1 IC Component Socket Overview

This chapter begins with an introduction to the concept of levels of interconnection. Three kinds of component-to-board interconnection are presented: solder joints, conductive adhesives, and integrated-circuit (IC) component sockets. The benefits and deficiencies of each of these IC interconnection methods are discussed. Different approaches to categorizing IC component sockets are presented next, with a focus on socket functionality, structural design, and assembly styles. These approaches are intended to present a context for detailed discussions in later chapters.

1.1 LEVELS OF INTERCONNECTIONS

An electronic system is a hierarchical interconnection network that allows communication among different electronic devices. A number of interconnects are needed to ensure the proper functioning of electronic devices for signal transmission and power distribution. The level of interconnection is defined here by the devices in the system that are being connected, not by the type of interconnect being used. Six levels of interconnection have generally been acknowledged [1–3]:

- *Level 1*: The interconnection is from chip bonding pads to the package leadframe or directly to the circuit board, such as wirebonds, tape automatic bonding (TAB), flip chip, or direct chip attach (DCA). This level of interconnection is usually intended to be permanent.
- *Level 2*: The interconnection is between the electronic component and the printed circuit board (PCB), such as a solder joint or an IC component socket. The solder joint is a permanent interconnection, while an IC component socket provides a separable connection between a component and a PCB.
- *Level 3*: This generally separable level of interconnection is between PCBs, such as connections between a daughter board and a motherboard, through a card-edge connector.
- *Level 4*: This generally separable level of interconnection is between two subassemblies of a system. The subassemblies can be individual PCBs,

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IC Component Sockets, by Weifeng Liu and Michael Pecht
ISBN 0-471-46050-8

power supplies, or separate units, such as disk drives. The interconnection can be achieved through ribbon cable assembly.

- *Level 5*: This generally separable level of interconnection, between subassemblies and the input–output (I/O) of the system, can be accomplished through a board-mounted connector or a cable assembly.
- *Level 6*: This generally separable level of interconnection is between the electronic system and a peripheral device, or between systems. The interconnection is usually accomplished through coaxial cable assembly.

1.2 COMPONENT-TO-BOARD INTERCONNECTION

For component-to-board interconnections, there are three primary ways to connect the electronic components electrically to the PCB: solder joints, conductive adhesives, and component sockets. Solder joints and conductive adhesives are permanent interconnections, whereas component sockets provide a separable interconnection.

Solder joints are the most conventional and common way to connect the components with a PCB. Permanent solder interconnection is accomplished either through the wave soldering process (for insertion-mounted packages) or through the reflow process (for surface-mounted packages). The most commonly used solder composition is a lead–tin eutectic alloy. Other solder compositions are also used to enhance a particular performance, such as using high-lead solder for its heat resistance, or for other reasons, such as eliminating hazardous lead by using lead-free solders.

The ease of manufacturing and low cost make the solder joint the primary choice for interconnection. However, solder joints are not without problems. The lead and chlorofluorocarbons (CFCs) (used to remove flux) can be hazardous to the environment. The Montreal Protocol had mandated the elimination of CFC use in component assembly by the year 2000. The European Council Directives on Waste from Electronic and Electrical Equipment (WEEE) set a target date of July 1, 2006 for a European ban on hazardous materials, including lead. The high assembly temperature for lead-free solder, usually from 220 to 260°C, will become another problem. During assembly, the fast exposure to high temperature (within several minutes) can result in the rapid evaporation of saturated moisture inside the package, causing package delamination, cracking, and popcorning [4–6]. Finally, as the solder joints hold the relatively rigid package body and circuit board mechanically, the mismatch of coefficients of thermal expansion between package and circuit board causes solder-joint fatigue under thermal cycling conditions. Numerous analyses and reviews have been published regarding thermal-cycle-induced fatigue failures of solder joints [4–14].

The continuous enhancement in device functionality requires a high number of component I/O terminals. The number of I/O terminals for a state-of-the-art component has reached several thousands. To account for the increase in I/O counts, the component terminals tend to extend from the bottom of packages, not from the package periphery. Examples include ball grid array (BGA) and chip-scale packages (CSPs). However, this change of configuration poses major challenges for assembly engineers: (1) it is much more difficult to solder and inspect a high-I/O component connection to a circuit board, and (2) if there is a problem during assembly, such as terminal misalignment or package failure, rework proves very difficult. Rework of assembled components, or even direct soldering, can also cause damage to the circuit board, which becomes more expensive with increases in routing density and number of layers.

Accompanying the I/O increase, the size of components also increases. For a component with 2500 I/Os and a 1-mm pitch, the component dimensions can be greater than 50 mm × 50 mm. The package size becomes a limiter in applying more I/O terminals onto a BGA package. The large package size causes reliability concerns. The large thermal stress caused by the CTE mismatch could easily break or fatigue a solder joint under thermal cycling conditions. Although innovations are being developed to address this issue, such as using a stress compensation layer in the BGA substrate (IBM HyperBGA) or using high-CTE (coefficient of thermal expansion) materials (e.g., a high-CTE glass ceramic package), the reliability of large packages is still not satisfactory.

To cope with these problems, *conductive adhesives* are being studied as potential substitutes for solder joints [15–17]. Conductive adhesives are formed by dispersing metallic particles into a polymer matrix so that current is conducted throughout the polymer via particle bridging. Although direct bonding with conductive adhesives is technically feasible, no successful commercial production process has yet been reported, primarily because conductive adhesives are inferior to solder joints in mechanical and electrical performance. Conductive adhesives cannot self-align to correct misregistration. Moreover, rework remains a problem for conductive adhesives, since thermosetting plastics are typically used.

A major constraint concerning permanent interconnections is the need to replace failed or imperfect components or to upgrade components. Moreover, sometimes it may be necessary to use a specific PCB repeatedly to test many similar components. In these situations, a permanent interconnection is inappropriate.

Component sockets provide a cost-effective solution to these problems. A component socket is an electromechanical system that allows a separable interconnection between components and PCBs. However, compared with solder and conductive adhesive joints, component sockets add extra contact interfaces between components, sockets, and PCBs, and require mechanical structure to maintain a stable contact interface, which is essential to proper functioning.

1.3 CLASSIFICATION OF COMPONENT SOCKETS

Component sockets can be classified by a variety of design features and characteristics. These can include the application function that a socket is intended to perform, the assembly process through which a socket is mounted onto a PCB, or the target component that is to be socketed, to mention a few. Table 1.1

TABLE 1.1 Classification of IC Component Sockets

Classification Category	Types of IC Component Sockets
By function	Burn-in sockets Test sockets Production sockets
By assembly process	Through-hole sockets Surface-mounted sockets
By contact technology	Metallic socket Elastomer socket
By number of contact points	Single-point contact Multipoint contact
By number of piece	One-piece sockets Multiple-piece sockets
By insertion force	Normal insertion force Zero insertion force Low insertion force

lists categories and types of component sockets. Some of them just follow the classification methods for connectors given by Viswanadham [14], since component sockets can be considered a subset of connectors. However, some of these categories are not in common use in industry.

A socket may belong to several categories: for example, a pin grid array (PGA) socket can be a surface-mounted assembly type with multipoint-contact design for burn-in applications. Combining categories gives an engineer a clear picture of the sockets and also helps the process of selecting suitable component sockets for a given application.

Suitable component sockets can be found for all packaging styles, and for a given packaging style, several contact designs may be available. To facilitate the reader's understanding, in this book we introduce contact technologies based on mated packaging styles:

- *Sockets for PTH (plated through-hole) packages*: SIP sockets, DIP sockets, PGA sockets, and so on.
- *Sockets for SM J-leaded packages*: SOJ sockets, PLCC sockets, and so on.
- *Sockets for SM gull-wing-leaded packages*: SOP sockets, QFP sockets, and so on.
- *Sockets for packages with array interconnections*: BGA/CSP sockets, LGA sockets, MCM package, and so on.

1.4 STRUCTURE OF IC COMPONENT SOCKETS

As an electromechanical system, a component socket is composed of parts that act synergically. The basic structure of a component socket includes the socket

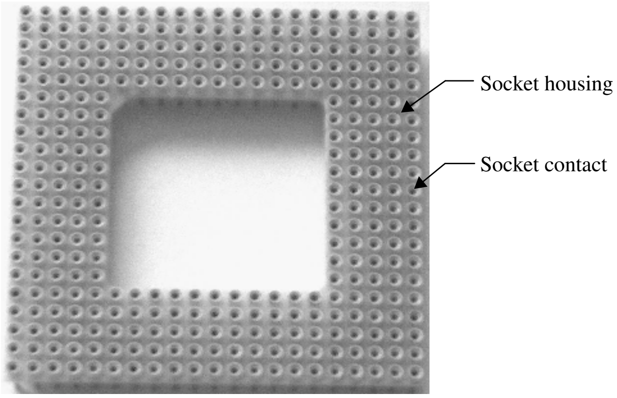

Figure 1.1 IC component socket.

housing and socket contact. An IC component socket (PGA socket) with one-piece design is shown in Figure 1.1. For this design, the material for the entire housing is a thermoplastic polymer; for a two- or multipiece design, different parts of the housing may be made from different materials. Other peripheral features, such as a heat sink, actuation system, and polarization chamfers or pins, may add value, but may not be necessary for all types of sockets.

1.4.1 Socket Housing

The following bullets list the functions of the socket housing. The first two functions are necessary for the socket housing to perform; the remaining functions may not be applicable to all socket designs.

- It insulates the contact members electrically to prevent leakage current between contacts.
- It supports contact members mechanically and maintains them in position. The socket housing should be able to keep contacts in the right positions and to bear both mechanical and thermal loads, including the insertion and extraction of a component from the socket, high assembly temperature, and mechanical shock.
- It exerts and maintains contact pressure. Under some circumstances, it may be required that contact force be exerted by the contacts themselves or by the contacts and socket housing synergically.
- It shields the contact members from operating environments. The design for the shielding function of socket housing may depend on its potential application environment. The socket housing may be designed as an open structure to maximize airflow for heat dissipation. However, a closed structure may be required to shield contact interfaces from outside environmental pollutants.

- It provides protection for the contacts against flux and contaminants during assembly.
- It provides features for pin 1 orientation and package orientation to facilitate assembly and component insertion.

There are different types of socket housing designs. A socket housing may be a closed-bottom structure to prevent solder wicking, or may be an open-bottom structure to facilitate solder-joint inspection and repair after assembly. A socket housing may be open frame to maximize airflow, or closed frame to withstand high mechanical impact. Figure 1.2 shows dual-in-line package (DIP) sockets with an open-frame structure and with a closed-frame structure. This classification is commonly used for many types of sockets, such as DIP, PGA, SOP, SOJ, PLCC, and QFP sockets.

Figure 1.3 shows a clamshell structure versus an open-top structure. These two designs are more common with BGA sockets. The former is operated manually; the latter is used to facilitate high-volume automatic loading of components. With the clamshell structure, closing the lid will automatically complete the alignment of packages and exert contact pressure on the contact interface. With the open-top structure, external z-axis compression is applied to actuate the socket contacts before mounting BGA components.

Another design for socket housing features a lid (often metallic) and screws. The clamping force is exerted on the contact interface by driving in the screws. The driving distance controls the extent of the applied force and contact deflection. The structure is especially designed for mounting BGA and LGA packages.

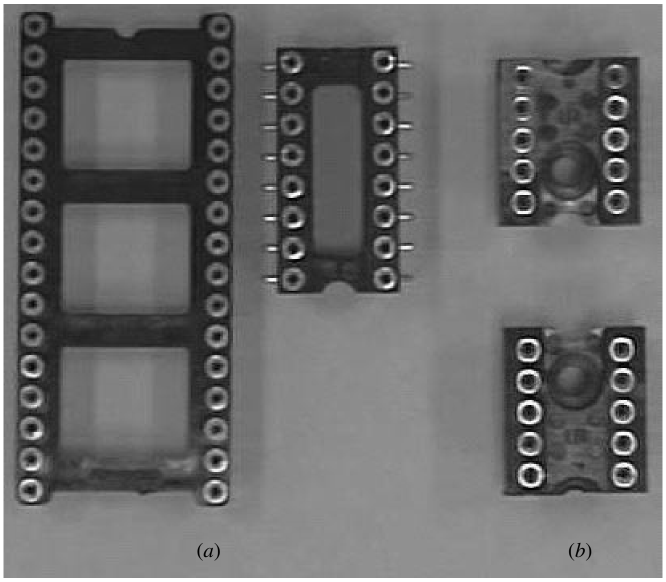

Figure 1.2 Top view of DIP sockets: (*a*) open-frame structure; (*b*) closed-frame structure.

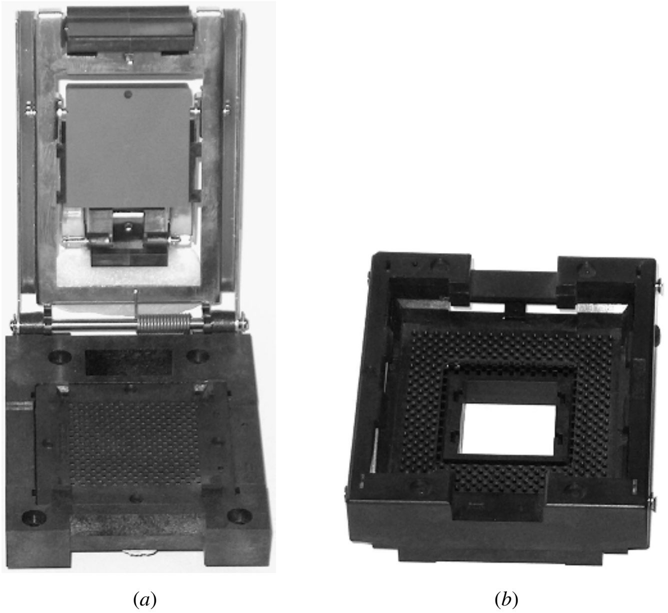

Figure 1.3 BGA sockets: (*a*) clamshell structure; (*b*) open-top structure.

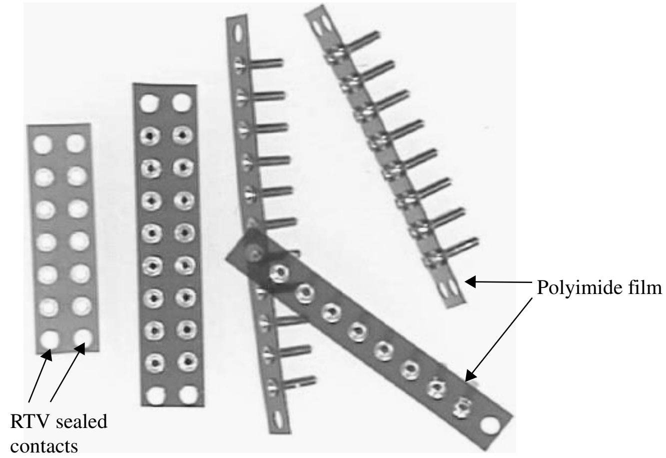

Figure 1.4 DIP sockets with disposable terminal carriers.

Another socket housing design is actually “no housing.” In this case, the socket housing is made of thin films, which after assembly can be peeled away and disposed. This design allows complete soldering visibility on both sides of a PCB, better flux rinse, and maximum airflow. Figure 1.4 shows DIP sockets with disposable terminal carriers.

1.4.2 Socket Contact

Socket contact refers to the electrical conduction path from the components to a PCB, although the connection between the socket and the PCB for some types of sockets is often referred to as the *socket terminal*. Socket contacts are usually made of copper alloys because of their high conductivity. Conductive elastomers are used for some special applications. A variety of contact designs are available; these are presented in later chapters.

The socket contacts provide an electrical connection between components and the circuit board, by exerting a contact force on the contact interface through deformation of the contact materials. The mechanical function of socket contacts is to maintain a stable contact interface.

1.4.3 Socket Actuation

In many sockets used for through-hole components, a force is needed to insert the component. With very high I/O count components, the force needed to insert a device package into a socket may be large, which may damage socket contacts, package pins, or even the package body. The actuation system is designed to facilitate insertion or extraction of packages without using insertion force.

Figure 1.5 shows a top actuation design, where actuation is carried out by the socket housing. Pressing down on the socket housing opens the socket contacts so that the package can be mounted with zero insertion force (ZIF). Releasing the press causes the contact interfaces to be mated.

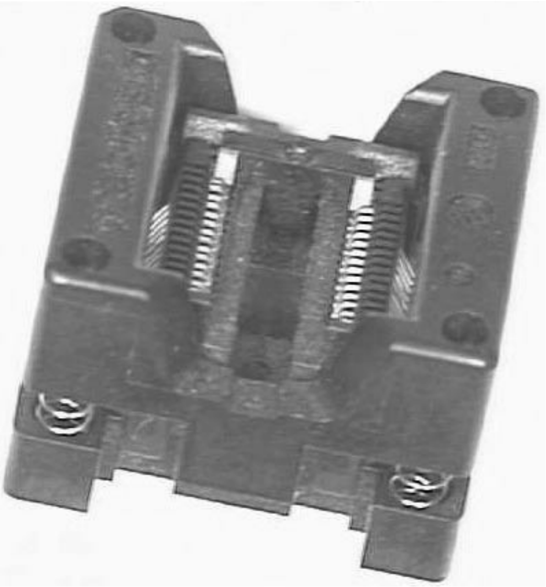

Figure 1.5 Top actuation system for IC component sockets.

Another actuation style uses metal levers, which move in a horizontal direction. Raising the actuation handle puts the contacts in the open position so that a package can be inserted and extracted without using force. Lowering the handle closes the contacts.

1.4.4 Heat Sink

There are three mechanisms for heat dissipation from an electronic device: conduction, convection, and radiation. *Convection* is heat transfer from a solid surface to a moving fluid, which is typically air, or a fluorocarbon liquid. Heat transfer in solids occurs primarily through *conduction. Radiation* involves heat transfer through energy emission to the surroundings. In most cases, heat transfer is generally a mixture of the three mechanisms, in which conduction and convection are the dominant modes. Effective heat dissipation must be implemented in the socket design.

There are different approaches for heat dissipation in the socket design. The heat transfer can be enhanced through optimizing socket interconnections or designating some interconnects purely for heat transfer, so the heat generated can be conducted effectively to the PCB. Heat dissipation can also be enhanced by maximizing airflow or adding a heat sink within the socket housing.

A heat sink normally provides extended surfaces for heat transfer from a component to the airflow. It is usually made of aluminum or copper and formed in four typical shapes: plate fins, serrated fins, pin fins, and disk fins [13]. The heat sinks can be part of the socket housing. The plate-fin heat sink is the most popular design because of ease of manufacture. Figure 1.6 shows a heat sink in the shape of plate fins.

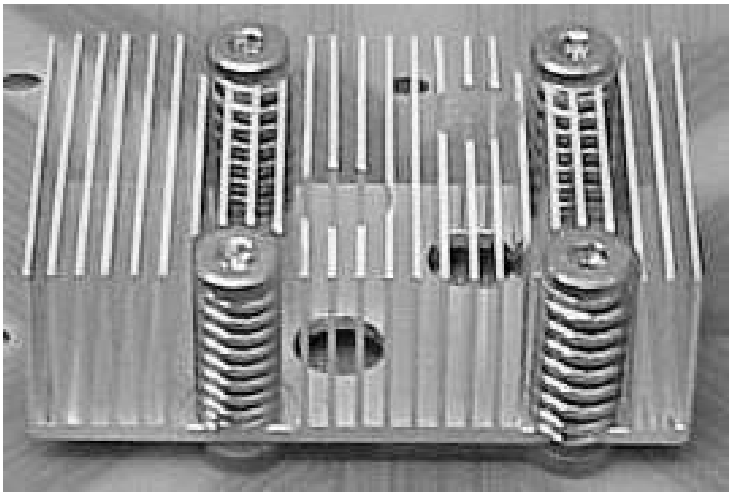

Figure 1.6 Heat sink with plate fins.

1.4.5 Socket Polarization

Socket polarization is a design feature embedded in the socket housing. Its purpose is to locate the package pin positions to aid package mounting or determine socket orientation to facilitate assembly. Polarization features for package orientation and registration are often visual indicators for locating pin 1, which may be a notch, an embedded arrow, an ink mark, or a chamfered corner. For different types of sockets, these features may be different; even for the same type, different companies may use various polarization features. Polarization features on the bottoms of sockets are usually plastic pins. They not only help in socket registration, but also protect the delicate socket terminals from bending during storage, handling, and assembly. These plastic pins also control the standoffs of sockets on the PCB.

1.5 SOCKET FUNCTION

Although IC sockets may have different geometries, different structures, and different contact technologies, they can generally be classified into two groups: sockets used for component assembly, and sockets used for component testing or burn-in. These two groups of sockets are also called *production sockets* and *test/burn-in sockets*, respectively. Figure 1.7 shows production sockets assembled on a PCB.

IC manufacturers perform burn-in by subjecting electronic components to biased, high-temperature conditions in order to precipitate early component failures, and reduce what is commonly called *infant mortality*. During the process,

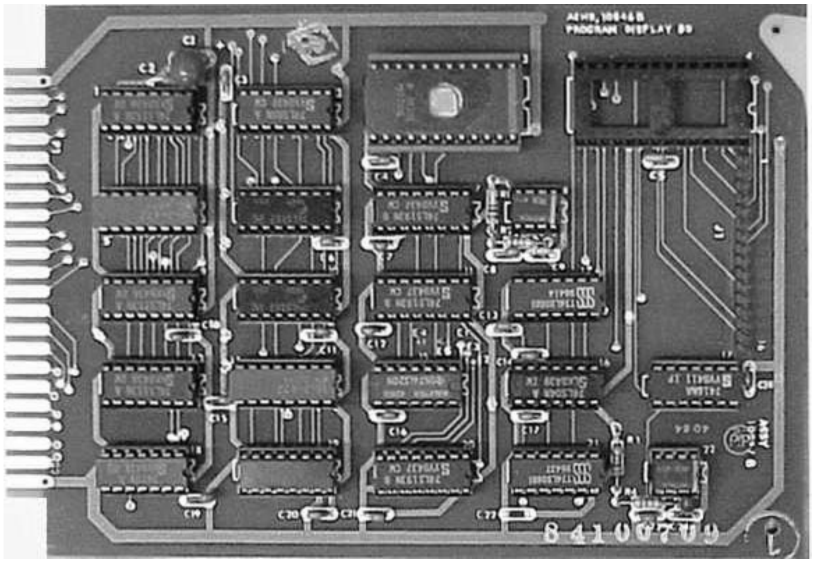

Figure 1.7 Printed circuit board assembled with production sockets.

burn-in sockets, mounted on test or burn-in boards, are used to test each IC package. Therefore, burn-in sockets must withstand high temperature for prolonged periods without performance degradation. To reduce cost, burn-in or test sockets must also experience tens of thousands of package test insertions and extractions before they need to be replaced.

Production sockets typically undergo very few insertions and extractions, and their operating temperature is usually below 100°C. A production socket has to be very cost-effective. The price of available sockets ranges from 2 to 20 cents per pin in volume. Burn-in sockets cost much more, with prices ranging from 50 cents to $5 per pin [18].

1.6 SOCKET ASSEMBLY

A component socket can be classified according to the way it is mounted on a PCB. A socket is the *through-hole* (TH) type if the socket pins are inserted into PCB holes to make the connection. If the connection is made by mounting the socket terminals onto metallic pads on the surface of the PCB, the socket is a *surface-mounted* (SM) type. The design characteristics of a component socket provide much flexibility; the socket can transform a through-hole package to a surface-mounted type, and vice versa.

For through-hole sockets, the connection can be formed through either wave soldering or solderless press fit. For the press-fit design, the compliant tail of the socket features precision-machined pins that are hollow and slotted to conform to the PCB holes. The fine serrations on the pins' tails form a "gastight" connection that does not require soldering. Two assembly methods are used for surface-mounted sockets; the socket can be assembled on a PCB through either solder reflow or solderless z-axis compression, as in screw-bolt design.

1.7 BENEFITS OF USING IC COMPONENT SOCKETS

Applications and benefits of IC component sockets include component test and burn-in; component upgradability and exchange; flexibility in IC design, assembly, and supply chain management; avoiding direct component soldering; opportunities for component replacement and repair; and in some cases, cost savings. These benefits are discussed below.

1.7.1 Component Test and Burn-in

Sockets are commonly used to test and screen components. Testing can include performance testing to determine if the components meet specifications or testing to bin components (e.g., by microprocessor speed).

Screening is a method to precipitate defects in a component in order to remove defective components and thus ship only nondefective components.[1] The purpose

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[1] Because the purpose of screening is to remove defective components prior to shipment, screening is by definition conducted on every component.

is to reduce infant mortality failures. One class of screens involves the use of loads (stresses) and performance tests to precipitate defects.[2] Within this class of screens, the use of one particular set of screens is called *burn-in*, in which the component is subjected to some combination of electrical bias, temperature, and perhaps humidity (load conditions). In some cases, the load conditions selected may be higher than the rated values of the component, to accelerate the defect precipitation process. Burn-in can also be used to determine faults in a device that can be repaired subsequently (e.g., a memory component can be tested to determine faulty memory cells, and then the cells can either be repaired or replaced with redundant cells).

In both test and screen applications, sockets must be able to handle large numbers of insertions. Test sockets may have to handle upward of a million insertions. Burn-in sockets may have to handle upward of 10,000 insertions and do so under somewhat stressful operating and environmental conditions [19]. According to a market research report by Bishop & Associates, test and burn-in sockets achieved $211 million in sales in 1999, comprising a 22% share of the world market. PGA sockets are the largest product segment, with $92 million in sales, followed by chip-carrier sockets with $64.5 million in sales. Major manufacturers in this area include Yamaichi, TI Japan, Enplas, Wells/CTI, and 3 M Textool [20].

1.7.2 Component Upgrade and Exchange

With advances in microelectronics technology, the performance and functionality of electronic devices have been enhanced dramatically. For example, the computer industry has seen an increase in the clock frequency of microprocessors from 266 MHz to over 2 GHz in the period from 1995 to 2003. Such enhancements have put customers in a dilemma: To keep pace with the latest technology, a customer has to buy a new product every few years or be out of date and perhaps unable to function efficiently.

An IC component socket allows for simple product improvements or updates, whereby new technologies can easily be installed into a fielded system without replacing the entire system. For example, in the computer industry, eight socket versions have been available to provide compatibility with a variety of microprocessors. The most widely known microprocessor socket is Socket 7, the configuration used for Pentium microprocessors. In 1999, Intel began to offer "PGA socket" versions of most of their microprocessors, to reduce cost and to simplify motherboard design [21]. Intel also has LGA sockets with 775 pinout for Prescott and Tejas central processing units (CPUs) for desktop personal computer (PC) and low-end server applications [22].

Sockets also enable exchangeability of compatible components from different manufacturers. Sockets add flexibility for customers to upgrade systems to achieve lower price and higher performance by using components from various manufacturers.

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[2] Screens can also be noninvasive; for example, visual inspection is a type of screen that can be used to identify (precipitate) defects.

1.7.3 Flexibility in IC Design and Assembly and Supply Chain Management

IC sockets can add flexibility to IC design, assembly, and supply chain management. In particular, sockets can be used to reroute I/Os, making IC layout more package independent. Because the socket is used to reroute, the IC can be optimized and the package does not have to change. Sockets also free the IC designer from interconnection issues associated with packaging of the component, since the socket can be used to match any package style to the PCB pad layout. For example, sockets can convert leaded components to surface-mounted components, and vice versa. This exchangeability between packaging styles created by using sockets also adds flexibility in supply chain management. That is, there are more options when creating a supply chain and finding suppliers.

Sockets also help manufacturers standardize and simplify the assembly process, enabling, for example, a single soldering process (wave or reflow), regardless of package requirements. This is especially important when an assembly technology or a component package type is not available. Sockets provide a way to mount different packaging styles onto one type of PCB, making it easier to design and manufacture.

During some product initiations, new IC packages are often unavailable in full quantity. Use of IC component sockets allows assembly to proceed without interruption by using just-in-time components. Thus, new components can simply be plugged in when the delivery arrives. In addition, IC component sockets help reduce in-process inventory by making it possible to install devices during final assembly. Less handling and exposure to manufacturing environments can increase yield as well as reliability, although exposure to electro-static discharge (ESD) conditions can be increased.

1.7.4 Use of Sockets to Avoid Soldering

Soldering is generally the most conventional and cost-effective means to connect a component to a PCB electrically and physically. However, soldering is not without problems. Key problems with component soldering are associated with solder connection yields of high-I/O-area array packages and damage inflicted on certain types of packages subjected to solder reflow temperatures.

Continuous enhancement in device performance and functionality has led to increases in the number of I/O terminals. The Semiconductor Industry Association (SIA) has predicted a 12% increase in the number of I/Os for high-performance ASIC packages; by 2005, there will be over 3000 I/Os in these packages [23]. To account for the increase in I/O, package terminals have been designed to cover the bottom of the package (area grid array package), with connections in the form of ever-decreasing-diameter solder balls (ball grid array packages).

In 2003, state-of-the-art packaging technology made it possible to mount over 2000 I/O terminals on a single package. However, yield problems arise due to inaccuracies in component placement on the circuit board, noncoplanarity of the component with respect to the board (e.g., due to inherent dimensional variations, warpage, or nonuniformity of temperature profiles across the package and board), and the inability to reflow the balls uniformly to the board. For example, high assembly (solder reflow) temperatures, ranging from 220 to 260°C, as well as fast exposure to high temperatures (within several minutes), can result in package damage in the form of delamination, cracking, or popcorning [24]. In addition, solder joints are prone to solder joint fatigue due to mismatches in the coefficients of thermal expansion of the component and the board under operational and environmental thermal cycling conditions. Furthermore, if failures occur, it is difficult, often impossible, to rework the assembled soldered packages; rework at elevated temperatures incurs some risk of damaging the components and often, the more expensive PCB itself. The use of compliant or nearly decoupled sockets can virtually eliminate this type of failure mechanism.

Use of sockets provides ease of assembly without the soldering and rework difficulties of large packages. Electronic components can be mounted after assembly so that the thermal impact on components can be avoided. The influence of nonplanarity in packages can be minimized by increasing the compliance of socket contacts. However, due to the softness, oxidation, and plasticity of solder balls, BGA packages are seldom socketed onto a board in the final assembly. Land grid array packages (LGAs) have been introduced to substitute for BGA packages. LGAs are similar to BGAs, except that instead of solder balls, I/O terminals are typically made of arrays of pads (generally gold-plated) on the bottoms of packages.

1.7.5 Component Replacement and Repair

Sockets allow easy replacement and repair of IC components. Advanced state-of-the-art components, whose development is still early in the learning curve, can have a high failure rate. Such failures often occur during assembly level burn-in of equipment before shipment. Socketing provides an easy way to replace components that fail in early life. Removing socketed components also helps inspection, troubleshooting, and repair. Replacing failed components is always far more cost-effective than replacing a complete board or system.

1.7.6 Cost Savings

Sockets provide a cost-effective approach to production testing and screening. Sockets also provide a cost-effective solution to upgradability. Although sockets add cost to the bill of materials, cost benefits can be realized over soldered components if rework costs are high and assembly yield for repair and rework in the soldered components is low. Cost savings may also arise in reducing system downtime via ease of maintenance and repair.

In the case of overseas PCB assembly, the use of sockets can also be used to reduce tariffs on partial assemblies and duties associated with components. That is, an assembly can be made and then shipped to another country where components are infected. The final assembly can then be sold within tariffs and duties on the components.

1.8 CHALLENGES FACING IC COMPONENT SOCKETS

Some challenges confront the application of IC component sockets. A socket may reduce electrical performance by adding extra electrical length, occupy increased assembly area, be incompatible with new IC package designs, and introduce reliability concerns. Clearly, designing a socket that keeps pace with the evolution of microelectronics technology poses a challenge for socket designers.

1.8.1 Extra Signal Path

The evolution of microelectronics toward higher speeds and switching frequency creates more stringent requirements for socket design, since sockets introduce an extra electrical path that can cause excessive propagation delay and crosstalk. For example, for radio-frequency (RF) and microwave devices, the operating frequency is often from 1 to 10 GHz. This requires that the bandwidth of the socket be several times the operating frequency of the device being tested, due to the harmonic content of the waveform's rise and fall times [25]. Thus, it is essential for sockets to be equipped with short contacts, and sometimes, special grounding and decoupling schemes, to enable a high bandwidth and to assure adequate signal fidelity. The traditional cantilever spring contact, with an electrical length of typically around 5.0 mm, cannot meet the strict requirements of high-frequency applications. New technologies and designs, such as conductive elastomer contacts and microstrip contacts [26,27], are designed to scale down the electrical length.

1.8.2 Increased Assembly Area

Depending on the socket housing and the type of IC to be socketed, there may be additional real estate on the printed circuit card and extra height. Some DIP and PGA sockets may add height, but no extra real estate is occupied. For components with peripheral leads, such as plastic quad flat packs (PQFPs), sockets are usually 20% larger, with profiles kept within 5 mm, demonstrating almost the same height as that of socketed packages.

For production sockets, specific requirements may be imposed on sockets concerning their dimensions and profiles. For test and burn-in applications, this is usually not a primary concern.

1.8.3 Compatibility with Fine-Pitch Applications

There has been a continuous reduction of I/O pitches in IC packages, from 1.27 mm to below 0.5 mm, and even to 0.25 mm in some cases in 2003. The shrinkage of package pitches, together with small terminals such as solder balls, requires compatible IC component sockets. For example, for the stamped contact design, BGA sockets are mounted to the board using a through-hole method. This can create a significant bottleneck for escape routing on the PCB, making it unusable for a 0.5-mm pitch application [28]. Similarly, the pinch-style contact design of BGA sockets, where the solder balls are "grabbed" from their sides which works well for a pitch of 0.75 mm, but is not suited to smaller pitches. At 0.5 mm there is simply not enough space between the solder balls for the thickness of the metal pitch contacts [29]. One way to go down to fine pitches is to make contact materials thinner. However, this can pose difficulties for manufacturing and assembling very small contacts into a socket.

Some companies are designing alternatives to pinch-style contacts, such as spring-style contacts that touch the bottom of the solder balls, eliminating the dimensional constraints of side contacts [29]. By adapting to a smaller diameter, the Pogo-pin contact design has been used for 0.65- and 0.5-mm pitches, but the cost is quite high [29]. A further move toward finer pitches will pose tougher challenges, not only in socket design but also in contact reliability, coplanarity, and cost.

1.8.4 Reliability

Although using sockets eliminates many reliability concerns related to solder joints, it introduces others. Compared with a solder joint, a socket adds additional contact interfaces, degradation of which may cause an increase in contact resistance. The ability to maintain good electrical contacts over time under all application environments is essential for the application of a component socket.

Table 1.2 is a summary of the failure mechanisms that may be experienced by component sockets. These failure mechanisms can be divided into two categories: overstress and wear-out. Overstress failures occur due to a single occurrence of a stress event that exceeds the intrinsic strength of a socket. Wear-out

TABLE 1.2 Potential Failure Mechanisms of Component Sockets

	Overstress	Wear-out
Contact	Buckling Yielding Fracture Device walking out	Oxidation Corrosion Electrochemical migration Intermetallic formation Creep Stress relaxation Contact wear Friction polymerization Whisker growth Fungus growth Fatigue
Housing	Dielectric breakdown Fracture Cracking	Outgassing Swelling Moisture absorption Creep

failures occur when the accumulation of incremental damage exceeds the socket endurance limit.

To address reliability concerns, socket manufacturers utilize qualification methods. The testing procedures usually follow EIA or military standards. Requirements and testing procedures may also be issued by original equipment manufacturers (OEMs) or component manufacturers. For example, Intel issued two documents on design specifications and performance and reliability assessment of sockets that support their microprocessors [30, 31]. The environmental durations are usually short or moderate (e.g., 100 or 240 h), and the tests usually do not establish the long-term performance of a socket. In fact, most methods are assessed in terms of pass or fail, based on a specific criterion. As a result, the traditional qualification methods are rarely of any value in understanding the useful life of a socket, especially for new socket designs. Furthermore, socket manufacturers rarely understand actual application conditions, which must be incorporated in any reliability assessment plan since they may introduce unexpected failure opportunities.

1.9 IC COMPONENT SOCKET MARKET

The worldwide market for IC component sockets almost reached $1 billion in 1999 [20]. Table 1.3 presents the IC component socket world market in 1999, with sales by product type. The PGA socket captured the largest market share, with SIP/DIP sockets second. Advances in the microelectronic technology, coupled with a need for more integrated devices, is driving a shift toward area array packages. In 2001, the sales of PGA sockets increased to $652 million [32].

TABLE 1.3 Worldwide Market of IC Component Socket, 1999

Product Type	1999 Sales (millions of dollars)		Market Share (%)	
Production sockets	749.0		78.0	
PGA sockets		252.9		33.8
BGA sockets		2.7		0.4
LGA sockets		40.0		5.3
SIP and DIP sockets		189.4		25.3
Small-outline sockets		81.7		10.9
Chip carrier sockets		156.3		20.9
All others		26.0		3.5
Test and burn-in sockets	211.0		22.0	
PGA sockets		92.0		43.6
Chip carrier sockets		64.5		30.6
All others		54.5		25.8
World total	960.0		100	

Source: Ref. 20.

Demand for LGA sockets is projected to increase fivefold by 2006. This creates significant opportunities for socket manufacturers.

The United States is the world's largest market for IC component sockets, but China may surpass the U.S. [33]. Manufacturers competing for the socket market are led by Tyco, FCI, Molex, and Yamaichi [Appendix B].

For some manufacturers, IC sockets may be only one part of their connector production; others may produce sockets only. IC component sockets are available for all types of packages; even for one type of socket, dozens of novel designs are on the market.

1.10 SUMMARY AND FUTURE DIRECTIONS

IC component sockets provide designers and manufacturers with much flexibility to optimize electronic systems. The need for component test, burn-in, upgrade, or repair puts IC component sockets in an important position in the microelectronics industry. Socket manufacturers are now providing solutions for low-profile, fine-pitch, and high-I/O applications, which require more stringent requirements as to performance and reliability. Among the trends observed are signal path reduction, built-in grounding and decoupling schemes, fully shielded sockets and interconnects, and the use of conductive elastomer designs. It is expected that sockets will continue to evolve to keep pace with semiconductor and package developments and to meet the requirements of IC designers and component and equipment manufacturers.

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