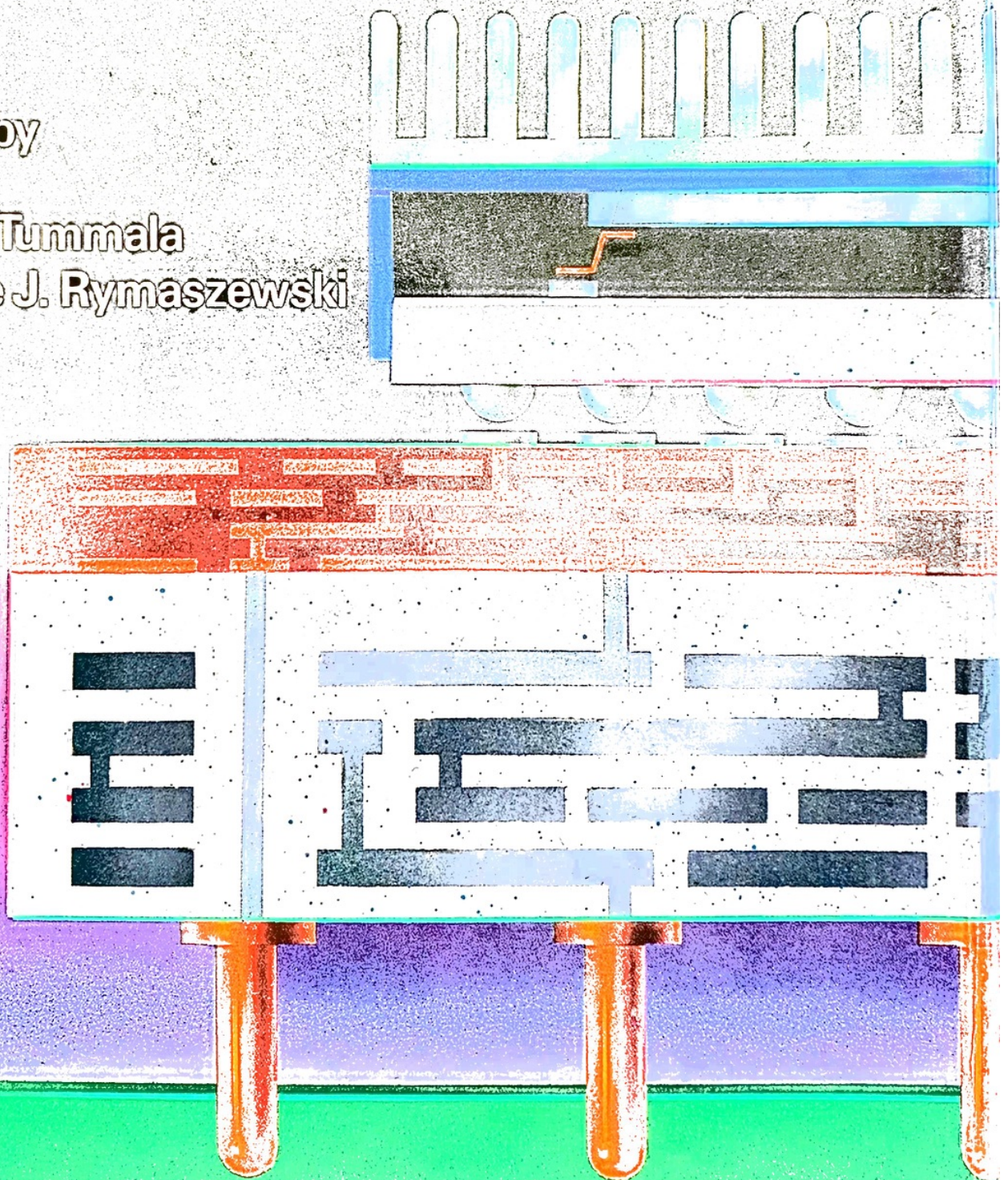


Microelectronics Packaging Handbook

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CONSUMER PRODUCT THROUGH MID-RANGE COMPUTER PACKAGING

G. ALBERT LEMKE

15.1 INTRODUCTION

In these final two chapters, packaging technology will be discussed from the product applications viewpoint, using currently marketed products to show both the requirements and the characteristic packaging solutions used. The products selected will be presented in order of increasing complexity, beginning with those designed for consumer usage, progressing through personal computers, and finishing with mid-range computers. Mainframes and supercomputers are covered in the next chapter. This division of applications into two chapters is due to the distinct differences in the requirements and packaging solutions between the two. The mainframes and supercomputers emphasize the ultimate in performance; the consumer to mid-range products emphasize the cost for the function provided.

A listing of consumer, personal computers, and mid-range systems together with the technologies used at each of the packaging levels is shown in Table 15-1. Each of the products listed represents a distinctive design approach and derives a unique benefit from the packaging implementation. Other products examples might have served this purpose equally well; but the products selected in this chapter were the most familiar to the authors.

This chapter is divided into four major sections. The first introduces products and unique technologies that are representative of each of three groups (consumer products, personal computers, and mid-range systems), and outlines the content of the chapter. The second section describes unique characteristics of each of these three segments, which require distinct packaging technology solutions. The third section, accordingly, reviews the important technologies in the context of these products, complementing the packaging technology descriptions in Chapter 6, "Chip-to-Package Interconnections," through Chapter 14, "Connector and Cable Packaging."

Table 15-1. Packaging Technologies in Consumer Products to Intermediate Systems.

	Chip Conn.	1st-Level Package	1st- to 2nd- Level Conn.	2nd Level Package	2nd- to 3rd- Level Conn.	3rd- Level Package	Chip Cooling	Maj. Chips/ System
Consumer Products								
Sony CD	WB	PSCM	SMT/PTH	Card	—	—	—	4
TF-TV	WB/ TAB	PSCM	SMT/PTH	Card	—	—	—	4
Watch	WB	—	—	Card				4
Low End Systems								
Sharp	WB	PSCM	SMT/PTH	Card/Flex	—	—	—	8
IBM Printers	WB	PSCM	SMT/PTH	Card	Cable	—	—	
IBM PS2	WB	PSCM	SMT/PTH	Card	Conn.	Board	Air	≈10
Apple PC	WB	PSCM	SMT/PTH	Card	Conn.	Board	Air	
IBM Storage	WB	PSCM	SMT/PTH	Card/ Flex	—	—	—	
Intermediate Systems								
DEC 8600	WB	C-PGA	PTH	Card	Conn.	Board	Air	≈100
Fujitsu 730	WB	C-PGA	SMT	Card	Conn.	Board	Air (w/Fin)	
Hitachi 630	WB	C-PGA	PTH	Card	Conn.	Board	Air	
IBM 9370	C4	C-TCM	PTH	Board	Conn.	Cable	Air	
	WB	C-PGA	PTH	Card	Conn.	Board	Air	

Key:

C-4: Controlled Collapse Chip Connection
 CD: Compact Audio Disc
 C-PGA: Ceramic Pin-Grid Array
 C-TCM: Ceramic Thermal Conduction Module
 PSCM: Plastic Single Chip Module

PTH: Plated-Through-Hole
 SMT: Surface Mount Technology
 TAB: Tape Automated Bonding
 TF-TV: Thin Film TV
 WB: Wire Bond

The final section illustrates product examples that are representative of consumer products, personal computers, and mid-range computer systems.

Before the products themselves are discussed, it may be helpful to examine briefly some of the reasons why similar products from different manufacturers often differ greatly in the mix of technologies used in their implementation. Each systems architect strives for an optimum design which is determined both by technological and business considerations for that particular manufacturer. The final choices are based on financial considerations, since the goal of any product is to return a profit to the manufacturer directly or to provide some other marketing advantage that ultimately can be translated into a financial advantage.

Some of the business considerations that play a strong role in the technology selection process include the installed manufacturing capability and capacity, prior designs that can be adapted, specialized in-house skills, qualified external sources for components, technology, and the like. All of these can be considered the "assets" that can help to greatly reduce the necessary investment, shorten the development time, and lessen risk of delayed completion and missed performance targets. Resource availability, or alternately, limits on resources play a part in determining what technology and design options may be considered. It sometimes forces choices that are recognized as less than optimum, but necessary under the circumstances. The competitive situation strongly factors into the definition of the product characteristics: whether to exploit a technological strength of that particular manufacturer, or alternately to position the product where the competition is weak or possibly even nonexistent. All of these considerations play a role in the definition of the best product design. Since they differ for every manufacturer, the optimum solutions selected are certain to reflect these business considerations. These differences are particularly noticeable in the design of leading edge products, which usually rely on unique in-house technologies developed specifically to provide a competitive advantage unavailable to others in the industry.

It is the products that are founded on advanced technology that provide the most interesting and unique packaging designs that will be discussed in this chapter. Their technology excellence, measured on the basis of the technical parameters, establishes the state-of-the-art. But it should be kept in mind that the business considerations discussed above determine which is the best business solution. This can be evaluated only on a combination of the near term return and the strategic positioning implications.

15.2 PRODUCT CHARACTERISTICS

15.2.1 Consumer Products

Consumer products have often provided the vehicle for the introduction and refinement of new semiconductor, packaging, recording, display, and other technologies that, after further development, have been adopted for use in other segments of the electronics industry. The lower product complexity, characteristic of this segment of the industry, facilitates use of the newer and untried technologies, since the product-development effort and risk are in proportion with the smaller size and lower complexity level of these products. Success, correspondingly, provides a larger and often more perceivable benefit that can be exploited as a marketing advantage. Not only has this part of the industry responded rapidly to the opportunities presented by new technology advancements, but through aggressive implementation, has encouraged continued technology development both by the early identification of requirements and assurance of large-volume usage necessary to meet the needs of the mass market served.

What makes this segment of the electronics industry distinct from the military or data-processing sectors is a much faster rate of product evolution, and more direct effect on and response from the users, who for many of the products may constitute a substantial fraction of the total population. One of the more recent and noteworthy product examples that illustrates this interactive effect between a product and the market was the extremely miniaturized Walkman portable tape player introduced in 1983 by the Sony Corporation [1]. This product was only slightly larger than the size of the **magnetic cassette medium** utilized, and its very small size provided unprecedented convenience and ruggedness extending personalized audio entertainment to such active sports as jogging, skiing, and the like. Soon after its introduction its versatility established a fashion that rapidly spread to the general population. Packaging was one of the key technologies critical to the achievement of the miniaturization, which established an entirely new standard of performance and utility creating a new market that was not conceivable with the prior generation of larger products. A similar change in the marketplace has been occurring as a result of the recent introduction of the one-piece camcorders, miniature full-function still cameras, hand-held TVs, portable personal computers, terminals, copiers, and the like. In all these cases, the basic product concept has undergone a change. Technology advancement has been the key enabling factor that made these new product designs possible, and their market success has provided impetus for further technology developments paving the way for future product generations.

Besides the "marketing" benefits of miniaturization, size reduction also offers opportunities for manufacturing efficiency by reducing raw material usage, reducing the size and consequently the cost of the manufacturing ma-

chinery which lessens manufacturing space requirements, and general reduction of energy consumption for manufacturing, in-plant transportation, supply, and final product delivery. A fundamental attribute of scaling favors smaller parts "ruggedizing" the product and enhancing its dynamic performance. Simply stated, the mass of a part diminishes faster than its stiffness whenever the linear dimensions are reduced in proportion. The square root of ratio of mass to stiffness is the primary factor in determining the natural frequency of a mechanical element and its ability to withstand dynamic effects, whether internally generated or from external sources.

A simple measure of the technological sophistication for portable products is volume, weight, and power requirement. For the user, these determine convenience; the low-power consumption being especially important since it determines the operational time until power-supply replenishment is required.

The portable compact disc (CD) player, as a class, provides an excellent example of the technological progress characteristic of the leading edge of this industry. In three years, a number of different models by several manufacturers have been introduced, all with very similar functional specifications but increasingly miniaturized and reduced in power consumption. In subsequent sections, a number of packaging aspects of several of these portable CD players will be discussed in some detail, but at this point comparison of the externally measurable characteristics are sufficient to illustrate the keen competitiveness and rapid response characteristic of this part of the electronics industry.

The first portable CD player Sony model D-5 became commercially available in the last half of 1984 (Fig. 15-1) [1]. It was more than an order of magnitude smaller in size and lower in power-consumption than the "home-size" units that were previously available. Additionally, its shock and vibration immunity were improved significantly, in part through the benefits realized from the dimensional scaling. This was a revolutionary product. However, in the following two and a half years, the Sony Corporation and a number of other manufacturers introduced new, smaller models with a few additional features thrown in for good measure. Since the first portable CD player was introduced, the size and power consumption (Fig. 15-2) of the most recent models have been improved by a factor two, and the price (and presumably manufacturing cost) have been reduced as well. The CD players represent the leading edge of the technology; however, their improvement rate is representative of this segment of the electronics industry as a whole, and the frequent introductions of products from various manufacturers illustrate the keen level of competition that forces reliance on technology, and encourages rapid development of products to maintain competitiveness or, possibly even, gain an "edge."



Figure 15-1. Sony D-5 in Comparison to Home-Size CD Player.

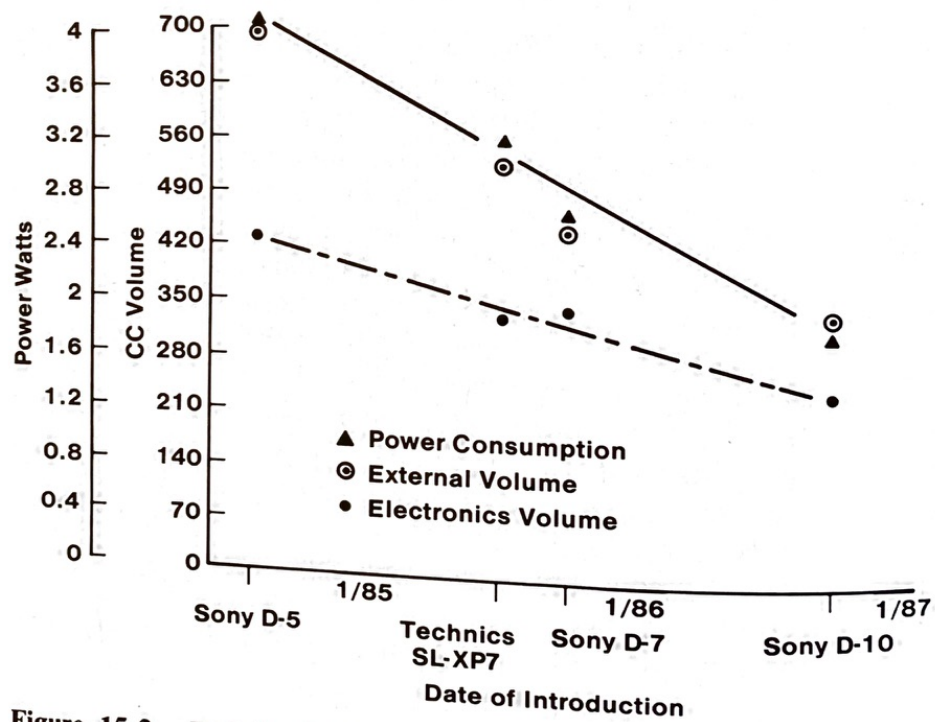


Figure 15-2. Portable CD Player Size and Power Improvement.

Compared to industrial and data-processing products, consumer electronics products are less complex and work with industry-wide media standards that determine many of the functional specifications and simplify product design. As a consequence, the development of a new product is generally a smaller undertaking which can be made dependent on one or more new technologies without incurring an inordinate level of project complexity and, consequently, an unacceptable level of risk. Unforeseen problems are more easily managed, and in the event that the complete project becomes unworkable, it is not likely to jeopardize other projects that may be part of a larger "systems" plan, as is often the case with industrial and data-processing development programs.

It is a combination of factors — the very competitive nature of this industry, the inherently smaller projects and shorter design cycles, a lower demand on technological sophistication, together with the ability and willingness on the part of the manufacturers to accept both business and technological risk — that have made this segment of the electronics industry the place where many of the new technologies have been introduced and the usual start-up difficulties resolved. Early volume-production experience in this technically less environment provides an ideal opportunity for continued technology development, which, when accomplished, can be applied to widespread use in industrial and data-processing applications. To cite a few of the more noteworthy examples, CMOS, LCD (Liquid Crystal Display), TAB, and SMT (all at a lower level of complexity) were first used in high volume in the smaller electronic products and since then have migrated up to become mainstay technologies for all segments of the electronics industry.

15.2.2 Personal Computers

At first it would seem that personal computers should be among the easier products to design. That is, with the large systems driving performance technology development and the consumer products driving cost, designing a personal computer should simply mean taking the best from both disciplines. This would indeed be the case if it were not for the many contending user and business requirements for entry systems which include, but are not limited to, the following.

First and foremost, the machine must be **cost competitive**, and offer on the order of a factor of 2 improvement in value in comparison to the products marketed just two or three years before. In the short history of personal computers this has been the compound rate of cost-performance improvement. **Performance**: today's machines must provide performance in the range of mainframe processors of just seven years ago. **Reliability**: the machine must work right out of the box just as any other modern electrical appliance, and for a comparable period of time. Also it should be easily assembled and

operated by the customers who usually do not possess a high level of technical skill.

The personal computer, more than any other data-processing machine serves a broad range of applications, and therefore must offer “expansion” cards for configuration to the problems of that specific user. As personal computers are typically customer-operated systems, provisions for automatic-fault detection and location are required to enable the owner to make repairs with a reasonable level of confidence. The “footprint” of the machine should be as small as possible, so that the machine will consume the minimum of desktop workspace and be an unobtrusive part of the office environment. It should be of reasonable weight for portability, whether for office rearrangement or for relocation to where the work is to be done. In the extreme, it may need to be a portable with self-contained power as will be illustrated in the discussion of the Sharp PC-1600 (Fig. 15-3).

The display capabilities expected by the customers are far more than the text quality graphics provided by the TV-like screens of the first generation personal computers. Current product generations approach CAD/CAM-like system’s display capability requiring high-speed and high bandwidth for the manipulation of this data. Video processing requirements and the hardware content for this aspect can easily surpass the complexity of the “central processor” hardware of the machine. The personal computer must not only be sparing in its power requirements, but also should be tolerant of electrically noisy power environments. Its electromagnetic radiation must achieve legislated standards which have been tightened world-wide in the recent past. And finally, the personal computer must “look good,” be “human engineered,” and also “user friendly.”

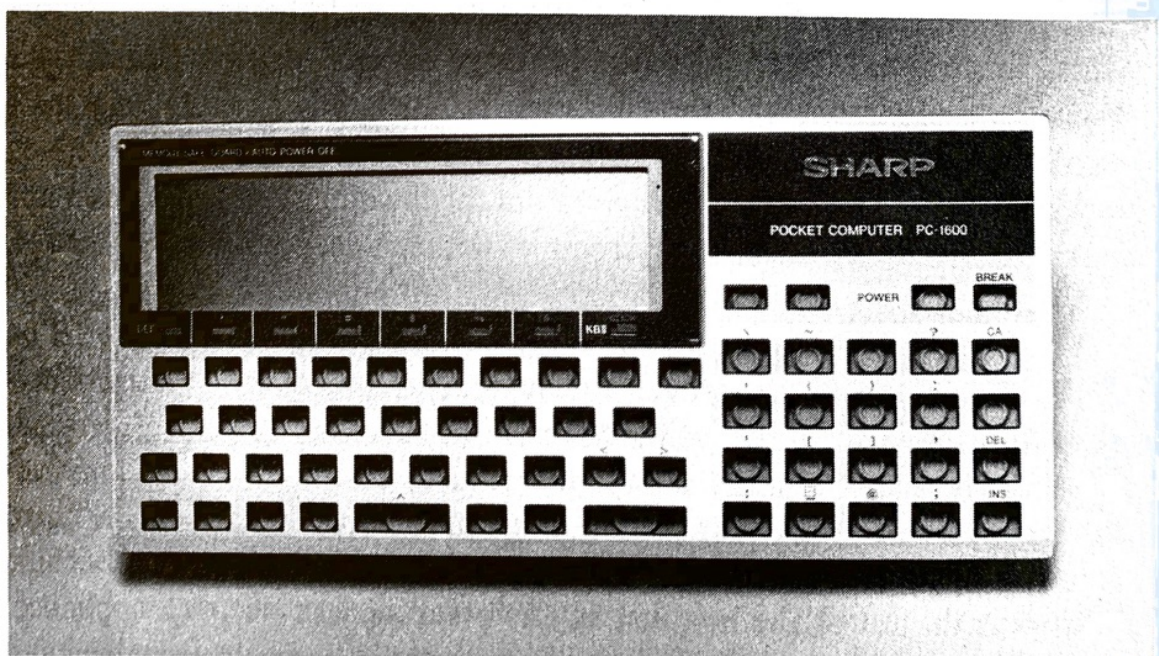


Figure 15-3. Sharp Hand Held Personal Computer Model PC-1600.

15.2.3 Mid-Range Systems

The mid-range data-processing systems require a blend of performance and low cost optimized for the lowest possible cost for a given performance. The typical performance range of these is between about an MIP (million instructions per second) or less, to almost the bottom end of mainframes, which in 1988 is 20-30 MIPs per uniprocessor. This range is generally achieved by a single processor, but sometimes with multiple processors, particularly in the top range of performance.

The semiconductor technology capable of providing the function necessary to achieve these performances has been primarily ECL and TTL, but recently both CMOS and BICMOS have begun to emerge as leading candidates offering much higher integration levels with lower power requirements. Single-card central-processing units are marketed with those silicon technologies and improved system's performance. BICMOS is a strongly emerging technology taking the best of bipolar and CMOS transistors on the same die providing an alternative to both those technologies in many applications.

The internal CMOS circuits offer very low power and low current operation sufficient for the short on-chip circuit to circuit communications and the bipolar circuits are used primarily for high speed off-chip drivers. In comparison, this technology provides a lower speed-power product than can be achieved by either of the semiconductor technologies. BICMOS is becoming more competitive economically as fabrication complexity is beginning to approach the number of mask steps necessary to fabricate CMOS VLSI circuits.

The most common first-level packages are ceramic, varying from lead-less-chip carriers to multichip modules. The organic cards are typically located in a cage parallel to each other with appropriate zero-insertion-insertion-force-edge connectors either on one end or two sides. An alternate approach used in the IBM 9370 relies on an air-cooled multichip TCM which plugs into a board for power distribution and fan-out to external connectors. The use of low-powered CMOS and BICMOS semiconductors in all mid-range systems make possible the use of cost-effective forced-air cooling. Many of the systems, however, do require heat sinks for enhancement of the first level packages.

15.3 PACKAGING TECHNOLOGIES

15.3.1 Introduction

The packaging technologies that are pertinent to this range of products are summarized in Table 15-2. Most of these technologies are covered in technology Chapter 6, "Chip-to-Package Interconnections," through Chapter 14, "Connector and Cable Packaging." However, a brief description

Table 15-2. Packaging Technologies in Consumer to Mid-Range Products.

	<u>Chip Level Connection</u>	<u>1st-Level Package</u>	<u>2nd-Level Package</u>	<u>1st-to 2nd-inter- Connection</u>	<u>Connection Between 2nd-Level</u>
Consumer Products	• Plastic • Wirebond • TAB	• Card • CC • None	• SMT • Flex • Chip on Board	• PTH	• Elastomeric connector • Single edge connector
Personal Computers	• Wirebond • TAB	• Plastic • CC	• Card • Board	• PTH • SMT	• Single edge connector
Mid-range Systems	Wirebond TAB C4	• Ceramic (SCM) • PGA • Ceramic • PGA (MCM) • PGA (TCM)	• Card • Board	• SMT • PTH	• Single edge connector • Double edge connector (ZIF)
C4	Controlled collapse chip connection		SCM	Single-chip module	
CC	Chip carrier		SMT	Surface mount technology	
PGA	Pin-grid-array		TAB	Tape automated bonding	
PTH	Plated-through-hole		ZIF	Zero insertion force	
MCM	Multichip module				

is included here in the context of product design which is the perspective and theme of this chapter. The focus will be on the selection of the technology solution among the possible alternatives taking into account the trade-offs that the system architect is faced with. For example, the space available in some of the portable consumer products may require direct wirebonding of the chips to the board or the use of flex to fit into the limited space available. Surface or butt soldering of pin-grid array modules on dense cards with 1.27-mm grid spacing may be necessary for the four times density improvement provided over conventional 2.54-mm grid spacing, especially where for the containment of the CPU to a single card is needed.

15.3.2 Chip-Level Interconnection Technologies

All three chip-level connection technologies, TAB, wirebond, and C-4, discussed in Chapter 6, "Chip-to-Package Interconnections," are used in the products that will be discussed in this chapter. Referring to Table 15-2, wirebond and TAB are the two most common technologies in consumer pro-

ducts, personal computers, and mid-range systems. To date, C-4 is used only in IBM's systems (1988).

Wirebond: Wirebond is the single most widely used technology, which is also covered later in this chapter in the "Chip-on-Board" section. The process is straightforward in all aspects, with the exception that a precise mechanical alignment is required for the alignment of the inner lead bond wire to the chip pad, whose size is typically below the limits of open-loop mechanical positioning accuracy. Manual visual alignment, which was the only technique available until the early 1970s, made this process somewhat costly and prone to human error. This was resolved with the introduction of automatic-alignment systems with optical vision which are now used exclusively.

Tape Automated Bonding (TAB): One of the most important and extendable technologies for bonding chip to the package is TAB. This technology, although started in consumer electronics, has found widespread use throughout the industry, including supercomputers. TAB packaging, as used in "Smart Cards" [2] and calculators, offers a greater increase in I/O than wirebonding, and a convenient local space transformer that facilitates electrical probing, a critical requirement for the very complex chips of the future. Additionally, the TAB film is inherently conformal, minimizing joint thermal-stress levels and easing heat-sink attachment and integration into the product structure as discussed in Chapter 6, "Chip-to-Package Interconnections." The TAB film and flex circuit-carrier substrates (see Chapter 12, "Printed-Circuit Board Packaging") discussed later in this chapter share a common technology, but differ primarily in their density, largely determined by the current applications. The combination of these two packaging technologies into a multichip TAB chip carrier that can also carry discrete components and provide integrated cables offers the possibility of eliminating a level of packaging and connections.

Currently, the majority of TAB chip packaging is used in consumer products such as watches, calculators, cameras, hearing aids, video-game cartridges, and smart cards, where the lowest profile and sometimes the smallest size are the determining considerations. The chip I/O count is typically low in these applications, making the TAB alternative a somewhat more expensive solution than wirebonding, but the combination of rework capability and the premium value put on thinness makes TAB the more commonly used solution. In particular, for products such as credit-card calculators and smart cards, where the chip package is often the thickest component, the fraction of a millimeter height savings possible in the final product seems to command sufficient marketing leverage to make TAB the preferred approach.

The fundamental concept of TAB is based on the handling of sprocketed film tape, much like 35-mm photographic film, that provides the required

accuracy of registration by mechanical pin-and-hole referencing alone, eliminating the need for the visual alignment. The continuous film is handled automatically in reel form using indexing mechanisms that are well suited for low-cost mass production. Much of the handling methodology and portions of the production tools were adapted from the film industry, which had encountered and resolved a similar registration problem many years prior.

All of the TAB processing equipment is designed around the handling of the two-layer insulator and conductor-film medium, with each frame providing the packaging location for a chip. The copper layer is lithographically personalized with the conductor pattern for the chip-to-module lead-frame electrical connections, and openings are formed in the insulator where mechanical access or clearance is necessary. The inner lead bond (ILB) connections between the chip and the copper-tape conductors are formed using either solder or thermo-compression joining processes. Chip and joint testing is facilitated at this stage of the assembly as the dimensions of the copper conductors can be increased in size away from the very dense ILB area. Failed devices are deleted by punching, and good devices continue as part of the tape to the encapsulation stage. Finished rolls of packaged chips provide a convenient form for lot handling that can be loaded directly on card-assembly machines for excising into individual parts and surface-solder attachment of the outer lead bonds to the corresponding card-land patterns. The tape OLB joint can also be mated to lead frames for the manufacture of conventional pin-type modules. A more detailed description of the TAB technology can be found in Chapter 6, "Chip-to-Package Interconnections."

Controlled Collapse Chip Connection (C4): The use of a reworkable chip to a substrate solder connection such as array C4 (Controlled Collapse Chip Connection) provides for a large number of I/Os, but it also brings with it the possibility of joint fatigue caused by the thermal-expansion coefficient mismatch between the packaging substrate material and silicon. To date, C4 has been used in consumer products only as chip on board, as discussed later in this chapter, for the packaging of very low-integration devices that have but few closely spaced solder terminals and large solder columns that help minimize the fatigue concern. However, as pointed out earlier, IBM's mid-range systems use this technology which can be referred to in Chapter 6, "Chip-to-Package Interconnections."

15.3.3 First-Level Packages

The first-level packages used in consumer products to mid-range systems are very diverse, ranging from very low cost plastic packages in consumer products and personal computers to large, very sophisticated multichip ceramic modules in mid-range systems. Both single and multichip ceramic packages are covered in Chapter 1, "Microelectronics Packaging — An Overview,"

and Chapter 7, "Ceramic Packaging." The plastic packages are covered in Chapter 1, "Microelectronics Packaging — An Overview," and Chapter 8, "Plastic Packaging." The encapsulation of these packages is covered additionally in Chapter 10, "Package Sealing and Encapsulation." The only new package that has not been covered previously and that is pertinent to the products discussed in this chapter is plastic pin-grid array (P-PGA). Pin-grid array modules lend themselves to plugging into sockets for those applications which require removal and insertion for test or featuring. A number of consumer products eliminate the first-level package altogether by bonding the chips directly to the board, leading to "chip-on-board" (COB) concept and terminology.

A good example of the use of plastic pin-grid array technology is in the Apple Macintosh II computer for the memory-management chip using a 70-pin module. This module was built utilizing the following technologies: compliant pins (rigid type), conductive epoxy back-bond material, epoxy-glass laminate, protective coat on both sides of the laminate, a glass-filled top seal layer covering the complete top surface of the laminate, and a protective metal cap that functions as a mold for the top seal material. No internal signal or power planes are used in the laminate as it functions only as a carrier for the surface circuitry. Aluminum wire fly-leads are used to make the electrical interconnection between the chip and laminate bond pads.

The pins are attached to the laminate using a rigid pin in a compliant hole. Although the design of the pin is basic, it is quite functional. The pins are pressed into plated-through-holes by an external force eliminating a number of process steps; fluxing, soldering and subsequent cleaning. Also, the pins are made to extend halfway into the plated-through-hole providing a slight cost savings by using shorter pins that require less plating material. The pin materials are phosphor bronze (96% copper and 4% tin) stock, plated with nickel, and then coated with tin/lead for solderability. Electrical and mechanical stability is ensured by the design of the pin. The end that inserts into the plated-through-hole is intentionally bulged to generate a severe lateral force on the barrel wall as a result of the insertion pressure. When the pins are forced into the plated-through-holes, the tin-lead coating is designed to cold flow onto the plated-through-hole surface as shown in Figure 15-4.

The protective coat used on this module serves two purposes: a plating mask for the nickel and gold layers, and protection of the surface circuitry. The laminate material is an epoxy-glass. The back-bond material used to attach the chip to the laminate is an epoxy, made conductive by the addition of silver particles.

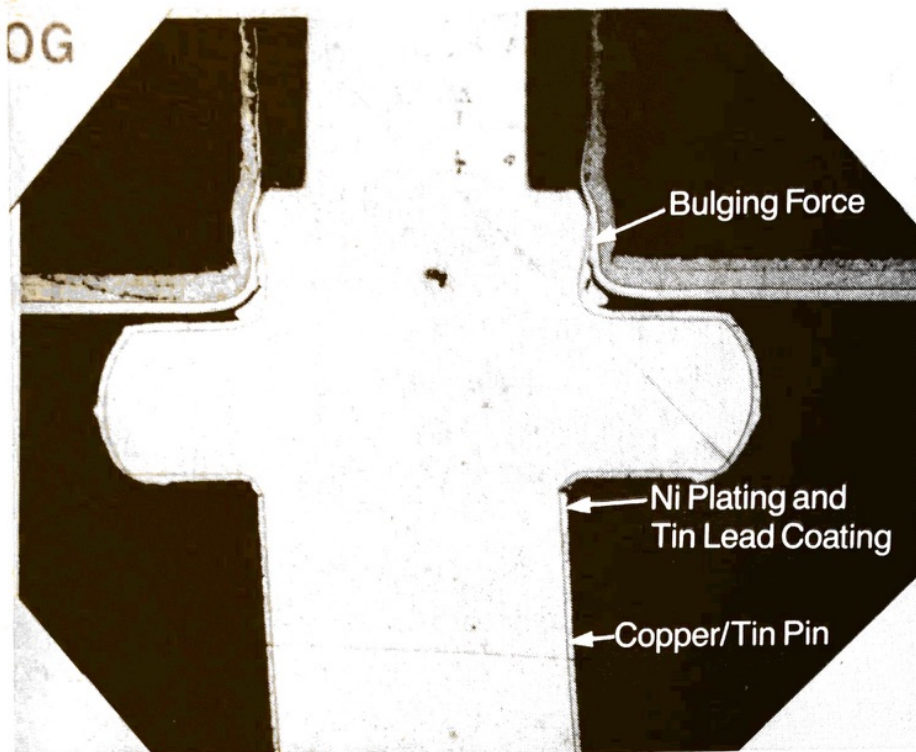


Figure 15-4. Press-Fit Plated-Through-Hole of Plastic PGA.

15.3.4 Second-Level Packages

All second-level package technologies discussed in Chapter 12, "Printed-Circuit Board Packaging," are used in this segment of the industry. These include organic card and board technologies based on epoxy-glass, injection-molded cards, and flexible circuits based on thin polyimide-copper wiring. In addition, metal-core substrates discussed in Chapter 13, "Coated-Metal Packaging," are used in limited applications where higher temperature of operation is required or for their rigidity, as for example in some computer keyboard applications.

Flexible Circuits: A flexible substrate can be bent and folded to fit into limited spaces that may be too irregular to fit rigid cards into providing both cost and packaging-density advantages [3]. The conformal nature of flex permits construction of large integrated subassemblies combining several smaller assemblies and eliminating connectors that are among the most expensive packaging elements and also somewhat prone to failure [4]. The flex substrate lends itself to attachment or clamping to covers or frame components that may provide sufficient thermal conductivity to take the place of separate heat-sink hardware.

Flex applications are categorized into two classes: static, when once installed, no further flexure is required; and dynamic, where continued flexure is expected. For example, static flex is used in 35-mm cameras to take advantage of many small spaces between various optical and mechanical components and to connect the numerous dispersed elements. An example

of dynamic-flex application is its use in a compact disc player, where it provides the connection between the moving optical-sled electronics and the fixed main electronic assembly. In some applications, where local rigidity or additional wiring capacity is required, a portion of a flex carrier may be bonded to a rigid printed-circuit card, forming what is called rigid flex [5].

The very smooth surface of the homogeneous flex insulator, most commonly polyimide, enables fabrication of copper conductor lines that are a factor of two-to-four-times smaller than can be made on conventional glass-epoxy substrates. As discussed in Chapter 6, "Chip-to-Package Interconnections," TAB films, which are really a simple version of flex, are in routine low-cost manufacture, with 25 μm conductor-line widths spaced on 125 μm centers as will be shown in section 15.4.1, "Consumer Products," on page 1044. One of the limiting factors to flex densification is the minimum size of vias that can be mechanically punched and kept in alignment to the printed geometries defined in subsequent steps. The lower limit of punching today is about 0.25 mm in diameter, which is a factor of ten larger than the minimum line that can be fabricated. Most designs are likely to become "via starved" before the line geometry limits are encountered. Additionally, the poor dimensional stability of the thin and flexible substrate, together with its temperature sensitivity and propensity for water absorption, puts severe limits on layer-to-layer registration accuracy that can be achieved over large dimensions.

Flex manufacturing follows the same methods and process steps as used for the fabrication of rigid cards, with the only difference being of handling in reel form as opposed to individual panels. For several of the chemical processing steps, continuous reel-to-reel processing is a practical possibility that can reduce the cost of material handling and simplify the process tool design. Continuous processing does however require a better level of process control, since the batch size is the reel and a defective section may require reprocessing of the whole batch, or alternatively, the splitting of it into multiple pieces. Also, continuous reel processing is less amenable to part-number change. The longer reels that are desirable from a handling viewpoint increase the time required to complete any processing step. In spite of these inherent limitations, reel processing is widely used, especially for the less critical high-volume parts.

On a per unit area at equal wiring density, rigid printed circuit boards are still somewhat less expensive than flex parts, and this cost relationship is not likely to change in the near future. Although the processes for both are quite similar, printed circuit costs remain lower because the processes are easier to implement on the rigid substrates and the overwhelmingly larger volume of usage. Hence, flex is used only for those applications where the overriding consideration is product size, in addition to those products that need dynamic flex for electrical connection to moving parts. To date, the most ex-

tensive and sophisticated use of circuit-carrying flex has been in 35 mm cameras and telephones which are ideal applications that benefit greatly by size reduction and increasingly rely on electronic components that must be fitted within fixed-external dimensions.

Human factors, together with the shape, size, and location of optical, mechanical, and film-transport elements, dictate the outside shape of a camera body and therefore define where the various sensor, control, and display components must be located. A few components, in particular the electronic chips, can be located almost anywhere the space is available and access is

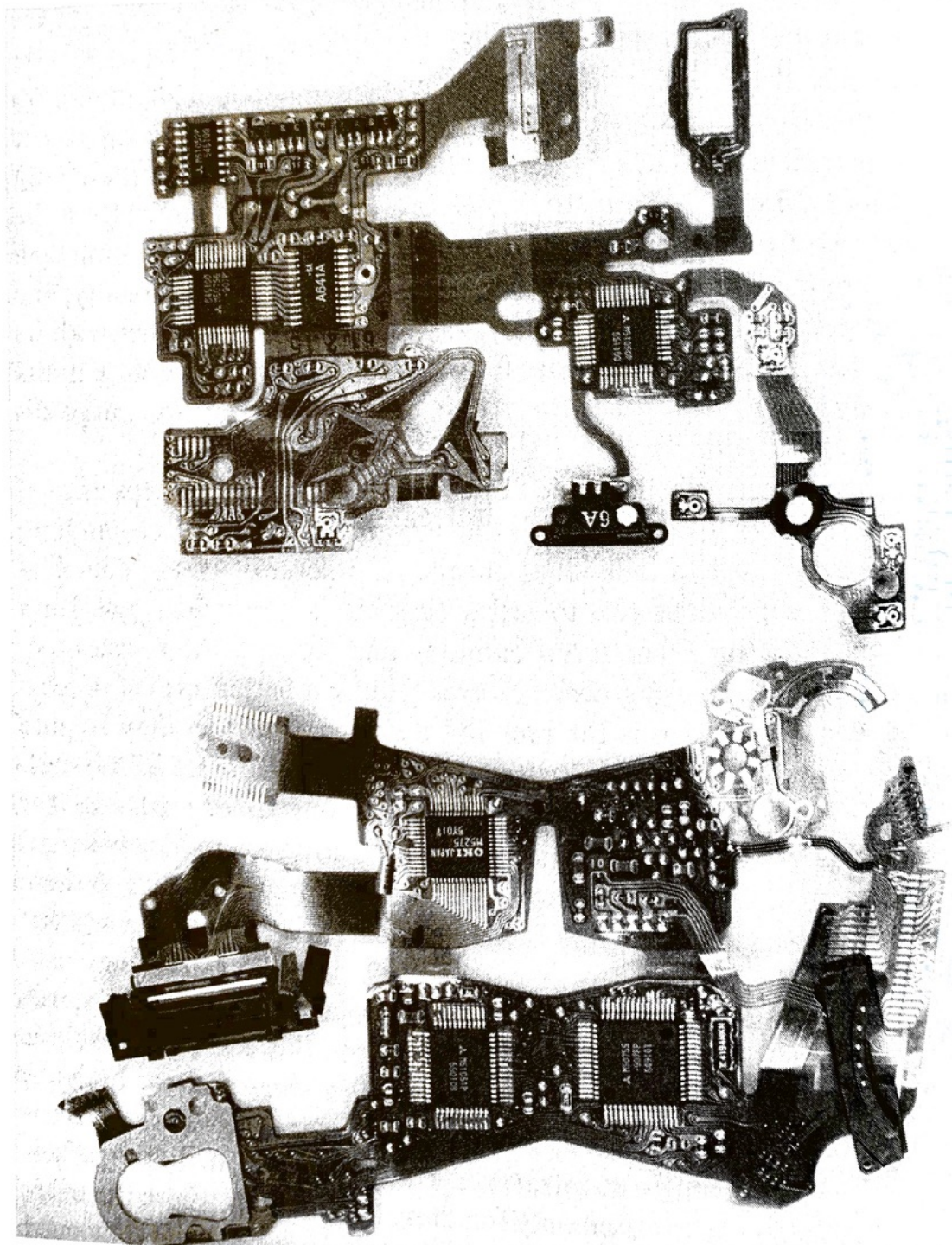


Figure 15-5. Minolta Maxxum 9000 Flex Circuit.

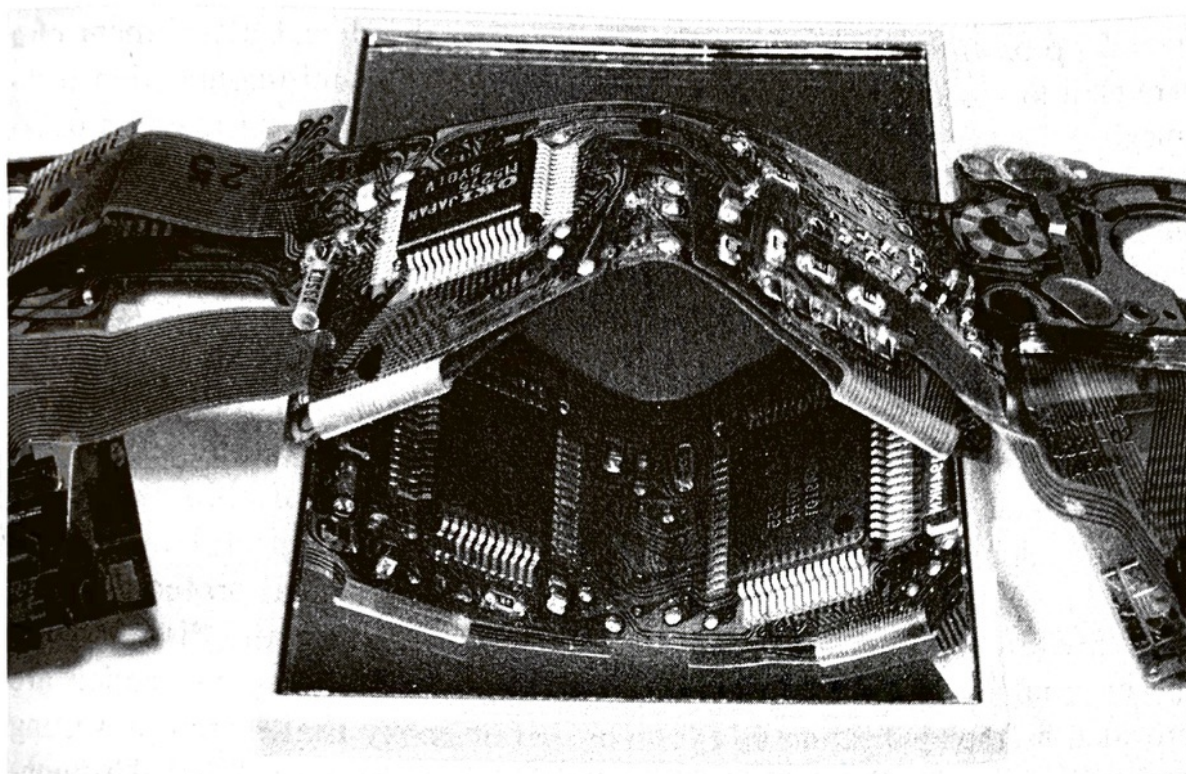


Figure 15-6. Minolta Maxxum Flex Circuit — As Installed.

possible for the electrical connections. The packaging challenge, therefore, is to form all the interconnections to the numerous elements using the least amount of volume possible. Fortunately, while the physical packaging requirements are quite demanding, the electrical requirements such as power, noise, etc., are very minimal.

The two main flex subassemblies used in such a camera are shown in Figures 15-5 unfolded in a plan view and in 15-6 a portion folded in a manner as it would be installed in the camera [6, 7]. To minimize manufacturing costs, the flex cross-section is limited to two wiring levels, and several individual flex pieces are assembled for greater wiring capability. Also, by the use of many individual pieces, the flex web layout can be optimally tiled to reduce wasted material in manufacturing. The motors, displays, solenoids, and other electromechanical and electro-optical components are soldered directly to the flex, facilitating off-line assembly and test prior to installation into the camera. Interconnection among several of the flex pieces is made by gold-to-gold pads which are brought into alignment using registration holes and pins and held with mechanical pressure.

Chip on Board (COB): Chip-on-board is the direct attachment of a bare chip to a board using wirebonding, TAB, or C4 chip-connection technologies. However chip-on-board, as generally referred to in low-end packaging, is direct wirebonding of chips to an organic substrate. TAB and chip-on-board are similar in that both eliminate a level of packaging. However, there are some parametric differences that may make one more suitable for an application than the other. Table 15-3 provides a listing of the key attributes of both, together with parameters typical of the current state of the art.

Direct attachment of chips to cards with ultrasonic or thermocompression wirebonding eliminates the module level of packaging altogether, providing a much smaller, simpler, and lower-cost method of chip packaging. The wirebonding takes care of the electrical connection aspect; however, additional provisions must be made for encapsulation, physical protection, and, if required by the application, a means for heat spreading and dissipation to the environment. Typically, the encapsulation and physical protection are provided by the application of a drop or two of epoxy that, through wetting and capillary action flows out to cover the chip and the wire leads. This non-hermetic seal is comparable in performance to most of the plastic module technologies, a restriction only in the most demanding severe environment applications. A modest amount of heat dissipation (≈ 0.1 – 1 W) is inherent through the copper wiring of the card. This can be enhanced somewhat by increasing the wire width in the vicinity of the chip. One of the limitations of chip-on-board is that rework of wirebond connections is difficult, since the removal of a bonded wire from a pad inevitably leaves a crater or residual metal that interferes with a new connection. Another problem limiting wide spread use of chip-on-board methods stems from the difficulty of testing uncased chips which statistically limit the printed-circuit board assembly yield if a large number are required. For example, even if individual chips have yields in the high 90%, the cumulative failure rate of the finished assemblies grows exponentially with the number of chips assembled and makes it difficult to economically justify throwing away large numbers of nonoperating boards. On the other hand, the cost driven marketplace for chip-on-board assemblies does not permit any expense for testing, repair and chip replacement. However, chip-on-board with C4 may solve this problem in the future.

The majority of applications of chip-on-board packaging have been in the simpler products that have only a few components, and are more economical to scrap than rework should a flaw be detected. As these are usually low-performance and low-power products, the cooling requirements are minimal and no additional provisions are usually required beyond those inherent in the assembly itself. Injection molding is sometimes used for the encapsulation step, which for some designs can also be the assembly method for a number of parts and produce the external surface of the final product in the same step. The processes, materials, and tools for chip-on-board manufacture

Table 15-3. TAB vs. Chip-on-Board (COB) Comparison.

	<u>TAB</u>	<u>COB</u>
Chip I/O spacing, mm	0.125	0.2
Height, mm (Above Chip)	0.1–0.2	0.2–0.5
Joint Strength, Typ, gm.	25–50	7–15
Chip Burn-in	YES	NO
ILB Pre-Test	YES	NO
OLB Rework	YES	NO
Cost		
<50 I/O	Higher	Lower
50–125 I/O	Equal	Equal
>125 I/O	Lower	Higher

are derived from those for the production of standard DIP and other similar plastic modules, which are discussed in detail in Chapter 8, "Plastic Packaging," and Chapter 6, "Chip-to-Package Interconnections."

Because of the cost-reduction benefit of chip-on-board, it is used in many products primarily for the benefits of size and volume reduction it makes possible, as for example in credit-card calculators, watches, and the like, where thickness, size, and weight are the critical parameters [8]. Table 15-4 provides a dimensional comparison of a representative chip

Table 15-4. Chip-on-Board Size and Volume Improvement.

	<u>COB</u>	<u>DIP</u>	<u>DIP-SO</u>	<u>PLCC</u>
Chip Size (mm x mm)	5x5	5x5	5x5	5x5
Chip I/Os	56	56	56	56
Card I/O spacing (mm)	0.3	2.5	1.25	0.8
Card Area (mm x mm)	7x7	73x14	37x14	12x12
Height (mm)	0.8	7	7	5
Packaging Volume (cc)	0.04	73	37	0.07
Volumetric Ratio	1	1500	750	18
Figure of Merit	1500	1	2	80

packaged directly to a board versus several industry standard modules. The last parameter, is a figure of merit normalized to unity for DIP and shown as a multiple factor for other packaging configurations.

Similar tables can be derived for any other chip I/O count and chip size. The general trend is that as chip I/O count increases, the volumetric ratio increases since pin-area requirements tend to be the dominant factor, but at low I/Os this trend may not hold because chip size and the module body size may dominate. factors.

One of the first high-volume applications of chip-on-board packaging was in electronic calculators, which require one or at most two chips, a key pad, and a display. The use of multiplexing techniques for the key pad and display enable the design of a basic four-function arithmetic calculator with one chip of only 30 I/O connections. CMOS logic and LCD displays minimized the power requirement, and the use of blister key pad [9] and a solar cell, both of which are also very thin, enabled the packaging of a calculator in what is now the very familiar credit-card size. There remains room for further miniaturization, because even in credit-card-size calculators, the size-determining component the key pad whose dimensions are defined by human factors and not by component size. This is evident in the combined watch-calculator product that is currently available with keys too small to be operated with fingers, requiring a pointed instrument for keying.

A more recent application of chip-on-board has been in "smart cards" which typically contain one to three chips, a flat battery, and electrical contact points for connection to a terminal [2]. Functionally, these products are far more complex and sophisticated than the calculators described previously, but are essentially the same in regard to packaging and the other technologies employed.

The cooling of chip-on-board assemblies can be improved significantly if insulated aluminum [10], porcelainized steel, as discussed in Chapter 13, "Coated-Metal Packaging," or ceramic substrates are substituted in place of the conventional organic printed circuit cards. Chip-on-board with an aluminum substrate material is used in high volume for power-component packaging both for audio amplifiers and power-supply circuits. A typical example (Fig. 15-7), of this type of product would have one wiring layer, 10 or so large components that may act as the wiring crossovers or alternately, "jumpers," formed using wirebonding methods.

The continued rise in chip integration tends to reduce the number of components that need packaging and hence the total number of chip connections necessary to implement any given function. As fewer connections are required, the need for rework capability is lessened, making chip-on-board a more attractive packaging solution. In particular, for consumer products, which are usually simpler, chip-on-board can be expected to become an increasingly practical and attractive solution in the future [11].

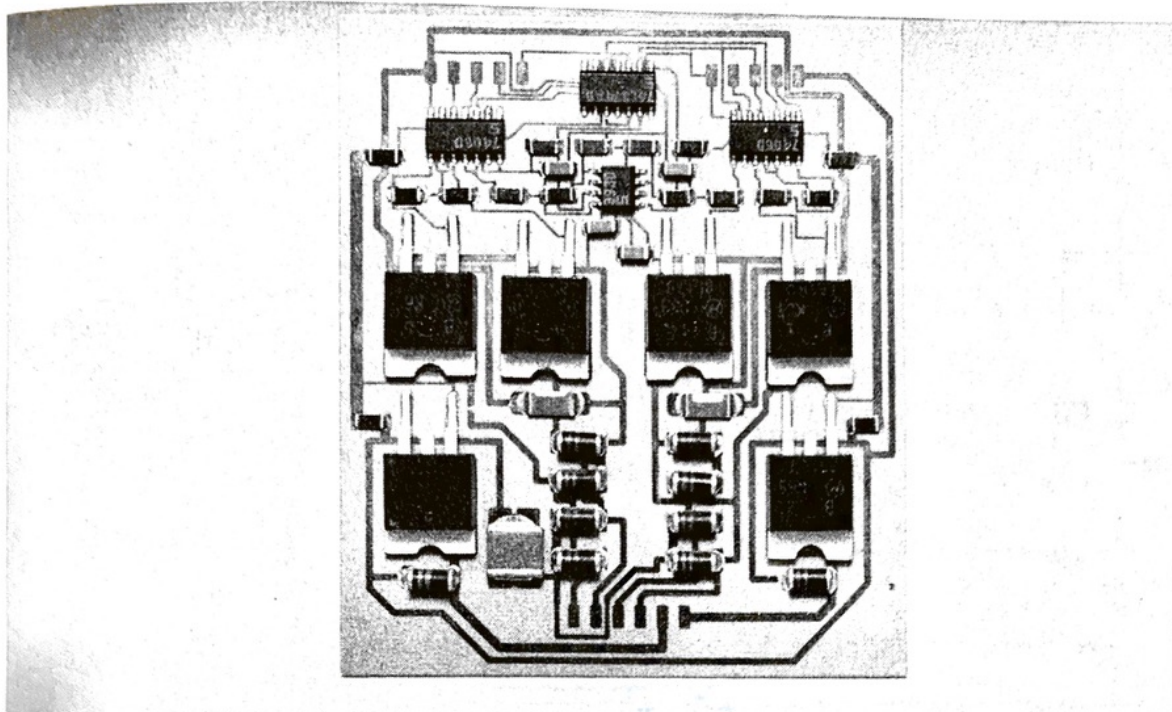


Figure 15-7. Polymer on Aluminum Power Card.

15.3.5 Surface Mount Plated-Through-Hole Technologies

Surface Mount Technology (SMT) is a card assembly method that relies on a solder joint both for the physical location and the electrical connection of the component on the card as was discussed in Chapter 11, "Package-to-Board Interconnections." [12]. In contrast, the Plated-Through-Hole (PTH) joining method uses a close mechanical fit between the component pin and the card via hole for the location of the component, and the solder provides the final bond as well as the electrical connection. As SMT components are inherently pinless, they can be made much smaller whenever heat dissipation requirements permit. A comparison of typical SMT and the equivalent PTH devices is provided in Figure 15-8. The SMT processes for component-to-card joining and a cross section of a typical joint are shown in Figure 15-9. Being smaller, the components require less area on the carrier, and if the carrier has sufficient wiring capacity, its size can be reduced accordingly.

The first applications of SMT were for military and medical products that had critical miniaturization requirements, together with the need for ruggedness and reliability, typical of severe operating environments [13]. Both of these premium markets could accept the higher start-up costs of a new technology which requires development of a totally new set of components, tools, and assembly processes. Much of this initial development work on SMT was done in conjunction with thick-film ceramic carriers that offered the required high-wiring density and the good thermal-dissipation properties necessary with the smaller and more densely packaged components. There is

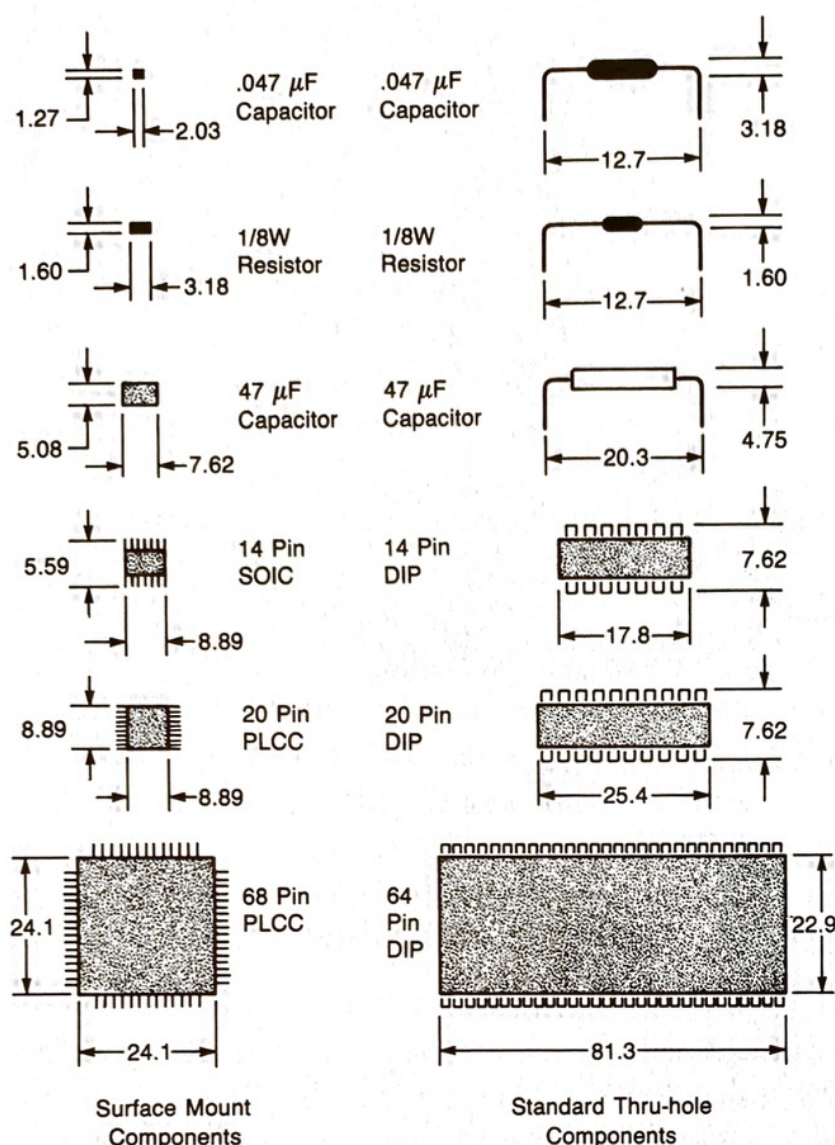


Figure 15-8. Comparison of SMT and PTH Component Size.

continued use of SMT in this form for a few very specialized applications for those product markets that can justify the added cost, however these currently constitute only a small fraction of the overall SMT manufacturing volume.

The majority of SMT usage is on conventional organic cards that are somewhat simpler and less costly than the equivalent PTH designs, compensating for the cost of SMT components which are still somewhat higher than the PTH equivalents. As SMT volume grows, it is projected that the component cost premium will diminish, and ultimately SMT components are expected to become less expensive. SMT printed circuits are less complex and less expensive than those used for PTH for several reasons stemming from the elimination of the component pin vias. Without pins and via holes, additional wiring channels become available, increasing the effective wiring capacity as measured on a per-layer basis. The number of wiring layers can be reduced

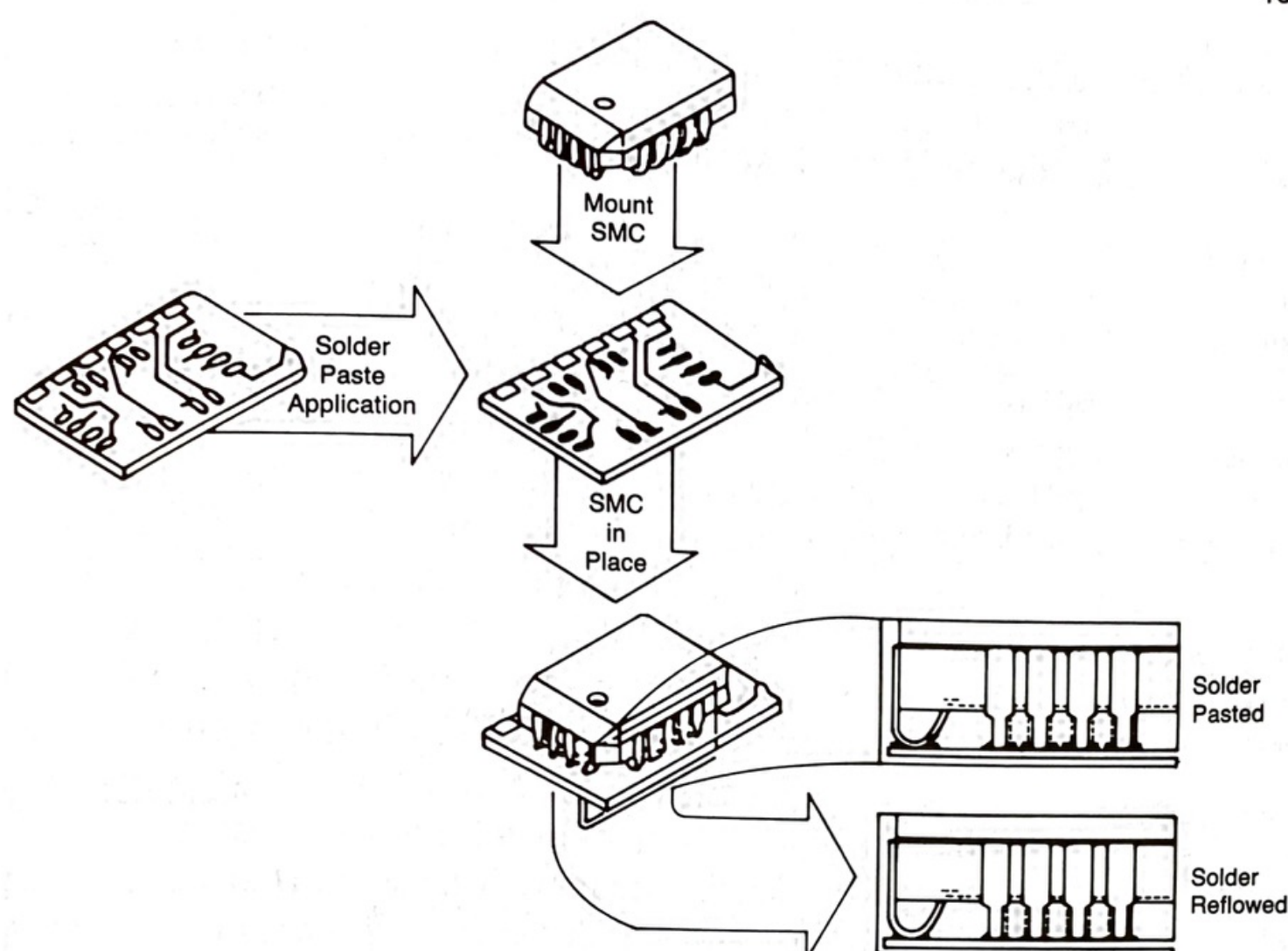


Figure 15-9. SMT Joining Processes and Joint.

as a result, or alternately, design and fabrication tolerances can be increased. Drilled-hole requirements are diminished to those required for plane-to-plane communication, and their size can be optimized for manufacturing considerations without regard for component accommodation. And finally, in addition to card cost-reduction benefits, the overall size of SMT assemblies can also be reduced in proportion to the much smaller SMT component area requirements.

It has been reported that when PTH designs are converted to SMT, using equivalent card technology, size reductions of about 40 percent are achieved when only one side component mounting is used. Because SMT eliminates the protruding pin ends present with PTH, the other side of the card can also be populated, further improving the size reduction factor by as much as 70 percent. Currently, most of the more advanced products use two-sided SMT mounting combination PTH components for the very large devices or those which are not available in an SMT configuration.

Table 15-5. Landmark Products with Advanced Packaging Technologies.

<u>Product</u>	<u>Example(s)</u>	<u>Packaging</u>	<u>New Market</u>
Watch Terminal	Seiko RC-4000	Chip-on-Board	Portable Computer Terminal
Calculator	Sharp	TAB	Credit-Card Size
LCD Color TV	Epson-Seiko	TAB/Flex	Low Power Extended Use
C-D Players	Sony D-5,7,10 Technics SL-XP7	SMT Planar Motor Voice-Coil Servo	Portable CD
35mm Cameras	Minolta Maxxum 7000 Display, Control	Flex	Electronic Sensing
Computer	Sharp PC-1600	Flex/Rigid Card	
Cassette Players	Sony Walkman	Integrated Design	Cassette-Case Size
Camcorder	Sony CCD-V8		One-Unit Design

In addition to reducing size and cost, the simpler and smaller wiring structures of SMT cards and the elimination of the component leads reduce electrical-circuit load and noise. The shorter line lengths also help reduce the signal time delay. These improvements open the circuit design space, which can be used in many different ways to help reduce costs, power, etc. The intrinsic advantages of SMT discussed previously, coupled with continued component cost reduction as usage increases, assures that SMT is likely to become the preferred and dominant card-assembly technology in the future. [14, 15, 16].

15.4 PRODUCT EXAMPLES

15.4.1 Consumer Products

Many of the major advancements in consumer electronic products can be linked directly to one or more new technologies as shown in Table 15-5.

Packaging technology is highlighted here, but other technologies, such as semiconductor, display, and recording, were equally important to the design of the products listed and the new market opportunities that were created. All of these are portable products, suggesting that manufacturers are pursuing a strategy to improve marketability by eliminating restrictions im-

posed by product, size, weight, and power requirements. In the following sections, three consumer products will be used to illustrate current packaging practice and the benefits derived by the manufacturers, which ultimately also benefit the end user.

Compact Disc Player (CD) Packaging: As presented in section 15.2.1, "Consumer Products," on page 1024, the very small portable Compact Disc Players recently developed were made possible by the use of several advanced packaging technologies. Surface Mount Technology, with components on two sides of the card, enabled size reduction of the electronic assembly by a factor of 2 to 3 over what may have been possible using conventional PTH methods. An adaptation of SMT technology was used in the construction of a low profile of spindle motor, which is a complete departure from the conventional cylindrical type in the construction method. Solder joining, analogous to that used in PTH card construction, is used for the final assembly and alignment of a voice-coil servo mechanism of unprecedented accuracy, especially for a low-cost mass-produced product. For illustrative purposes, parts from several commercialized products will be used as examples to show current practice, and demonstrate the role that packaging technology plays in the achievement of the functional objectives.

A brief description of the Compact Disc (CD) medium and operating specifications will be presented to provide the context for the requirements that are placed on the components to be described. [17].

This digital medium was developed as an improvement on the reproduction quality and playing-duration of the LP vinyl audio records first introduced by the CBS Laboratories in the 1950s. The CDs take advantage of the inherently high resolution possible with optical-storage technology to record the equivalent of 790M bytes of information on one side of a 120-mm diameter disc of about a millimeter in thickness. The data is arranged in a continuous spiral with track-to-track spacing of $1.6\ \mu\text{m}$ and bit change increments of $0.3\ \mu\text{m}$ along the length of the track for a net-formatted area density of about 1 million bits per square millimeter. The error-correction overhead increases this density by an additional 30%. To read the microscopically small bits of information, the players require accurate spindle speed control for playback frequency fidelity and two-axis submicron positioning servomechanisms for automatic optical focusing and track following.

Sony D-5 SMT Packaging [18]: The main electronics SMT card from a Sony D-5 portable Compact Disc Player, which was first introduced in 1984, is shown in its entirety in Figure 15-10, with a section magnified in Figure 15-11. On the side shown, the card supports approximately 400 electronic components ranging in complexity from two terminal passive devices to high density 80 I/O plastic quad flat packages with 0.8mm-lead spacing. All the components on this side are SMT mounted. The other side carries a