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Development of Interconnection Technology for Large-Scale Integrated Circuits

The size, cost, reliability, and serviceability of modern large data processing systems are influenced by the electrical interconnections required among the hundreds or thousands of chips they contain. The development of the complex interconnection design scheme is profoundly influenced by the interactions among the component and subassembly designs: modules, printed-circuit boards, cables, connectors, etc. The design scheme is also strongly affected by the constraints imposed by manufacturing process limitations and by environmental factors, such as cooling and corrosion. This paper deals with these interactions and constraints as encountered in the interconnection design of the IBM 3081 system and the design discipline required to deal with them.

Introduction

In the early 1960s, a system which had ten thousand active circuits was considered large. The recently introduced IBM 3081 Processor Unit (Model D) contains up to 27 field-replaceable modules with an average of about 30 000 circuits per module, or approximately 800 000 active circuits [1]. This enormous data processing power must be kept available in order for it to be useful. Its sheer size and complexity, however, make it difficult to design for high reliability and repairability characteristics. Even if it were possible to isolate and test the circuits individually, such a scheme would be impractical because of the very large number of circuits. A much better strategy is to subdivide the system into conveniently smaller numbers of replaceable modules, and to design into it a diagnostic scheme which will identify the faulty modules. If a faulty module can be easily replaced with a new one, the repair may be completed and the system restored to normal operation.

In practice, however, this requires that the module in the 3081 machine must be provided with 1800 pluggable contacts to provide it with the necessary electrical power and signal interconnections. The multilayer ceramic substrate used in the module (known as the Thermal Conduction Module) which carries the large-scale integrated circuit chips and interconnects them is 90 mm^2 [2]. To accommodate 1800 connectors in this size area, the connectors must be packed in a very dense array. In fact, a staggered square array of 2.5-mm diagonal was chosen in the design of the high-density printed-circuit board that supports and interconnects the modules [3]. The center-to-center spacing between nearest neighbors is 1.8 mm.

Each of these very small connectors must satisfy certain mechanical requirements. First, the force required to engage them must be kept moderate; if each connector requires 1.1 newtons, the force needed to actuate the entire array is nearly 2000 newtons (about 450 pounds). Supporting such a large load on such a small area requires a very sophisticated mechanical design.

Next, the wear damage suffered by each connector as it is mated and unmated repeatedly during its life must be controlled to maintain contact reliability. Finally, the design must be forgiving enough so that no contact will fail to properly engage its mating contact during any of the actuations. The latter requirement is particularly challenging because the best achievable manufacturing tolerances can accumulate to yield an uncertainty in the location of any one contact in the array.

In addition, certain electrical requirements must be fulfilled. To ensure that the supply voltages can be held within appropriate limits, the ac resistance must be held to a low and very constant value. Also, as the module ages and is repeatedly removed and replaced, the maximum tolerable change in contact resistance is only a few milliohms. Finally, as the current demand of the module varies, a voltage is induced across the inductance presented by the connector; to ensure that this induced voltage (commonly called ΔI noise) does not disrupt normal operation of the switching circuits, the inductance of each connector must be held to a few nanohenries. This implies that the current path from the printed-circuit board, to the modules, through the connectors, must be very short—somewhat less than a centimeter.

In summary, very stringent electrical, mechanical, and reliability requirements are imposed on the separable electrical connectors to be used in the very large data processing systems made practicable by modern large-scale integrated circuit technology. No pre-existing connector design was able to satisfy these requirements.

This paper describes the rather sophisticated design features which allow the new array connector to meet these technical challenges. We first provide a background discussion of the IBM 3081 packaging design scheme and of the theoretical, technical, and practical considerations which influence the connector designs. We then proceed to describe the physical means by which these various design requirements are concurrently satisfied. We conclude with a summary and integration of the objectives, philosophy, and implementation of the packaging design, with particular emphasis on the connectors.

New array connector and its packaging environment

As previously mentioned, the integrated circuit chips are contained within a module which supports, protects, interconnects, and cools them [2]. The module consists of an aluminum alloy shell (which accommodates a cold plate on the top in which chilled water is circulated) and a ceramic substrate on the bottom. The chips are soldered to metal pads on the top of the substrate. Metal-filled via holes in the ceramic provide interconnections from these pads to the internal wiring planes and thence to the array connector. An array of 1800 connector pins are soldered to the metal pads on the bottom of the substrate.

The pins mate with a corresponding array of bifurcated spring contacts whose tails are soldered into plated through-holes in the multilayer epoxy-fiberglass board [3]. The board contains both wiring planes for signal interconnection and solid copper power distribution planes. Appropriate connections are made with the through-hole barrels by photolithographic means. The edges of the board contain arrays of somewhat larger bifurcated spring contacts in a 2.5-mm grid. The edge arrays accommodate cables which provide signal interconnection among boards of the 3081 Processor Unit and between these boards and the rest of the system.

Connector design considerations

An examination of the physical phenomena involved in establishing a reliable electrical connection between two apparently flat pieces of metal brought into contact shows that, since no surface can be made perfectly flat, the first few points of contact are likely to be high points, or asperities, on the surface of one piece bearing against asperities on the other. As the load, the force with which they are pressed together, is increased, the asperities which are in contact compress and collapse, first elastically and then plastically. This allows additional asperities to make contact. The regions of intimate metal-to-metal contact thus created are usually called "a-spots," after the nomenclature of the pioneering researcher Ragnar Holm [4], and are typically very small at moderate loads, even with carefully polished and cleaned surfaces. The a-spots typically account for virtually all the electrical conduction between the two surfaces.

A metallic surface exposed to the atmosphere is almost instantaneously covered with several atomic layers of adsorbed gases. This film, which covers otherwise clean noble metal surfaces, can support moderately high mechanical loads. It is, however, usually disrupted by increasing the contact load to a level which will cause local plastic deformation of the metal. This is especially true if wiping motion occurs. The effects of adsorbed gas films are seldom perceptible in practical connector designs. The thicker solid films, however, may have a significant effect. A solid film even a few nanometers in thickness may be able to support the mechanical load, leaving the metallic surfaces effectively insulated from each other. Low-resistance electrical connection can be established only if the film is broken down by either electrical or mechanical means. Electrical breakdown usually requires higher potential differences than are available in most digital circuits.

Mechanical breakdown of tarnish films is a two-step process. First, the load must be increased until sufficient deformation of the metal occurs to cause the brittle tarnish film to fracture. Then, a relative shearing motion must be established between the two metal surfaces to displace the fragments and establish clean metal-on-metal contact. If the curvatures of the surfaces are small, rather long sliding wipes will be required to accomplish this and the fragments will tend to be embedded rather than being displaced laterally. The same is true, of course, of foreign particles which may have been deposited before the surfaces were brought into contact. If the surfaces are repeatedly unmated, recon-

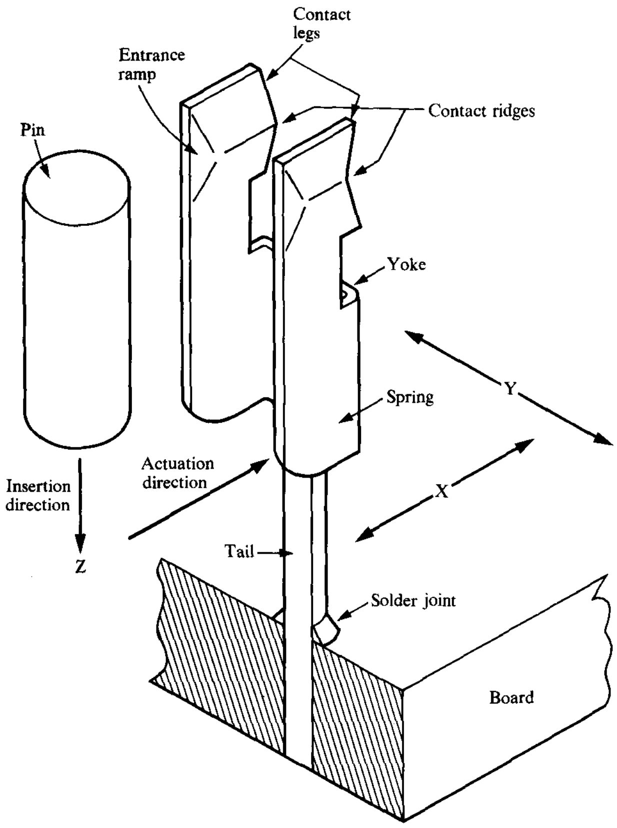

Figure 1 Connector elements: 1800 connectors of this type form the array which mates a module with the printed-circuit board. All elements of the array must move simultaneously as shown.

taminated, and remated, or if the contamination is extremely severe, so much debris can embed in the metal that substantially all of the asperities in contact are nonconducting. The contact resistance would then be very high and extremely unstable.

Achieving high reliability in a low-energy electrical connector depends, therefore, on the fulfillment of the following design criteria:

1. Sufficient load and load-concentrating geometry to ensure that plastic deformation of the contact surfaces will occur.
2. Sufficient wiping motion to ensure efficient removal of debris from the contact area.
3. Pore-free noble metal coatings on the contact surfaces to ensure minimal film formation.
4. Precautions, such as effective lubrication, to ensure that porosity is not created by wearing through the noble metal coating during the life of the connector.
5. Mechanical durability sufficient to guard against breakage.
6. Dimensional tolerances controlled to ensure that each contact in the array will be captured by its mating contact as the connector array is mated.
7. Bifurcation to provide a redundant path for each electrical connection such that system failure will not result from the failure of any single contact.

Descriptions follow of some of the practical considerations associated with having the 3081 array connector meet these design criteria.

• *Contact pressure*

First, it is necessary to select a spring material of sufficiently high conductivity which will also allow the spring beam to develop adequate force over a sufficient deflection without risk of excessive permanent set or fracture. Beryllium-copper alloy C17200, ½H temper, heat treated at 315–343° C for two hours in an oxygen-free atmosphere, was chosen. A plated bifurcated spring of this material will then capture the pin. The pin, in turn, is stiff and strong enough so that its deflection is small. The spring is contoured to provide a lead-in ramp to facilitate capture of the pin and to guide it onto the cylindrical contact surfaces as it wedges the spring open. Thus, a crossed-cylinder configuration and contact redundancy are established. Allowing the pin to move further into the spring establishes adequate wiping action. (See Fig. 1.)

• *Contact materials*

Noble metal coatings must be provided on the contact surfaces, but which noble metals? All noble metals tend toward adhesive wear. As two surfaces slide against each other, asperities on one surface friction weld to the other surface. Small pieces of metal are thereby transferred from one surface to the other. If the hardnesses of the bulk material of the two surfaces are similar, the small pieces of transferred metal, having been severely deformed, are likely to be much harder than the surrounding material. They then provide sharp, hard edges to scrape away more material from the other surface. Some of these small pieces of metal can break free and be rolled between the two sliding surfaces to form small, hard balls of metal which, in turn, tend to embed in the surface. The result is rapid wear and a rough wear track. This phenomenon is called "galling." If, on the other hand, the asperities on one surface did not adhere to the other surface, they would tend to be flattened rather than being torn away. This would result in very smooth wear tracks of negligible depth, and this effect is called "burnishing." Noble metals wear in this mode only at very low loads.

Suppose, now, that one noble metal surface is very much harder than the other and that the harder surface is initially very smooth. Transferred material from the softer surface is still softer than the hard surface after strain hardening and

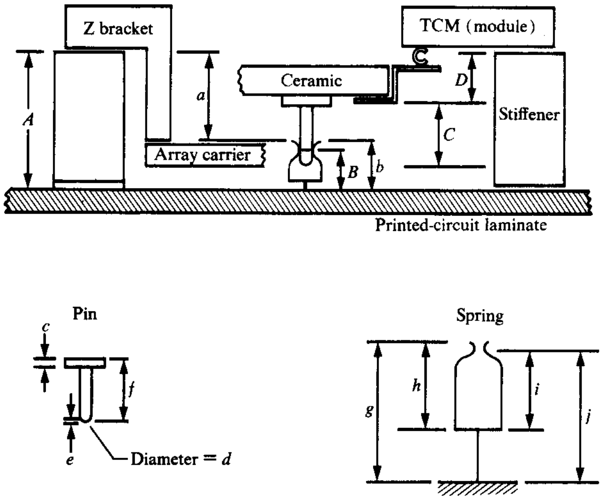

Figure 2 Key dimensions: The distance from the tip of the pin to its point of contact with the spring is given by the specified dimensions $B + C + D - A$. These, in turn, are composed of the dimensions of seven subcomponents and of the joints between them. The other key dimensions which must be precisely controlled are indicated.

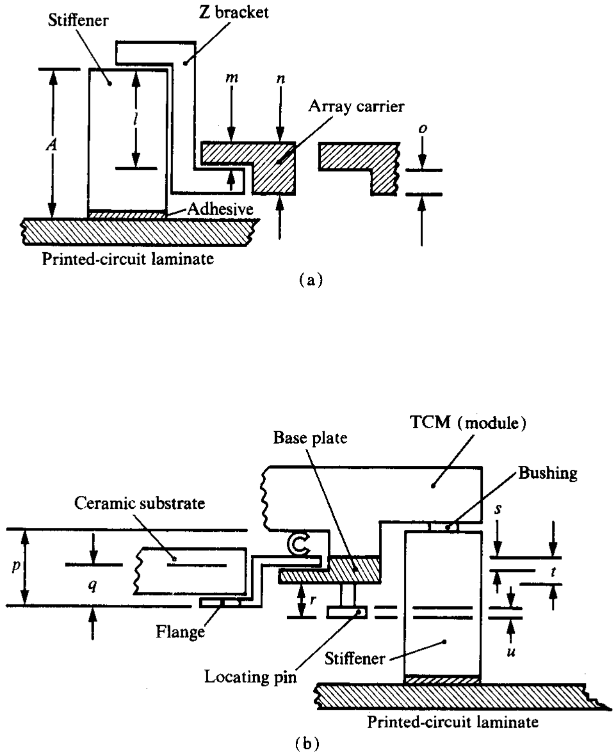

Figure 3 Key dimensions: Detailed sketches of (a) the array carrier and (b) the module indicate the critical dimensions which ensure engagement and noninterference during insertion and actuation of the array.

so tends to fill the slight depressions in the hard surface; the hard surface therefore tends to become even smoother with wear. The soft surface, in turn, develops a smooth, shallow wear track. Although this is not true burnishing because adhesive transfer of metal is involved, the end result strongly resembles burnishing.

Suitable lubrication will support some of the load during sliding, reducing the number and size of the asperity-to-asperity contact spots. When the sliding ceases, however, the hydrodynamic forces cease and the full load must be supported by the asperities which compress under the increased load, causing the contact spots to increase in size and number to approach the unlubricated situation. The liquid lubricant is able to flow out of the final contact area through the depressions in the two surfaces between asperities. The result of effective lubrication, then, is a significant reduction in wear rate and friction with little effect on contact resistance. The lubrication tends to discourage galling and to promote burnishing, which leads to much smoother wear tracks. The smoother wear tracks, in turn, enhance the ability of the connector to wipe away debris, rather than having it embed in the contact surfaces. The reduced friction leads directly to a reduction in actuation force of the connector.

• *Dimensional tolerance*

Each spring in the connector array must capture its mating pin on every actuation in order for the connector to function reliably. In the Z-axis (perpendicular to the planes of the printed-circuit board and substrate), the point at which the spring will make contact along its length is determined by several linear dimensions in tandem. (See Figs. 2, 3, and 4.) Local variations from pin to pin within the array are introduced by any out-of-flat variation of the board and substrate surfaces. The module is inserted into the board site along the

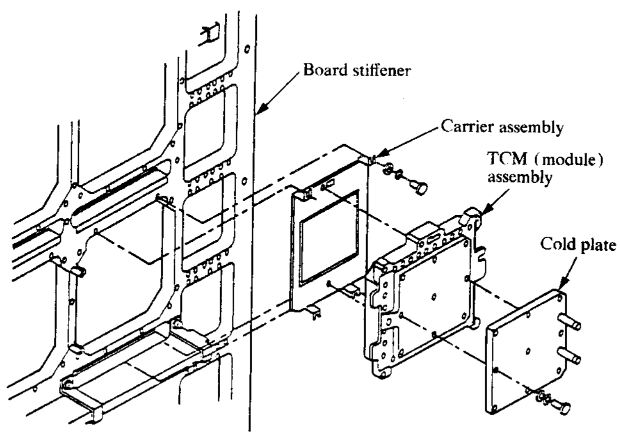

Figure 4 Module I/O connection.

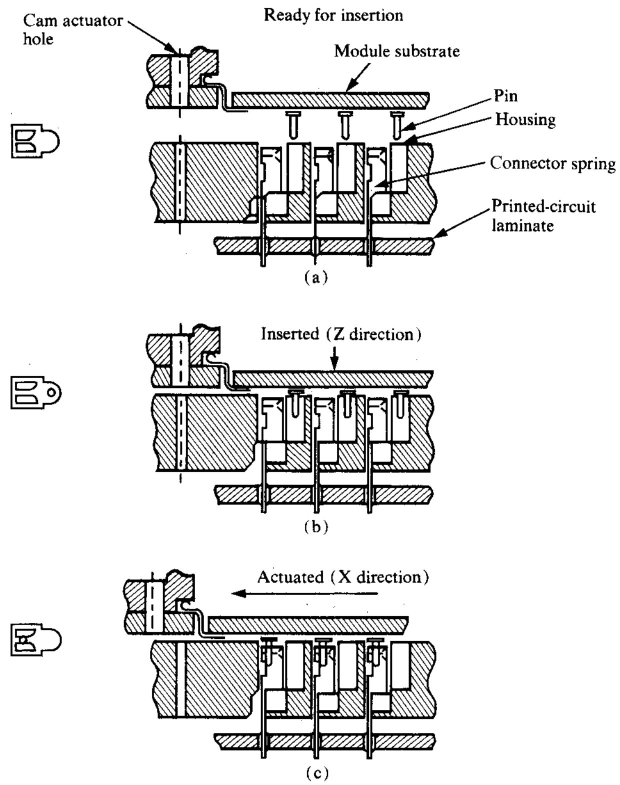

Figure 5 Module insertion: (a) Module is ready for Z-direction insertion. (b) Inserted—rough pin position guide. Pins have established precise pin and spring relationship—seating plane is established also. (c) Side actuation completed—pin entry and contact wipe complete—system is in neutral, minimum-stress position—contact is established and system is ready to operate.

Z-axis, then is actuated along the X-axis (see Figs. 4 and 5). After insertion and before actuation, each pin is positioned beside its mating spring, facing the entrance opening [see Figs. 1 and 5(b)]; actuation drives the pins into the springs [Fig. 5(c)]. Manufacturing tolerances required to ensure that this target is consistently met are achievable. As shown in Fig. 1, the spring consists of a bifurcated head which makes contact with the pin, and a thin post, or tail, which is soldered into a plated through-hole in the board. The height of the spring above the board surface is controlled by a cross-piece (called the *Z-stop*) on the tail of the spring which is too wide to enter the hole. By seating the Z-stop against the mouth of the plated through-hole (called the *land*), the spring is accurately located in the Z-axis.

The Y-axis alignment requirement is that the first contact of the pin with the spring must lie in the spring entrance ramp area. This permits pin capture by the spring as long as the pin center line is no more than 0.2 mm from the spring center line; this provides a target about 0.4 mm wide.

Misalignment within this limit is corrected by deflection of a very flexible spring tail. In fact, the Y-axis spring rate is so low that the full 0.2-mm deviation will cause the contact force to fall on one side (and to rise on the other) by less than 0.2 N. Thus, a nominal contact force as low as 0.6 N suffices to ensure an absolute minimum contact force of at least 0.4 N, necessary for adequate contact resistance stability.

In the X-axis, the tolerance constraints are that the pin must drive all the way through the lead-in area of the spring and wipe some distance along the ridges, but must not travel all the way through to strike the back of the housing. Failure to achieve the former criterion will produce unstable contact resistance because the pin will not be captured. Failure to achieve the latter will result in excessive force applied and hence permanent deformation of both the pin and the housing. The target in the X-axis is about 0.4 mm wide.

Finally, the spring must not be excessively twisted. If it were initially twisted 10°, the pin might drive it back until its corner would jam against the back of the opening in the housing. As the pin continued to advance, it would then apply a torque which would tend to increase the degree of twist on the spring. In this case, therefore, the pin, spring, and housing would all be subject to gross distortion. Repeated actuations would crush the spring, either by jamming one blade into the pin entry slot in the housing on attempted withdrawal or by failure of the pin to enter the lead-in area on attempted actuation.

• *Mechanical durability*

Given the small size of the contact members and the extreme reliability required, some resistance to physical abuse had to be incorporated into the connector design. For example, the pin stiffness is sufficiently high that it will not take a permanent set in normal handling or actuation. If the pin is overloaded, its ductility is sufficient to allow bending rather than breaking off, and it may then be straightened again using a simple tool. The strength of the pin-to-ceramic solder joint is sufficient to avert fracture during pin bending or straightening.

The springs also have sufficient ductility to permit straightening. The housing, however, restricts external access to and motion of the springs well enough to avoid significant incidence of spring damage by mechanisms other than those treated in the preceding section. The housing is also strong enough to support the 1000-to-2000-N load applied to the array during actuation without significant yielding. Finally, a guidance system is provided to prevent the pins from striking the array carrier housing during module seating, and the actuation mechanism is constructed in such a manner that under-travel, over-travel, and over-torque are prevented.

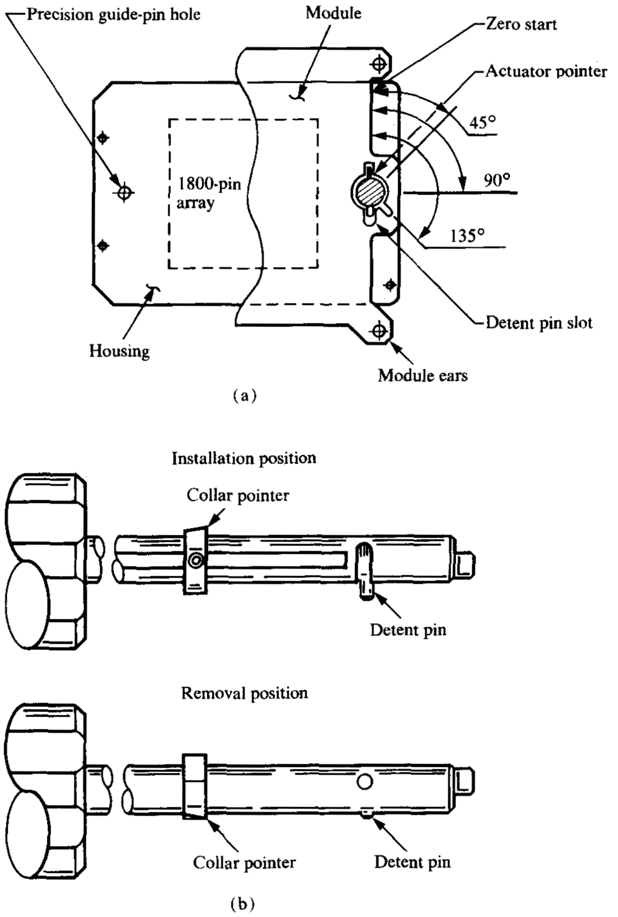

Figure 6 (a) Schematic for module actuation. (b) TCM actuation tool.

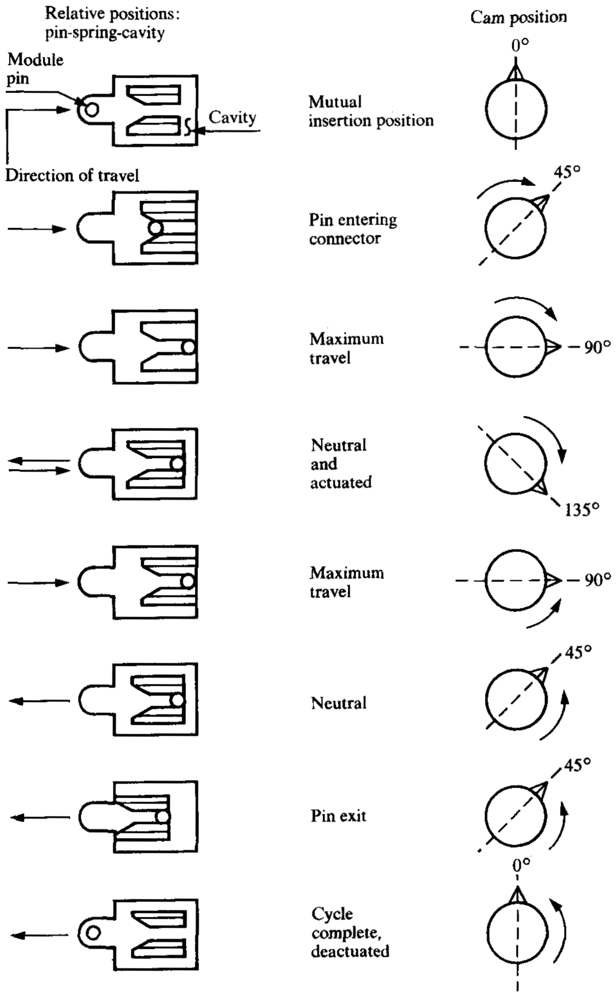

Figure 7 Module actuation: *From 0° to 45°*—the module moves freely; the 1800 pins move from the housing entry slots up against the entry angles of the springs. *From 45° to 90°*—the highest forces of actuation are experienced and the pins are driven the maximum travel of the system. *From 90° to 135°*—the module direction is reversed. It is allowed to move back approximately 0.125–0.250 mm to relax the system to its neutral position.

Design elements

• *Fail-safe actuation design*

The prime objectives throughout the mechanical design of the array connector have been minimizing the opportunity for human error to cause damage to the board or module as well as ensuring connector function after proper actuation. In the Z-axis, rough guide pins extending from the spring housing ensure that the module is correctly oriented and that the precision guide pins on the module will engage the corresponding slots in the spring housings. The precision guide pins, in turn, ensure that the module pins will enter the openings in the spring housing and align with the springs. Spring clips are put in place at this point to hold the module in its seating plane while permitting motion in the X-axis during actuation.

Placing the cam guard in position to accept the actuation camming tool ensures that the hold-down screws have not yet been inserted and, in fact, covers the threaded holes. This prevents any inadvertent attempt to cam the module without removing the hold-down screws.

These steps prepare the module for actuation, held in place by the spring clips with its motion constrained in the Y- and Z-axes by the heads of the precision guide pins riding the precision slots in the spring housing, yet free to move along the X-axis. The camming tool, set in the actuation position, may then be inserted through the hole in the module to engage its tip in the actuation slot of the spring housing (see Fig. 6). As illustrated in Fig. 7, clockwise

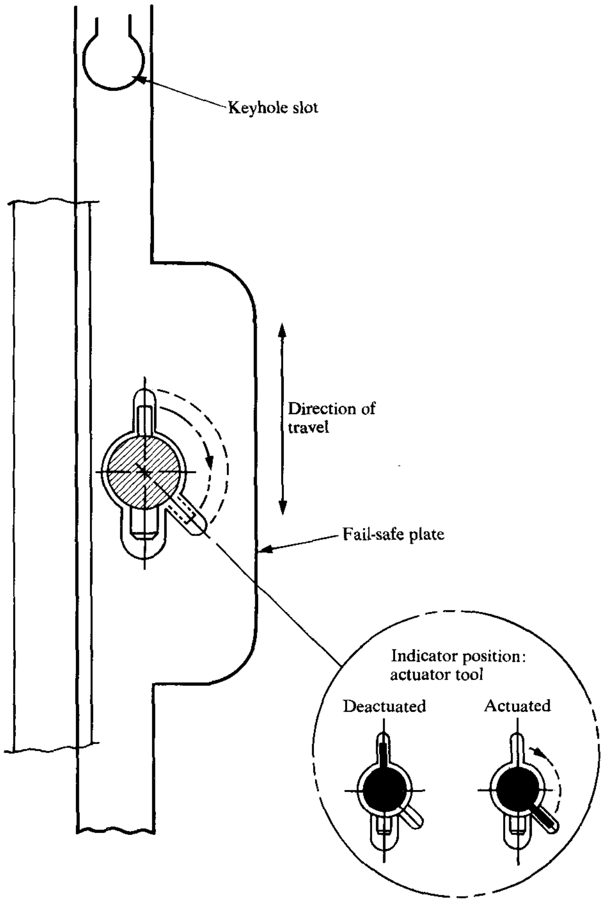

Figure 8 Fail-safe plate: The fail-safe plate prevents attempts to deactuate the module while the retention screws are in place.

rotation of the tool through the first 45° moves all the pins into the entry ramps of their mating springs while the precision guide pins maintain proper Y- and Z-axis location of the pins and the springs self-align to accept the pins. Rotation from 45° to 90° (top-dead-center position of the cam) drives all of the springs to the back walls of the openings in the spring housings. The pressure of the pins against the entry ramps wedges the blades of the springs apart while the pins climb the ramps to wipe along the ridges under full contact force and finally come to rest. If any pin should be driven too far, it will hit the back wall of the housing cavity and stop rather than slip out the back of the spring.

Rotation from 90° to 135° (past top-dead-center) reverses the direction of travel. The springs continue to grip the pins but travel forward in the housing cavities. Thus, the stresses on the spring housing, module, solder joints, and actuation cam are relaxed. At the 135° position, the actuation tool is freed for removal; it cannot be removed in mid-cycle. (See Figs. 5, 6, and 7.)

The actuation tool is then removed and a cam guard is shifted to allow the retention screws to be inserted and tightened. The actuation tool cannot then be reinserted until the screws are removed and the cam guard shifted back again.

The four captive retention screws serve to lock the aluminum module shell to the aluminum board stiffener. The effects of mechanical shock, vibration, and thermal cycling on the connector array are thus minimized. (See Fig. 8.)

Connector materials and process constraints

• *Structure of the pin*

An alloy of iron, nickel, and cobalt was chosen as the base material of the pin. The primary reason for this choice is that it provides a good match in coefficient of thermal expansion with the aluminum oxide substrate to which it is soldered. This serves to minimize the stresses induced in the solder joint by changes in temperature. The alloy also has high enough modulus and yield strength to ensure that elastic deflections and permanent set will be small during actuation.

The pin is plated first with electrodeposited palladium. This provides resistance to corrosion and also the hard surface required to ensure a favorable wear mode, while its electrical conductivity is high enough to allow the contact resistance to remain low and stable. Prior to the deposition of a final gold plating, the pins are diffused in an electric furnace to ensure maximum adhesion of the plating. The iron diffuses into the palladium more rapidly than the nickel or cobalt, producing a zone of iron-palladium alloy about 1 μm thick at the internal interface of the palladium plating. This enhances solder joint strength.

The final plating consists of electrodeposited gold. The gold surface resists organic contamination, enhances solder wetting, and limits the extent to which the solder fillet will climb on the pin. An upper limit must be set, however, on the gold plating thickness. Some of the gold in the wear track on the pin is transferred to the spring on the first actuation. Therefore, the actuation force rises sharply with increasing gold plating thickness on the pin (see Fig. 9).

During the soldering of the pin to the substrates and chip joining processes, some interdiffusion of the gold and palladium occur. The depth of the wear track on the pin increases rapidly during the first few actuations until the bottom of the gold-palladium alloy zone is approached. The wear

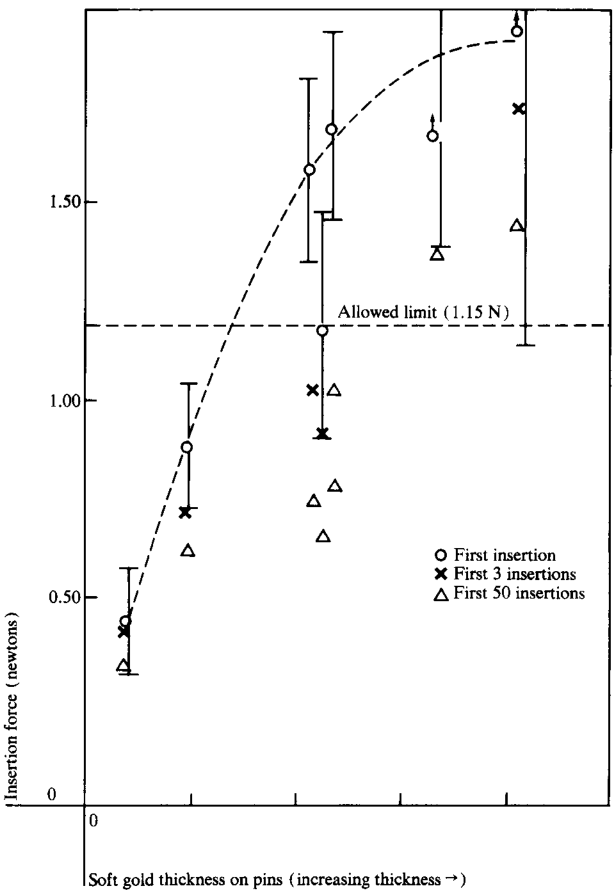

Figure 9 Insertion forces *vs* gold thickness: Increasing the gold thickness is not only costly but also increases insertion forces beyond acceptable limits. High insertion force results in incomplete connector mating and damage to connector pins, springs, and housings.

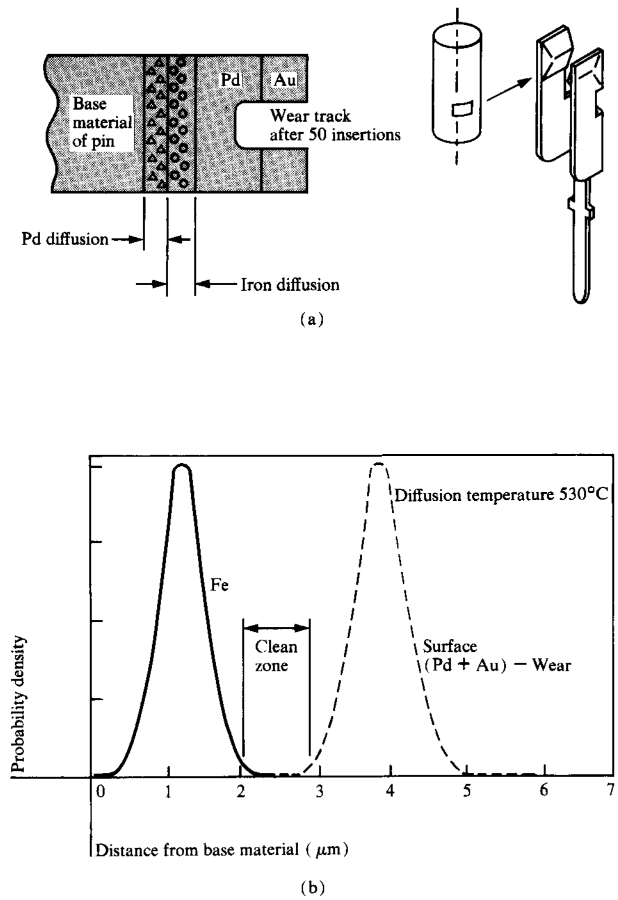

Figure 10 (a) Illustration of diffusion and wear track. (b) Final distribution of surface and Fe-contaminated zone at 530°C. Module heating cycles must be controlled to prevent iron diffusion out to the precious metal surface in the wear track. Any iron in the wear track represents a potential contact-resistance failure. A "clean zone" must exist to ensure connector reliability.

process then stabilizes with a smooth, thin layer of transferred gold on the bottom of the wear track and very little increase in wear track depth with further actuations as long as a continuous coating of gold remains in the wear track on the spring.

Ensuring that the connector pin satisfies all its design requirements (high solder joint strength, low and stable contact resistance, and low actuation force) demands, then, that a complex set of physical interactions be considered. The gold thickness on the pin must be precisely controlled to provide the minimum needed to ensure proper solder wetting while avoiding excessive thickness which would cause intolerably high actuation forces. The extent of solid-state diffusion in the connector pin must be controlled by controlling its thermal history. It is observed that the iron diffuses into the palladium plating much more rapidly than the nickel or cobalt. Thus, the deleterious effects of excessive diffusion are primarily the result of iron contamination in the wear track, which leads to corrosion susceptibility and a large increase in resistivity of the alloyed palladium. Both of these effects cause, in turn, sharp rises in the initial contact resistance and in the tendency toward instability with time. There may also be a deleterious effect on the wear rate.

Balanced against this is the need to provide a sufficiently thick diffused alloy zone to allow a workable time and temperature window for the soldering process. Thus, the plating thickness, the diffusion time and temperature, the soldering time and temperature, and the permissible number of chip-joining furnace cycles must all be simultaneously optimized. (See Fig. 10.)

- *Structure of the spring*

The basic material of the spring is beryllium-copper alloy C17200-½H. Its formability is evident from its ultimate elongation of 15–20% and its Rockwell hardness (about C21) as obtained from the mill in strip form. After stamping and forming, the contact springs are heat treated at 315°C for two hours in an oxygen-free atmosphere to precipitation harden the beryllium copper. This increases the hardness to C41 and brings the yield strength up beyond 1100 MPa while retaining about 3% ultimate elongation. The springs have, in other words, strength and hardness comparable to surgical steel without becoming excessively brittle and yet have about 22% of the conductivity of pure copper.

Next, the springs are electroplated with a sulphamate nickel to level some of the surface roughness caused by the forming and to facilitate subsequent plating. Then they are electroplated with palladium to provide corrosion and wear resistance. Finally, they are electroplated with gold to provide a low resistivity surface layer.

As the gold plating thickness on the spring is increased or its hardness is reduced, the actuation force is increased. Also, the thickness of gold required to achieve a given wear life on the spring is reduced as the harness is increased. This implies an advantage in selecting the hardest available electroplated gold in terms of securing a desirable reduction in actuation force.

The gold plating bath selected produces a deposit which contains up to 1% nickel in solid solution with the gold. This has the effect of greatly increasing the hardness without affecting the tarnish resistance or disturbing the favorable wear mode.

Mechanical analysis of connector spring housing design

The intended functions of the array connector housing are many. Not only must it protect the springs from accidental damage and electrically insulate them from one another, but it must also guide the module during insertion and actuation, support the 1000-N to 2000-N load developed on the 1800 springs during actuation, force the pins to clear the entry ramps, and control the length of wipe along the ridges of the springs. The last requirement demands a precision of 0.05 mm in the dimensions of the housing cavities which locate the springs.

The thermoplastic molding resin selected for this application is a flame-retardant polyphenylene oxide filled with 30% glass fiber. This material is capable of achieving the required dimensional tolerances and is strong enough to support the actuation load. Its dimensional stability under changes of temperature, humidity, and mechanical stress is adequate and it is inert to the stabilized hydrocarbon oil used to lubricate the connector array. Also, the reinforcement provided by the glass fiber in the resin brings the modulus of elasticity of the material up to a level which allows optimal elastic deformation during actuation.

Finite-element analysis of the critical displacements and stresses on the housing in the array cavity region and near the metal insert which carries the actuator slot has been performed. This was done to ensure an adequate safety factor against fracture, sufficient wiping action of the connector, and avoidance of contact between the pins and the back walls of the housing cavities. It also revealed, however, an explanation for the rather surprising observation that the peak actuation force of the array is considerably less than 1800 times the peak force developed as a single pin enters a spring. During actuation, the housing deflects enough that only about half of the pins seat simultaneously. The others seat a few at a time as the cam travel continues and the housing relaxes under the reduced stresses generated by the previously seated pins. In plotting the force *versus* travel as a single pin is pushed into a spring, it is observed that the peak force is developed as the pin reaches the top of the lead-in ramp. This peak force is typically 50 to 100% greater than the force needed to slide the pin along the ridges of the spring. Clearly, if the housing were made more rigid, more pins would be forced to seat simultaneously and some of the beneficial reduction of the array actuation force would be lost.

A Monte Carlo technique was applied to the results of the stress analysis and to typical distributions of the relevant dimensions to evaluate the effects of twist and lateral misalignment, solder joint stress, and length of wipe. None of these are easily accessible for direct measurement and yet all are critical for reliable functioning of the connector.

In the course of these studies, an interesting phenomenon was observed: the peak actuation force is much greater on the first actuation than on the second. Further small reductions are typically observed through the fourth or fifth actuation, after which the actuation force decreases very slowly during the remainder of the normal wear life. This suggested that some additional reduction in actuation force might be achieved by pre-conditioning the board by actuating a pin array several times in each module site before it leaves the factory. This has been verified by experiment and adopted as normal manufacturing practice. (See Fig. 11.)

Conclusion

Great complexity was imposed on the packaging design by the small physical size combined with the large number of highly reliable electrical interconnections which were required. Further complication was introduced by the necessity of retaining compatibility with automated manufacturing processes. In general, as each design parameter is varied, some of the performance criteria benefit while others are degraded by the same change. Overall optimization of the design could not, therefore, be achieved by varying the parameters one at a time; a systems approach which considered the interactions among the parameters and the concurrent effects on all of the performance criteria was necessary.

Successful implementation of the connector design concepts described in this paper has been achieved by subdividing the interconnection functions among several types of replaceable units. The first level of interconnection is provided by the integrated circuit chips themselves and by the multilayer metallized ceramic substrate to which they are attached. The vulnerability of the chips to physical and chemical assault requires that the chip side of the substrate be enclosed in a strong, hermetically sealed vessel which must also provide efficient removal of heat from the chips. This assembly, the module, must then be easily removed from and replaced in the system.

This scheme placed demands on the connectors which necessitated a high level of design sophistication. The arrays need to remain functional at an extremely high level of reliability, yet must accommodate a very large number of interconnections in a small physical size. The array must also resist handling damage and, above all, be easily actuated properly while being very difficult to actuate improperly.

The objectives were not achievable using any previously existing packaging technology. Success has depended, rather, on invention, design innovation, use of exotic materials in complex structures, precise control of manufacturing processes, exhaustive inspection, early discovery and correction of manufacturing defects, thorough testing at system assembly, and efficient system diagnostic techniques.

The result achieved is a manually inserted 1800-pin connector that is a combination of low cost concurrent with high performance and high reliability.

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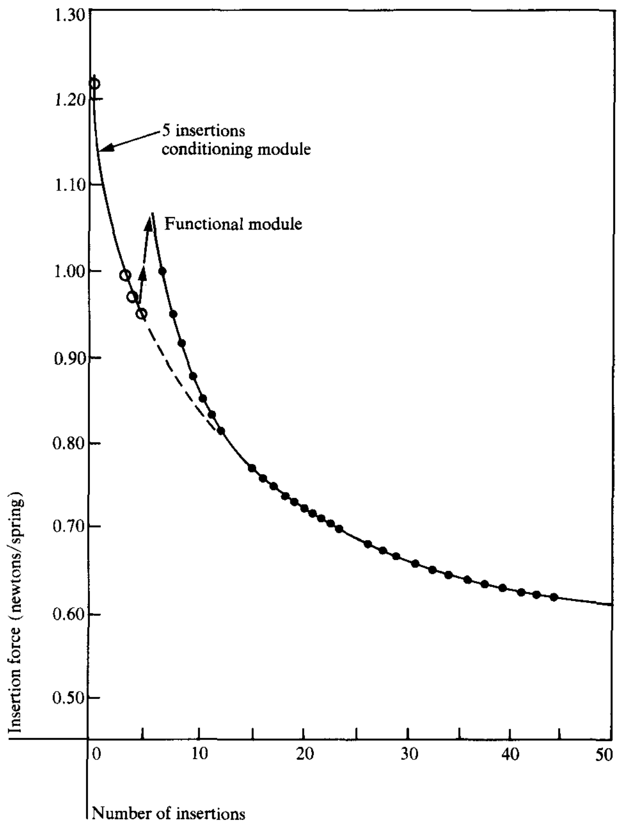

Figure 11 Insertion force *vs* insertion cycles: The first insertion requires the highest force. The force for subsequent insertions gradually decreases until the curve becomes asymptotic because the contacts become burnished and the softer gold is worn off the connector pins. When a new module is plugged, the insertion force is reduced because the spring wear tracks are already burnished.

References and note

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