much of the wiring harness and cable connectors now in use.

The thin-film crossover pattern on the substrates can be combined with solderable thin films to accommodate assembly of add-on components not readily available as thin-film elements.

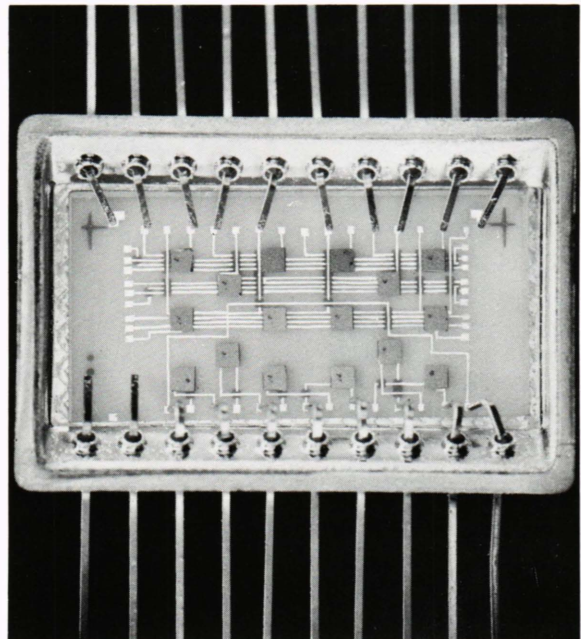


Fig. 7—Large-scale array in dihedral package.

The flip-chip bonding technique has not been put to large-scale use because it is limited by the availability of only a relatively small number of types of device which the semiconductor industry can supply with the bonding bumps on them. The Microelectronics Laboratory has successfully developed the capability of reproducing these bumps on the thin-film crossover substrates and bonding semiconductor devices without bumps to the substrate. The limitation of procuring bonding bumps on commercial chips, is therefore greatly relieved.

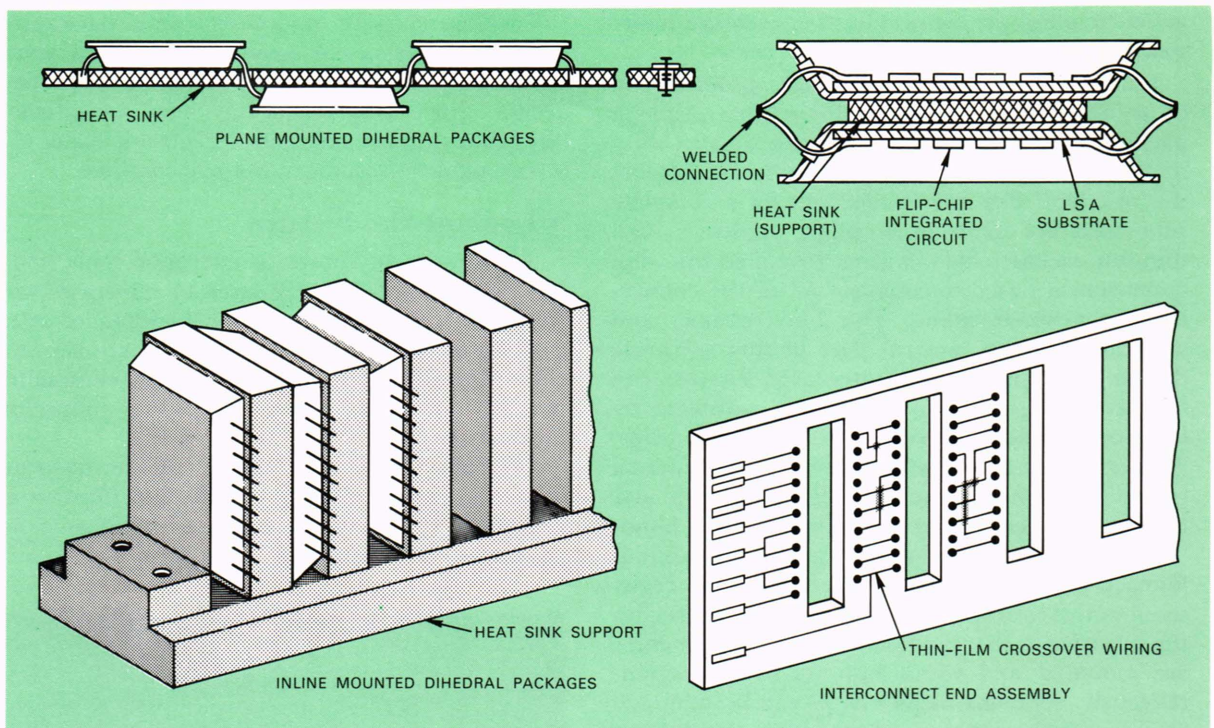


Fig. 8—Multiple package assembly of large-scale arrays.

Large-scale arrays are now a reality as the photograph in Fig. 7 demonstrates. These packages are assembled into systems with due consideration to circuit complexity, package types, interconnection simplicity, thermal power dissipation, economy, and reliability. A multipackage assembly must provide connection between packages, adequate heat dissipation, and environmental protection. One such multipackage concept is shown in Fig. 8. The leads from individual packages are welded to a thin-film crossover mother board which also serves as the main connection of the assembly to the next functional subsystem. The package mounting structure provides a heat flow path away from the packages. This structure can be designed in a range of sizes and shapes to provide for variations in power dissipation from the large-scale array packages. Environmental protection is provided by hermetically sealing each array package in an inert gas under very clean conditions. Further protection from use and handling can be provided by encapsulation of the assembly.

This account of the progress and evolution of microelectronic packaging may stimulate new ideas in packaging and in systems design. However, there may be a more significant effect. A high-performance, low-power-level large-scale array may become a "black box component" representing a whole block in a system block diagram. This is an important departure from implementing system designs by development of circuits using currently available individual components.

Capabilities developed through new microelectronic techniques in reduction in volume, decreased power consumption, and an increase in packaging density suggest a shift in design concept from the component level to the system level. As an example, a design currently conceived as strictly an analog system may be redesigned as a digital system to achieve either increase in the number of functions or improved performance.

Predicting the effect of microelectronic packaging on system design concepts is a difficult task. The future growth of microelectronics will depend on using the system design approach and injecting microelectronic technology, at that point, rather than continuing down the path of miniaturizing one circuit after another by applying similar techniques. The development of microelectronic technology at the system design level can be accomplished only as a part of a specific educational program. As an example, grouping specialists of each discipline on a team working together on a new system design would not only accelerate the development, but would also provide an acute incentive for learning. A significant interchange of knowledge is no longer a suggestion, but a defined need.