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FUTURE DEVELOPMENT OF ELECTRONIC COMPONENTS

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The rapid progress of semiconductor products in the electronic industry over the past two decades in the group of active components has not been matched by an equal progress of the passive components. Integration has blurred the traditional boundary between components and circuits. With integration penetrating deeper and deeper into electronic circuitry the connecting methods of the IC with the rest of the system becomes a cost and quality determining factor of prime importance. It is stressed that connecting methods of the other, passive components have to be compatible with the connecting method of the IC.

1 INTRODUCTION

Over the past two decades the progress of semiconductor development – from simple diodes, through transistors, to integrated circuits – has had far-reaching effects on many aspects of electronic design. Notable, for example, has been the shift to much lower currents and voltages than were used with vacuum tubes. Still more significant, though, is the way the integrated circuit has blurred the traditional boundary between components and circuits. The distinction between a circuit designer and an *integrated* circuit designer is progressively narrowing. Before long, it may vanish – and, in fact, in many cases it probably should.

But, while semiconductors were forging ahead, other electronic components and the ways in which they are assembled into circuits changed very little. Will this situation continue, or will the electronic equipment of tomorrow be very different from what we know today? What changes are in store?

2 THE PRESENT SITUATION

Before undertaking any predictions about future developments, let us divide electronic components into the traditional two classes: *active devices* and *passive devices.* Under the heading *active devices* we can then make a further division into *solid-state* and *vacuum tube* or *gas-filled* devices.

Although vacuum tube circuits have, for the most part, already been taken over by solid-state, there is no doubt that the cathode ray tube and the picture tube will be with us for some years to come. In all probability, so will the camera tube, though its life-expectancy may be shorter. Its driving circuitry is already solid-state, and solid-state replacements for the tube itself are well on the way. Only cost and performance are holding them back. Apart from these two pockets of resistance, the solid-state invasion of vacuum tube territory that started fifteen years ago is almost complete.

In solid-state, the integrated circuit is clearly the pace setter, although in some applications discrete semiconductors will be hard to replace for a long time. But designers of electronic equipment will in future tend to think first about how much they can

TABLE I
Active devices

Solid-state devices	*Vacuum tube devices*
Diodes	Transmitting and receiving tubes
Rectifiers	Picture tubes
Transistors	Oscilloscope and other cathode ray tubes
Thyristors, triacs	
Integrated circuits	Camera tubes
Solid-state displays	*Vacuum or gas-filled displays*
Light-emitting diodes	Cathode-ray tubes
Liquid crystals	Gas-discharge tubes
Electrochromic displays	Fluorescent displays
Passive devices	
Resistors	
Capacitors	
Inductors	
Other frequency selective elements	
Memory cores	

integrate, and only after that about what external parts or functions they will have to add on. These add-on parts – mainly passive – will have to match the new generations of integrated circuits in terms of size, method of assembly, dissipation, operating voltage, and other properties. Thus, before we can make any realistic predictions about the future of passive components, we must try to foresee which way integration will go.

3 TRENDS IN INTEGRATION

To begin with, we must distinguish between *digital* and *analog* integrated circuits. In general, digital circuits are easier to integrate because many functions can be put on one chip and inter-connected. Higher orders of integration scarcely affect the number of outside contacts that have to be provided. For example, an integrated 1024 bit random access memory (RAM) may need as few as 18 contact pins, because timing, coding, and decoding circuits can all be put on the same chip. But exactly the same number of contact pins will also suffice for a 4096 bit RAM!

Analog ICs, on the other hand, cannot always incorporate complete functions. Resistors with very high or very low values of resistance, or very close tolerance, are impossible; inductors and medium or high value capacitors cannot be integrated either. Nevertheless, it pays to integrate as much of the circuit as possible, provided it is to be manufactured in large quantities. The larger the quantity, however, the more important becomes the interconnection of other components with the IC as a factor in overall costs. Let us therefore take a look at the present and future possibilities for making interconnections between an IC and the rest of a system.

4 CONNECTING THE IC WITH THE SYSTEM

Comparing the spacing of contact pads on a typical integrated circuit with that of the holes in a printed wiring board, we find at least an order of magnitude difference: 0.2 mm versus 2.5 mm. In one way or another we have to overcome that difference. The commonest way is to use an intermediate "frame grid" (Figure 1), a diecut metal frame to which the contact pads of the IC are connected by thin gold or aluminum wires. The IC chip is then enclosed in a plastic moulding outside which the leads of the frame grid are bent through 90° to fit into the holes of a printed wiring board (Figure 2). This is the well-known dual in-line package ("DIP" or "DIL"), the most popular form of IC package now in use and, probably, for some years to come.

However, there are reasons to doubt whether this method of packaging is in fact the most economical one. Originally, when the manufacture of integrated

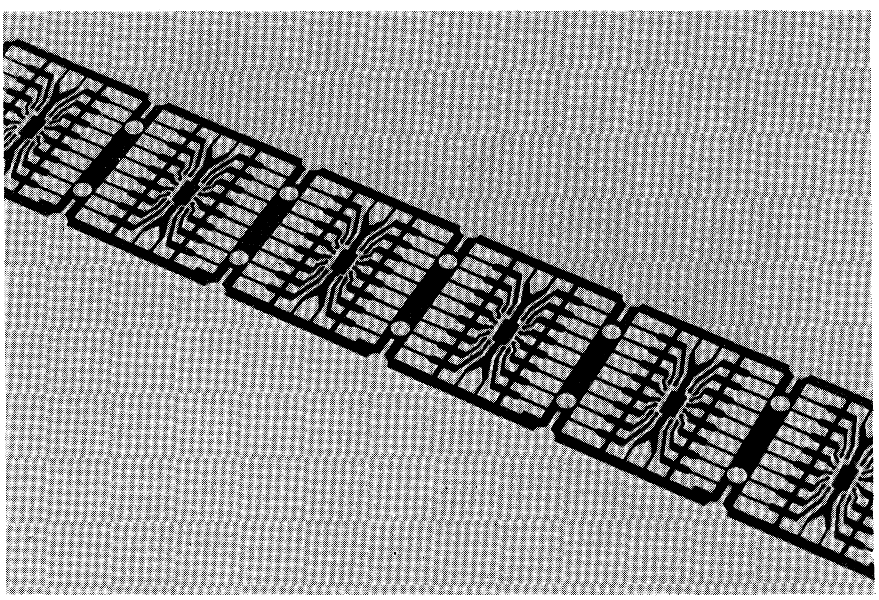

FIGURE 1 Frame grid used for integrated circuit assembly (Approx. x0.8)

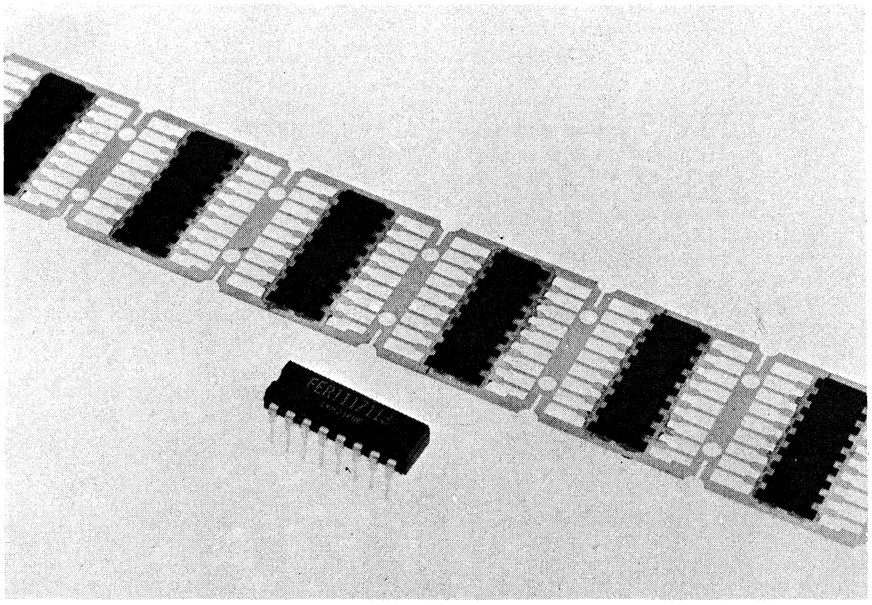

FIGURE 2 Plastic moulded integrated circuits in frame grid and showing the Dual Inline Package. (Approx. x0.8)

circuits was still in its infancy, the cost of the silicon chip constituted a major part of the cost of the finished product. Today, however, it accounts for only a fraction of the total cost. With increasing diffusion yields, the added value of the wire bonding and transfer moulding, plus the value of the materials used in them, has become many times more than the value of the chip itself. The same thing has been evident for some time in silicon planar transistors, where the cost of the silicon chip may represent less than 10% of the total.

It is worth while to take a critical look at the costs of matching the micro-dimensions of the silicon chip to the mini- or macro-dimensions of the rest of the circuit. Particularly so in view of the economically motivated trend to cram as much circuitry as possible onto a single chip. Interconnections that cost many times more than the actual circuit would defeat the purpose of the whole exercise.

There are four ways to lower the cost:

Get rid of the wire bonding

Get rid of the frame grid

Replace transfer moulding by a simpler surface protection or passivation

Make the match between micro-circuit and macro-circuit better, either by finding a cheaper matching pattern or making the macro-circuit smaller.

Any of these will help. If we can avail ourselves of all four, so much the better.

Two of the world's largest electronics companies, Bell Telephone and IBM, have already come to grips with the problem, and each has chosen a different solution: beam-lead and solder-ball contacts. Both of these meet the first three of the conditions listed above, though neither has yet gained wide acceptance by other companies.

Beam leads are small metal beams, usually of gold, projecting from the sides of the silicon chip (Figures 3 and 4). By combined application of heat and pressure (thermo-compression bonding) the chip is attached to a thin film on a glass or ceramic substrate.

Solder-ball contacts (Figure 5) can be plated or evaporated onto the integrated circuit. The solder, usually lead–tin, is separated from the aluminum metallization of the silicon by another metal (nickel, zinc, or chromium is often used, in combination with copper or gold). The chip is attached to a thin- or thick-film substrate by reflow soldering.

Another variation is to evaporate *aluminum bumps* onto the contact pads of the integrated circuit. The chip is then ultrasonically welded to the thin-film substrate. In yet another method the chip is *wire-bonded* to the substrate (Figure 6). Owing to the

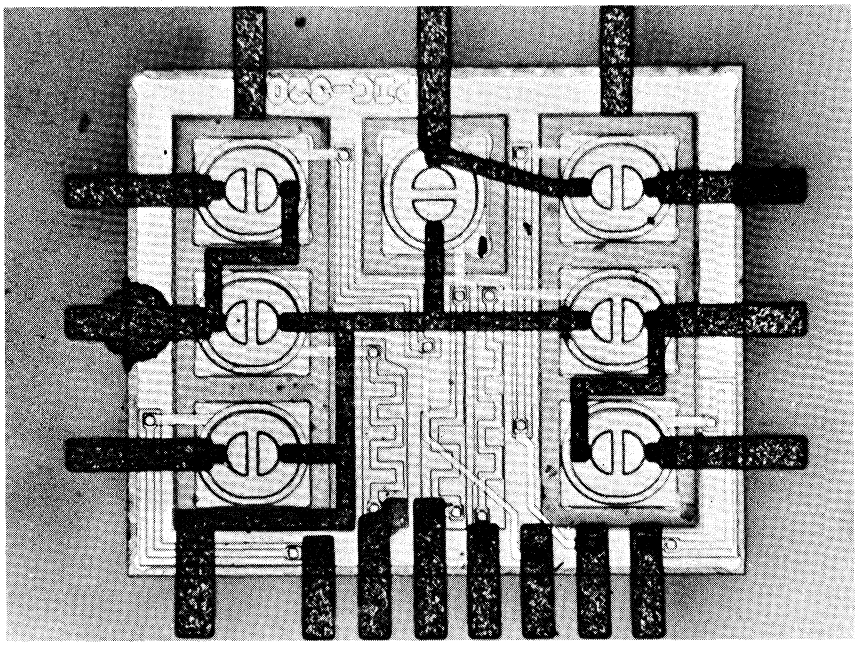

FIGURE 3 Integrated circuit chip with air isolation and beam-leads. (Approx. x40)

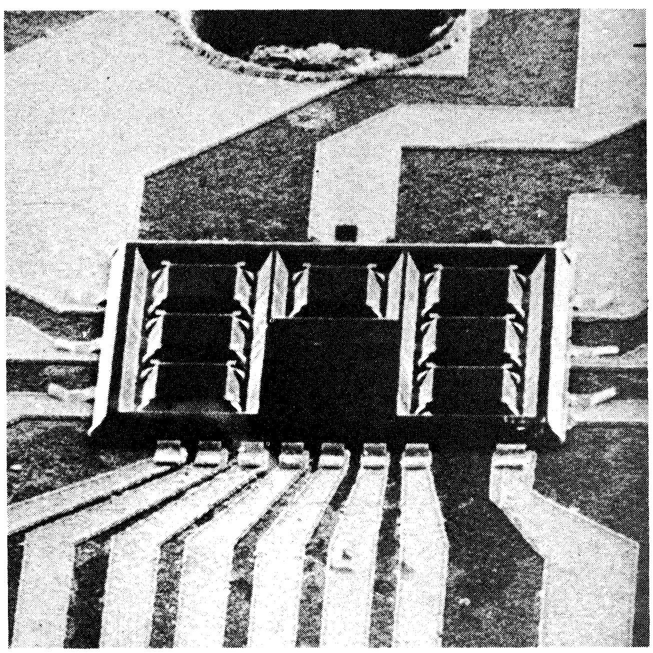

FIGURE 4 Integrated circuit with beam-leads from Figure 3 bonded to a substrate by thermal compression. (Approx. x30).

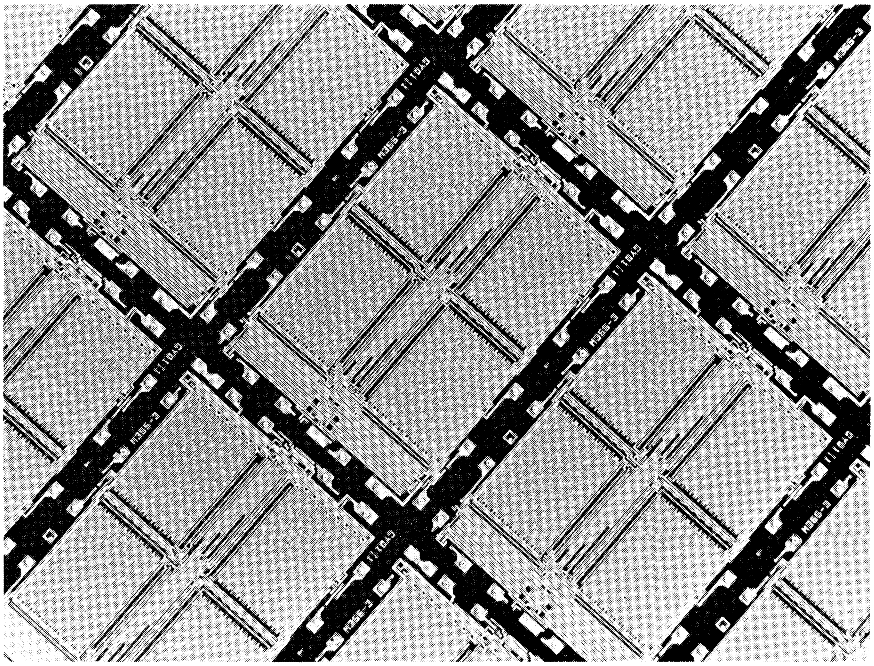

FIGURE 5 Silicon wafer with 1024 bit MOS memory chips with solder-balls (Approx. x12).

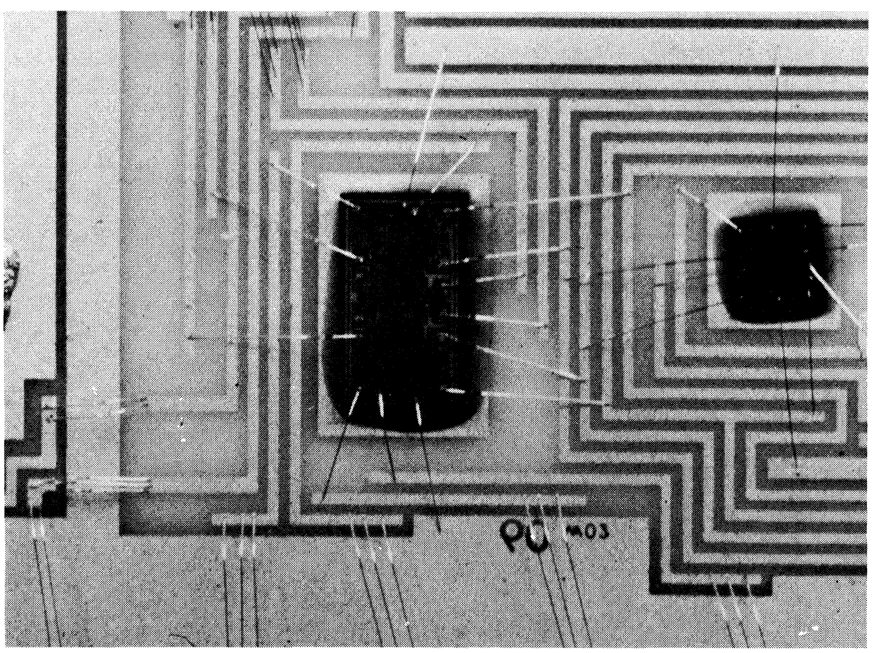

FIGURE 6 Wire bonded silicon chips on a hybrid substrate. (Approx. x10).

unavailability of the special chips required by some of the alternatives, this method is often used nowadays. In all of the methods so far described, however, the chips bonded to the thick- or thin-film substrate are naked, so still another process step is necessary: passivation or some other means of protecting the chip against ambient conditions. Here, too, there are several methods in current use:

Sealing the silicon surface with a layer of silicon nitride;

Sealing the silicon surface with a layer of glass or quartz;

Protecting the mounted chip by layers of silicone or other lacquer;

Sealing the complete hybrid circuit in a hermetic envelope.

Although each has its own merits under certain conditions, the only absolute protection is the hermetic envelope; it is also the costliest.

5 QUALITY, PERFORMANCE AND COST

From the user's point of view there are only three criteria: quality, performance, and cost. With regard to cost, it is obvious that if the IC and the other components can be attached simultaneously – for example, by reflow soldering after positioning them all on the substrate with rosin flux – there will be a considerable saving. In this respect, solder bumps have a distinct advantage over beam leads and aluminium bumps, both of which require a preliminary bonding step.

As far as the cost of the chip itself is concerned, the beam-lead chip is generally more expensive than either of the bumped chips. Although a very reliable technique, it does have a thermal disadvantage; the thin gold beams do not conduct heat so well as the larger area bumps. For very high frequencies, however, it is the best technique available: the beams lend themselves naturally to use in microstrip circuits.

To avoid unnecessary and costly repairs, the chips must of course be completely tested before bonding. It is useful, however, if they can be removed and replaced. All three types we have discussed so far can in fact meet these requirements, but testing, handling, and replacement may indeed present some difficulties.

Yet another method of mounting, hinted at earlier in the suggestion to find a cheaper matching pattern between micro-circuit and macro-circuit, is the application of a thin, fanned-out pattern of metallization to a high-temperature resistant kapton (polyimid) film or foil (see Figure 7). One form of this, known in the U.S.A. as "mini-mod", is used to attach integrated circuit chips to printed wiring boards; many electronic cameras use such assemblies.

The advantages of foil mounting are numerous. Complete testing of the chips before assembly is easy. The foil is resilient enough to be attached to a printed wiring board that has a coefficient of expansion quite different from that of the silicon chip. Foil-mounted chips can even be supplied on reels if necessary (see Figure 8), which not only makes testing easier but

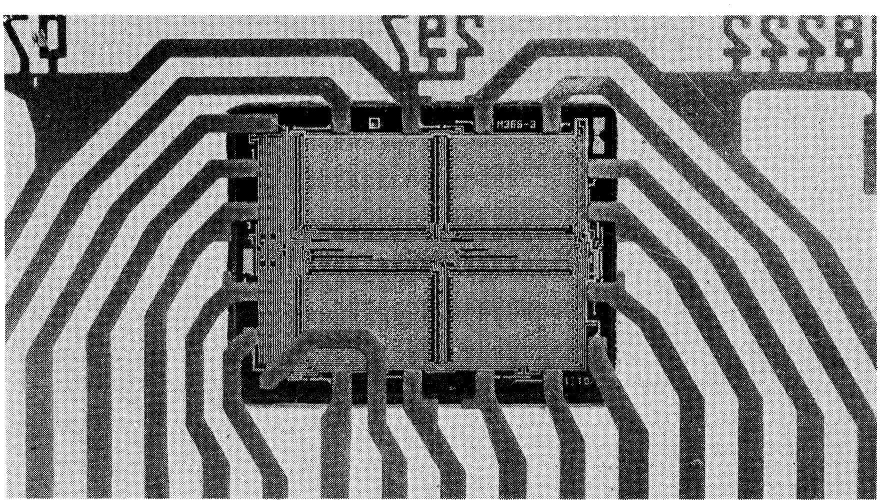

FIGURE 7 1024 bit MOS memory chip with solder-balls attached to polyimid foil (Approx. x12).

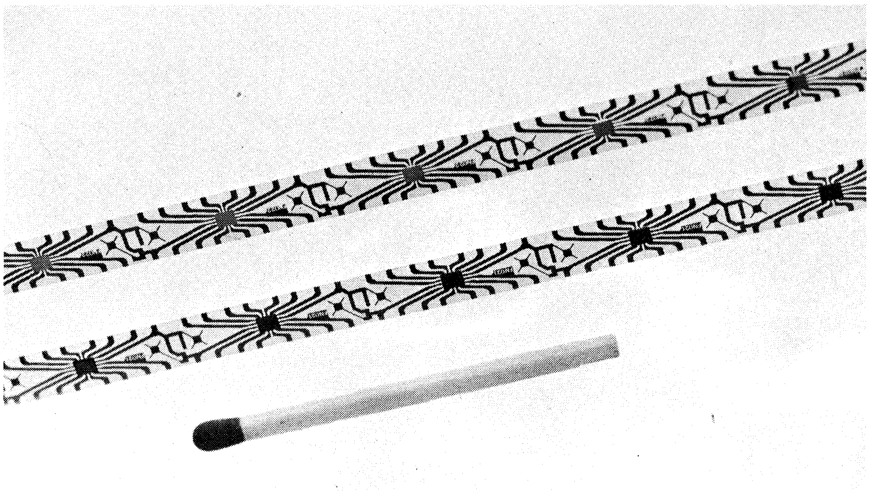

FIGURE 8 Integrated circuit chip mounted on polyimid film, to be used on reels (Approx. x1.6).

also facilitates handling in automatic assembly machinery.

Because neither bump nor beam-lead chips are widely available, producers of hybrid circuits usually buy normal IC chips, solder them to a substrate or bond them with an epoxy glue, and then wire bond from the chip to the substrate with gold or aluminium wire (see Figure 6). Although this "flying wire" bonding is costly, it is about the only means of attachment possible. To protect the bonding wires against damage, the whole hybrid circuit has to be either lacquered or encapsulated.

For discrete elements, a special small encapsulation, the SOT 23, has been developed (see Figure 9). Several European firms make transistors and diodes in this envelope, and its use is steadily increasing (Figure 10).

6 ADAPTING PASSIVE COMPONENTS

In discussing the consequences of these developments for passive components, we must bear in mind that whatever changes may take place will do so over a

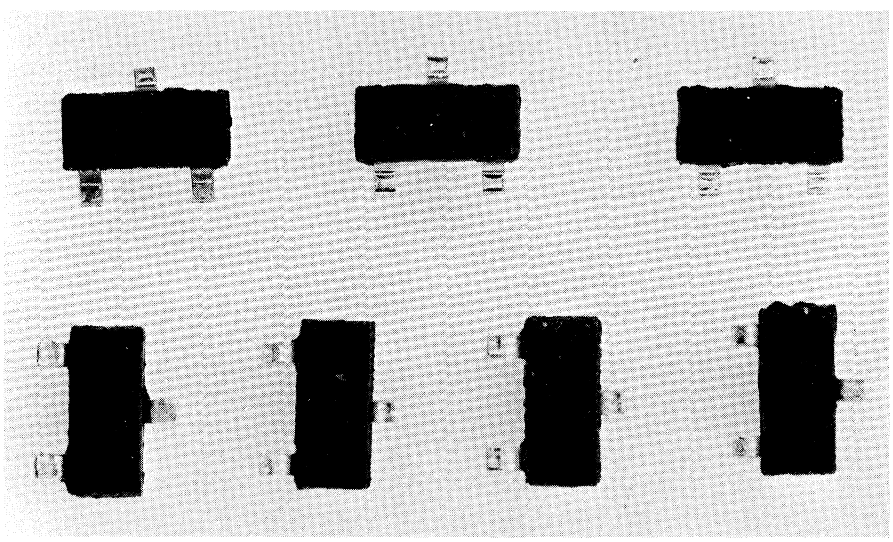

FIGURE 9 Miniature transistor in SOT 23 encapsulation (Approx. x8).

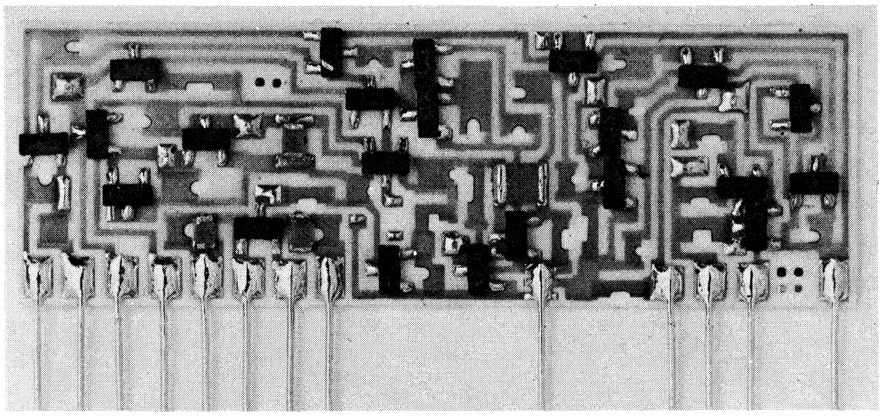

FIGURE 10 Hybrid circuit using SOT 23 encapsulated transistors (Approx. x2).

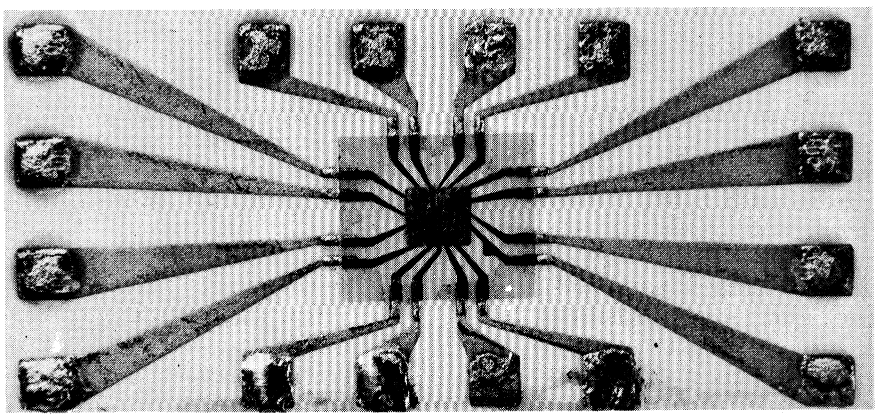

FIGURE 11 Integrated circuit on polyimid film, mounted on a ceramic substrate (Approx. x8).

considerable period. Today, most electronic circuits are mounted on printed wiring boards, using the traditional forms of axial-lead or single-ended passive components (depending on the method of insertion used). Of the active components, the diodes usually have axial leads, transistors are single-ended, and integrated circuits are nearly all in the dual in-line package. In the next few years this scheme of things will certainly not vanish, and the only important modification that is already making headway is the use of ICs mounted on kapton film (Figure 11).

More and more people are becoming convinced, however, that we will have to exploit more fully the potential cheapness of unencapsulated IC chips in the future. Hybrid thick- or thin-film circuits will then be a prime necessity, but unless the other components are also compatible with mounting on such a substrate, the cost advantages of inexpensive IC chips will for the most part be lost.

This virtually rules out the beam-lead chip in the medium frequency range, leaving us with the question: Can we make reflow soldered passive components economically available? Thick- and thin-film resistors have already been used to some extent, and so have special resistor chips. Capacitors are more difficult. Single- and multi-layer, single-ended, ceramic capacitors are now in production (see Figure 12), but the available capacitance range is limited; their size is also something of a drawback, as is their price. This last is in part due to the low production volume, but it is not expected that multi-layer ceramic capacitors will ever be very cheap. Small aluminium and tantalum electrolytic capacitors (Figure 13) are also becoming available. Here again, however, price is heavily dependent upon production volume.

Inductors are hard to fit into the hybrid circuit scheme, unless they can be plated on as is done in the

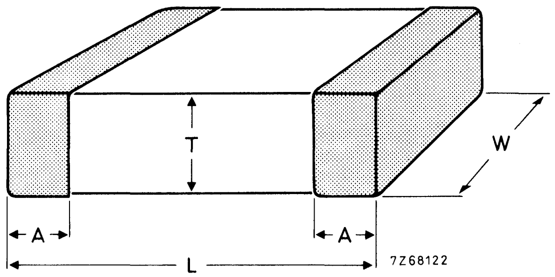

FIGURE 12A Ceramic chip capacitor.

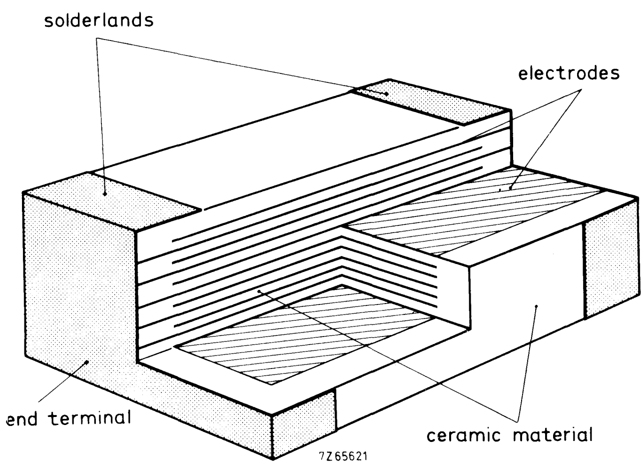

FIGURE 12B Multi-layer ceramic chip capacitor.

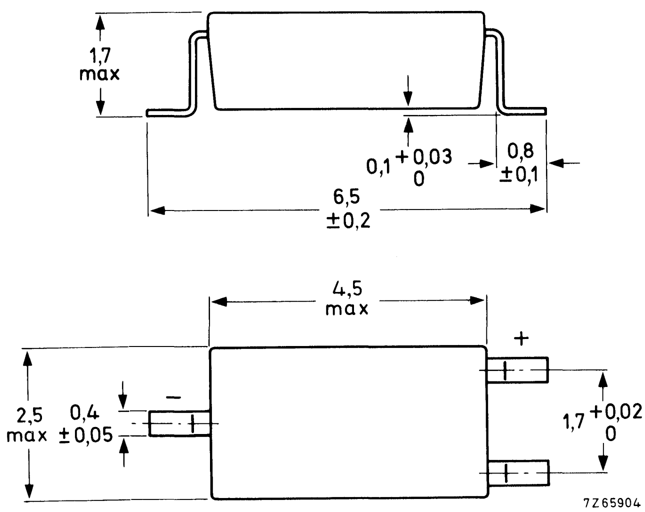

FIGURE 13 Tantalum capacitor for mounting on hybrid circuits.

uhf range. Other frequency selective elements in solder-on form are therefore badly needed. Ceramic filters for the lower and medium ranges, and surface-wave filters for the higher frequencies are possible solutions, provided that they can withstand the soldering operation.

Earlier attempts to mass produce hybrid circuits – in consumer products, for instance – have often failed because the manufacturer was forced to use cheap, standard components that were available but incompatible. Now the question is, will compatible, economically feasible sets of components be available in the future? If not, then it will be necessary to design around them. To a large extent, that is already being done in the development of monolithic ICs. Some of the design rules state, for example:

A resistor is expensive; a resistor with a very high value is impossible; and all values may have a large spread with respect to nominal.

A capacitor can only be of very low value; like a resistor, a capacitor is expensive because it takes up too much "real estate".

A small-signal transistor is cheap.

There are of course many others. But in spite of the limitations they impose, it is still possible to come up with designs that are in all respects as good as, or even better than, could be made using discrete components.

Before ICs can take the place to which their inherent cheapness entitles them, we must therefore come to terms with the problem posed by the passive components in hybrid circuits. Either they will have to be made available in a compatible form, or designers will have to learn to use them sparingly and design around them, taking advantage of the additional possibilities offered by integration technology. In this respect, the adoption of digital techniques in preference to analog could be of great help. If that were done, complementary and single-channel MOS would very probably become the preferred technologies.

7 CONCLUSIONS

Although integrated circuits will undoubtedly set the pace as solid-state continues to drive out the vacuum tube, that pace may be limited by the speed with which compatible passive components and interconnection systems can be made available.

For frequencies up to 1 GHz, the solder-ball contact between IC and substrate is the method of choice. Above that frequency, beam leads are preferable though more expensive. For matching the contact patterns of ICs either to printed wiring boards or to thick- or thin-film substrates, kapton film is a useful and convenient mounting vehicle.

International standardization of components for hybrid circuits is badly needed. However, to avoid some of the difficulties now associated with passive components in particular, it is possible to design around them. This might eventually lead to digital solutions for analog problems.