IC Component Sockets

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IC COMPONENT
SOCKETS
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The interconnection between an electronic component and a printed circuit board (PCB) can be classified according to whether it is permanent or separable. Soldering the package terminals directly to the trace pads of a PCB provides a permanent device-to-board interconnection, which has been the most conventional and popular method of component assembly. The application of conductive adhesives is another choice for the permanent interconnection, as an alternative to solder-based interconnects. Integrated circuit (IC) component sockets provide a separable interconnection between electronic components and PCBs, and they are the focus of this book.

An IC component socket is an electromechanical system that provides a separable mechanical and electrical connection of a component to a PCB. The characteristics of an IC component socket make it possible for an IC component to be easily connected to or disconnected from the PCB many times. This gives IC component sockets many advantages over traditional solder joints. Through their use, IC designers can test or reprogram electronic components in a system, and IC customers can upgrade their devices just by removing out-of-date components and plugging in state-of-the-art components. Before being assembled onto a PCB, electronic components can be stress-tested to ensure their functionality; an IC component socket is necessary for the electrical connection between the device under test and test equipment. With the advance of new microelectronic technologies and the continuous performance enhancement of electronic components, IC component sockets have assumed an essential role in IC design, test, and performance upgrade.

At this writing, there are more than 50 IC component socket manufacturers inside the United States alone. A variety of contact designs is available on the market to satisfy the need for test, burn-in, and assembly of different kinds of electronic packages. It is, in practice, a difficult task to select the right choice for a specific application from among so many socket manufacturers and technologies. Moreover, until now there has been no single source covering all aspects of IC component sockets. We aim to remedy this deficiency and to present the state-of-the-art technologies and science behind IC component sockets. The book is written for IC managers and engineers who want to use IC component sockets for test, burn-in, and assembly applications, and for others who want to grasp and understand this interconnection technology.

The book is organized into nine chapters, covering the IC component socket industry, socket design, socket materials, performance characteristics, reliability, and related standards. Various levels of interconnection, with a special focus on
device-to-board interconnection, are discussed in Chapter 1. The advantages and
disadvantages of solder joints, conductive adhesives, and sockets are compared.
The functions, structures, and assembly of IC component sockets are introduced.

In Chapter 2, common performance characteristics of IC component sockets
are examined. These characteristics are the keystones specifying the performance
and quality of a design and a product.

Material issues are covered in Chapter 3. The properties of these materials are
essential to understanding the overall performance of socket technology.

Socket contact technologies are presented in Chapters 4 through 8 with respect
to the packaging styles of the components to be socketed. Chapter 9 introduces
the failure modes and mechanisms of socket housing and contacts. Chapter 10
concentrates on reliability and qualification issues of IC component sockets. There
is a section on mixed flowing gas test methods written by Ping Zhao. A theoretical
approach, contributed by J. Wu and M. Sun, is presented in Chapter 11 to predict
contact reliability. The standards and specifications for references are provided
in Chapter 12.

Ever-increasing IC speed and density and reduced product size add more stringent
requirements to IC component socket technology and inevitably promote its
progress. We hope this book will serve as a valuable reference for IC managers and engineers who face the challenge of grasping the rapid evolution of interconnection technology. We hope further to stimulate further research on IC component sockets, their electrical and mechanical designs, performance testing, reliability, and effective incorporation of sockets into the design of an overall electronic system.

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Michael Pecht
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,
IC COMPONENT SOCKET OVERVIEW

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 sub-assemblies 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 popcornning [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
IC COMPONENT SOCKET OVERVIEW

TABLE 1.1 Classification of IC Component Sockets

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

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
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](image)

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

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 Yamaha, TI Japan, Enplas, Wells/CTI, and 3M 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.

\(^2\) 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>
<thead>
<tr>
<th>TABLE 1.2 Potential Failure Mechanisms of Component Sockets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overstress</strong></td>
</tr>
<tr>
<td>Contact</td>
</tr>
<tr>
<td>Buckling</td>
</tr>
<tr>
<td>Yielding</td>
</tr>
<tr>
<td>Fracture</td>
</tr>
<tr>
<td>Device walking out</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Housing</td>
</tr>
<tr>
<td>Dielectric breakdown</td>
</tr>
<tr>
<td>Fracture</td>
</tr>
<tr>
<td>Cracking</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Product Type</th>
<th>1999 Sales (millions of dollars)</th>
<th>Market Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production sockets</td>
<td>749.0</td>
<td>78.0</td>
</tr>
<tr>
<td>PGA sockets</td>
<td>252.9</td>
<td>33.8</td>
</tr>
<tr>
<td>BGA sockets</td>
<td>2.7</td>
<td>0.4</td>
</tr>
<tr>
<td>LGA sockets</td>
<td>40.0</td>
<td>5.3</td>
</tr>
<tr>
<td>SIP and DIP sockets</td>
<td>189.4</td>
<td>25.3</td>
</tr>
<tr>
<td>Small-outline sockets</td>
<td>81.7</td>
<td>10.9</td>
</tr>
<tr>
<td>Chip carrier sockets</td>
<td>156.3</td>
<td>20.9</td>
</tr>
<tr>
<td>All others</td>
<td>26.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Test and burn-in sockets</td>
<td>211.0</td>
<td>22.0</td>
</tr>
<tr>
<td>PGA sockets</td>
<td>92.0</td>
<td>43.6</td>
</tr>
<tr>
<td>Chip carrier sockets</td>
<td>64.5</td>
<td>30.6</td>
</tr>
<tr>
<td>All others</td>
<td>54.5</td>
<td>25.8</td>
</tr>
<tr>
<td>World total</td>
<td>960.0</td>
<td>100</td>
</tr>
</tbody>
</table>

*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.

REFERENCES

REFERENCES


2 Component Socket Properties

Table 2.1 lists the common performance and reliability characteristics that are used to specify component sockets. They are classified in three categories: mechanical, electrical, and reliability. In this chapter we discuss the mechanical and electrical characteristics of component sockets, which depend on socket design, manufacturing process, and quality. Socket reliability is covered in Chapters 10 and 11.

2.1 SOCKET CONTACT

The socket contact provides a separable electrical path between IC components and PCBs. It is also a mechanical structure, generating the necessary contact normal force that establishes and maintains the contact interface. In evaluating the functioning of a socket contact, both mechanical and electrical aspects must be considered. These include insertion and extraction force, contact force, contact retention, contact wipe, contact resistance, current rating, inductance, capacitance, and bandwidth.

2.1.1 Insertion and Extraction Force

Insertion and extraction force, also called mating/unmating force or engagement/separation force, is the force required to insert package leads into and extract them from their normal positions in a socket [1]. In a conventional socket design, the engagement of mating contacts occurs in a plane approximately parallel to the plane of the mating surfaces.

Figure 2.1 illustrates a typical engagement process [2, 3]. The engagement force of package pins acts on the spring contacts of the socket and causes their deflection, which in turn exerts a contact normal force onto the package pins. Two stages have been used to describe the engaging process: In stage 1, a socket contact beam begins to deflect, a contact normal force is generated, and the insertion force increases rapidly. In stage 2, the contact beam is fully deflected and the package pin slides on the surface of the socket contact due to the normal force applied.

Figure 2.2 shows the insertion force versus the insertion depth during the two stages. During the first stage, the insertion force increases with the insertion
TABLE 2.1 Performance and Reliability Characteristics of Component Sockets

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Electrical</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact force</td>
<td>Contact resistance</td>
<td>Flammability</td>
</tr>
<tr>
<td>Insertion/extraction force</td>
<td>Current rating</td>
<td>Temperature rating</td>
</tr>
<tr>
<td>Contact retention</td>
<td>Inductance</td>
<td>Thermal shock/cycling</td>
</tr>
<tr>
<td>Durability</td>
<td>Capacitance</td>
<td>Temperature life</td>
</tr>
<tr>
<td>Contact wipe</td>
<td>Dielectric withstanding voltage</td>
<td>Temperature/humidity</td>
</tr>
<tr>
<td>Actuation force</td>
<td>Insulation resistance</td>
<td>Dust</td>
</tr>
<tr>
<td>Voltage rating</td>
<td>Salt spray</td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Vibration</td>
<td></td>
</tr>
<tr>
<td>Operating frequency</td>
<td>Mechanical shock</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.1 Schematic illustration of (a) contact mating and (b) engagement.

Figure 2.2 Insertion force versus insertion depth during mating.

depth until eventually, maximum force is achieved. For a given normal force, which is determined by the stiffness of the contact spring and the magnitude of its deflection, the maximum insertion force depends on the mating geometry and coefficient of friction. As the friction force opposes the direction of motion, it adds to the insertion force.

A simplified equation is used to calculate the maximum insertion force given a specific contact normal force [2]:

\[
F_I(\text{max.}) = 2F_n(\text{max.}) \frac{\sin \alpha + \mu \cos \alpha}{\cos \alpha - \mu \sin \alpha}
\]  

(2.1)
where $F_i$ is the insertion force, $\mu$ the coefficient of friction, and $\alpha$ the angle of the mating interfaces, as indicated in Figure 2.1. Suppose that the coefficient of friction is 0.4; a change of mating angle from $15^\circ$ to $30^\circ$ will result in about a 143% increase in insertion force. Therefore, any misalignment will increase the difficulty of package insertion and may damage the package leads and socket pins.

After surpassing the maximum insertion force, the insertion force lessens and levels off until the package pins reach their normal positions. The value of the insertion force becomes the same as that of the friction force:

$$F_i = \mu F_n$$  \hspace{1cm} (2.2)

where $\mu$ is the dynamic coefficient of friction and $F_n$ is the contact normal force.

As depicted in Figure 2.2, the force needed initially to deflect the contact springs can be significantly larger than the friction force between the contacts after full deflection has been achieved. Suppose that the coefficient of friction is 0.4 and the mating angle is $15^\circ$; the maximum insertion force is about 87% greater than the insertion force in the second stage. The insertion force is the maximum force required to mate contacts [1]. Therefore, it is the initial engagement force that usually presents the greatest difficulty in mating connectors and causes degradation of the plated surfaces of the electrical contacts.

The extraction of package pins from a socket is just the reverse process of the stage 2 insertion of package pins. The extraction force is equal to the friction force, so the extraction force is usually much lower than the insertion force.

The insertion and extraction forces for an entire socket are not simply the sum of individual contact insertion and extraction forces; they are also influenced significantly by other factors, such as contact misalignment and misregistration. A large applied force may cause difficulty in package mounting and demounting and may damage the package pins and package body. Thus, to protect the pins and body, different insertion and extraction forces may be required for different package pin counts. The following is an example from Mill-Max [4]:

- **Low force (recommended for PGAs with fewer than 150 pins):** typical insertion force 50 g per pin, typical extraction force 30 g per pin
- **Ultralow force (recommended for PGAs with a pin count of 150 to 250):** typical insertion force 25 g per pin, typical extraction force 15 g per pin
- **Ultra light (recommended for PGAs with a pin count above 250):** typical insertion force 12.5 g per pin, typical extraction force 7.5 g per pin

To minimize damage to contacts and to facilitate the insertion and extraction process, zero-insertion-force (ZIF) design has been used. These are needed especially for some types of packages, such as BGAs, due to the viscoelasticity of the solder balls. Some ZIF designs feature contacts that can be moved by actuation mechanisms. When an external force is exerted on the actuation mechanism, the socket contacts open and packages can be mounted into their normal positions.
without forceable mating or engagement. Releasing the actuation mechanisms will cause the socket contacts to close and the package pins to mate.

A ZIF design is usually costly but provides easy and rapid mating, as it eliminates the high initial-contact engaging force. A ZIF design reduces contact wear during mating and thus increases contact durability. It also allows for much higher contact normal forces to be exerted. In conventional designs, the insertion force is usually proportional to the applied normal force, as indicated in (2.1) and (2.2); a high normal force will inevitably result in “excessive” insertion and extraction force. Without the insertion force, much higher normal force is possible.

Along with less wear and high normal force, a plating cost saving is possible. In many applications, higher normal forces permit use of less noble (and less expensive) platings. Also, thinner platings can be used, due to less contact wear. Plating savings can also be achieved by restricting the platings to areas near the contact points. In conventional designs, contact engagement could cause wear debris and corrosion products to be dragged into the final contact area; therefore, plating along the entire engagement length is required. In a ZIF design, contacts are engaged in a direction normal to their mating surface, but cleaning or wiping action can still be accomplished [3].

Some standards relating to measurement of the insertion and extraction forces are listed below for reference.

- **EIA 364-TP05B**: contact insertion, release, and removal force test procedure for electrical connectors
- **EIA 364-TP13B**: mating and unmating forces test procedure for electrical connectors
- **MIL-STD-1344A, Method 2012.1**: contact insertion and removal force test method for electrical connectors
- **MIL-STD-1344A, Method 2013.1**: mating and unmating force test method for electrical connectors
- **MIL-STD-1344A, Method No. 2014**: contact engagement and separation force test method for electrical connectors
- **IEC 60512-1-3**: electromechanical components for electronic components: basic testing procedures and measuring methods; Part 1: General examination; Section 3: Test 1c, Electrical engaging length
- **IEC 60512-13-1**: electromechanical components for electronic components: basic testing procedures and measuring methods. Part 13: Mechanical operating tests, Section 1: Test 13a, Engaging and separating forces

### 2.1.2 Contact Retention

*Contact retention* defines the minimum axial load in either direction that a contact must withstand while remaining firmly fixed in its normal position within an insert. The contact retention force reflects the capability of sockets to resist impact from external forces. A high external force such as that produced by vibration and
shock during product transportation and operation can cause contacts to move from their proper locations and even cause contact pullout.

Contact retention can be a function of contact strength, contact normal force, coefficient of friction, contact area and geometry. High contact normal force, high contact strength, high coefficient of friction, and large contact area assure good contact retention. Other design features may be applied to maintain good contact retention, such as positive locking contact design and a protective plastic cover [5].

Some standards for measuring contact retention force are listed below for reference.

- **EIA 364-29B**: contact retention test procedure for electrical connectors
- **EIA 364-35B**: insert retention test procedure for electrical connectors
- **MIL-STD-1344A, Method 2007.1**: contact retention test procedure for electrical connectors

### 2.1.3 Contact Force and Resistance

Socketing introduces extra contact interfaces between a component and a PCB. To maintain a consistent and reliable contact interface, a contact normal force should be applied.

When two contacts are mated, an external normal force causes contact deflection, and a contact interface is created. This interface is usually far less than perfect. The surface roughness, surface insulation film, contamination, and dust in the contact interface may inhibit effective metallic contact. Thus, the effective contact area is usually a fraction of the total contact area; this fraction is determined by the contact manufacturing process, contact finish, and contact cleanliness.

Surface roughness is usually described by asperities and a-spots. Asperities are the protruding spots on a surface; during mating, only asperities actually come into contact. These contact spots are also often called a-spots. Due to their small size (the radii are measurable in micrometers), a-spots deform plastically even at low applied loads [2]. With increased loads, the a-spots deform further, and the contact area is enlarged. The number of a-spots depends primarily on surface roughness, material hardness, and the magnitude of the contact normal force.

Current is restricted to flowing through the a-spots. The limited contact area results in a contact resistance called constriction resistance. Figure 2.3 shows the contact interface, a-spots, and restricted current flow.

Constriction resistance is a function of number, area, and distribution of a-spots, described by [2]

\[
R_C = \frac{\rho}{na} + \frac{\rho}{D}
\]

where \( \rho \) is the resistivity of the contact material (assuming the same materials), \( n \) the number of a-spots, \( a \) the diameter of the a-spot, and \( D \) the diameter of the area over which the contacts are distributed.
Figure 2.3 Schematic illustration of contact interface, a-spots, and constricted current flow: (a) interface microstructure; (b) constricted current flow.

The area of a-spots is determined by the applied load. Thus the constriction resistance can be expressed in terms of contact normal force [2]:

\[ R_C = k \rho \left( \frac{H}{F} \right)^{1/2} \]  \hspace{1cm} (2.4)

where \( k \) is a coefficient that includes the effects of surface roughness, contact geometry, and elastic–plastic deformation, which can be determined experimentally; \( H \) is the hardness of contact material; and \( F \) is the contact normal force.

In equations (2.3) and (2.4), a pure metallic surface is assumed. However, in most applications, contact surface conditions are not perfect; surface films may grow initially or develop gradually during socket application. The film composition, structure, and thickness depend on the contact finish and application environment. Surface films may be displaced or disrupted completely or partially or remain intact, depending on applied contact force, applied bias, and film composition, structure, and thickness. Bias may cause the electrical breakdown of surface films. Applying a normal force may disrupt the oxide layers mechanically and expose the metallic contacts.

The overall contact resistance can be regarded as a combination of constriction resistance (due to a-spot contact) and film resistance (due to the oxide or corrosion film accumulated on the contact surfaces). A mathematical model has been proposed to describe the interface resistance due to constriction resistance and film resistance [6, 7]:

\[ R_{contact} = R_{constriction} + R_{film} = \frac{\rho \sqrt{\pi H}}{2 \sqrt{F}} + \frac{\sigma_f H}{F} \]  \hspace{1cm} (2.5)

where \( \rho \) is the base metal conductivity, \( H \) the hardness of the contact material, \( \sigma_f \) the film resistivity, and \( F \) the contact normal force.

Due to the contact surface roughness, the effective contact area between two surfaces is much lower than the apparent area. For example, for contact between a sphere and a plane, the effective contact area can be calculated as

\[ A = 1.21 \pi \left( \frac{FR}{E} \right)^{2/3} \]  \hspace{1cm} (2.6)
where $F$ is the contact normal force, $R$ the radius of the sphere, and $E$ the elastic modulus of the base metal. From this, a Hertz stress can be calculated as

$$\sigma = \frac{F}{A} = \frac{1}{1.21\pi} \left( \frac{FE^2}{R^2} \right)^{1/3}$$

(2.7)

However, a high Hertz stress may not necessarily mean low contact resistance, since contact resistance is also a function of contact area. For example, a sharp contact, even under a low force condition, may have a high Hertz stress but may yield a high contact resistance because of its small contact area.

Requirements on contact force depend on the plating system. For non-noble platings such as tin and solder, the contact force must exceed 100 g per contact in order to obtain a low and stable contact resistance. For noble platings, the required contact force is much lower. The usual specification for Au plating is approximately 30 to 50 g.

2.1.4 Contact Deflection and Resistance

A specification on contact deflection is not always required, but it is an important factor for some socket designs and applications (e.g., LGA socket). A contact will deflect under an applied contact force; the extent of contact deflection depends on the contact design, applied force, and contact modulus. The working range of a contact defines the range of contact force or deflection in which a contact can work reliably in its lifetime applications. Generally there is a minimal force or deflection that is needed and a maximum force or deflection that a contact can sustain, to achieve a stable contact interface.

Figure 2.4 is a schematic of contact resistance versus contact force and contact deflection. An elbow can be observed on the curve of contact resistance versus contact force, indicating a minimum of contact force and deflection that must be achieved to obtain low, stable contact resistance.

![Figure 2.4](image)

**Figure 2.4** Contact resistance versus contact normal force and deflection.
The contact deflection versus contact force may not be ideally linear, as shown in the figure. Other cases—for example, hard-to-soft, soft-to-hard—also exist. If contact force is large enough, a contact may yield (the contact deflects without applying any extra contact force) and the contact resistance may start to increase accordingly, indicating contact instability. In another case, contact force may increase exponentially with contact deflection once the contact deflects to a certain point. Both cases may indicate the maximum operating limits for the contacts.

Contact resistance is difficult to measure accurately through the two-wire method, because of its small value, usually in the range 10 to 100 mΩ. In two-wire measurement, the lead resistance will cause a significant voltage drop, and the voltage measured by the meter \( V_m \) will not be the same as the voltage directly across the contact interface \( V_R \). To eliminate the interference of lead resistance, a four-wire (Kelvin) method is generally used. Figure 2.5 shows a four-wire measurement in which the test current flows through the contact interface via one set of test leads, and the voltage across the contact interface is measured through another set of leads, called sense leads. The sense current (picoampere level) is much lower than the test current (usually, milliampere level); therefore, the voltage drop across the sense leads can be ignored, and the voltage measured by the meter is essentially the same as the voltage across the contact interface \[8\]. The contact resistance can be calculated as

\[
R = \frac{V_R}{I} \approx \frac{V_M}{I} \quad (2.8)
\]

The contact resistance can be significantly affected by the interface conditions. High current and voltage during measurement may change the conditions: for example, punctuating oxide films. Accordingly, the measured contact resistance will be lower than the value obtained if the interface remains intact, compromising the validity of the results. Therefore, the contact resistance should be measured under dry circuit conditions with an open voltage below 20 mV and a short-circuit current below 100 mA. In dry circuit conditions, the physical properties of the contact interface should not be affected.

![Figure 2.5 Schematic diagram of four-wire measurement.](image)
Some standards for measuring contact force and contact resistance are listed below for reference.

- **EIA 364-TP04**: normal force test procedure for electrical connectors
- **ASTM B539**: test methods for measuring contact resistance of electrical connections (static contacts)
- **EIA 364-TP06**: contact resistance test procedure for electrical connectors
- **EIA 364-TP23A**: low-level contact resistance test procedure for electrical connectors
- **MIL-STD-1344, Method 3004**: contact resistance test method for electrical connectors
- **IEC 60512-2**: electromechanical components for electronic components basic testing procedures and measuring methods; Part 2: General examination, electrical continuity and contact resistance tests, insulation tests, and voltage stress tests

### 2.1.5 Contact Wipe

Oxidation and corrosion of contact surfaces, as well as dust and contamination, can accumulate between contact interfaces and result in an increase in contact resistance. Maintaining a metallic contact interface is a critical requirement for low, stable contact resistance. Contact wiping disrupts surface films and displaces contaminants and debris to ensure a metallic contact and consistent contact resistance.

**Contact wipe**, also called *engagement wipe*, is a relative motion between mating contact surfaces during contact engagement or insertion. This sliding action serves to clean surfaces by removing contaminants from the contact area and breaking down insulation films at the same time. A contact wipe is generally considered very desirable, regardless of the type and quality of contact plating employed [3].

There are two modes of wipe action. The first mode occurs after a full contact normal force is applied during insertion of package pins. The second mode occurs when contact force is being applied, usually with ZIF contact designs. Although in ZIF design, the contacts are engaged in a direction normal to their mating surfaces, a small amount of relative contact motion is feasible by controlling contact actuation during exertion of contact normal forces.

**Wipe effectiveness** refers to the efficiency with which films, dust, and contaminants are removed during socket mating, which is usually indicated by a reduction in contact resistance. Effectiveness also depends on contact geometry, contact normal force, length of wipe, and the type of films or contaminants to be disrupted or displaced. Studies on hemispherical, elliptical, and cylindrical contact geometries show a distinct contrast in wiping effects [2]: At 50-g load, the hemisphere contacts show very good wipe effectiveness after the wipe length reaches 0.25 mm, while marginal effects are observed for elliptical contacts, and negligible effects are observed for cylindrical contacts.
To evaluate the wipe effectiveness of a specific contact, the effects of contact normal force and wipe length on contact resistance must be examined. For a non-noble metal contact, a high contact force must be used to penetrate and break the surface oxide layer. For a gold contact finish, a contact force of less than 30 g may be enough. For tin plating, a contact force above 100 g is usually required [3]. In addition to contact force, a minimum wipe length is usually required to effectively disrupt the oxide film and displace contamination; a small wipe distance may produce reverse effects and result in a large increase in contact resistance compared with the zero-wipe condition [9].

Figure 2.6 shows the effect of wipe distance on the increase in contact resistance of copper after exposure to humidity and pollutant gases. The graph indicates that a minimum wipe distance of 0.025 mm is required to establish low contact resistance for the design specified. For a nonlubricated, dusty electric contact surface, studies show that when the length of wipe is comparable to the size of dust particles, contact failures may arise. When the dust particle size is within the upper limit of the hazardous size range, the number of contact failures can be reduced if the wipe length is long enough [10].

Following the initial wipe, a back-wipe is the same action but in the opposite direction. Back-wipe has been incorporated into many socket contact designs. However, conflicting data have been reported concerning the role of back-wipe. Studies on soft and hard copper showed the ineffectiveness of a contact back-wipe in improving contact performance [9]. For nickel contacts after exposure to MFG testing, contact resistance was consistently reduced after a 0.025-mm back-wipe; but the beneficial effects of the back-wipe were not observed in a study of gold-plated samples [11].

Improvement in wipe effectiveness must be balanced against the probability of high contact wear. Using a sharp-point contact geometry or increasing the
contact force may break oxide film easily and produce good wiping effects, but at the risk of increased contact wear and decreased contact durability.

2.1.6 Current Rating

Current rating, also called current-carrying capacity, specifies the maximum current that a conductor can carry safely. Due to current flow, Joule heat is generated in a conductor and the local temperature will be increased. The local temperature rise, compared with ambient temperature, depends on the heat balance between Joule heat and heat dissipation to the neighboring regions. If the current flow is too large, excessive heat will be generated and accumulated, and the local temperature will rise so high that it may surpass the maximum operating temperature of the insulators that separate socket contacts. If the housing is plastic, the maximum operating temperature of the socket housing usually determines the maximum current flow through a socket contact.

Although current rating can be specified in terms of the transient current rating or overload current rating [2], the continuous current rating has generally been adopted by the socket industry. This current rating is based on the local temperature rise above the ambient, as induced by a current flow. It is commonly taken as the current that produces a 30°C temperature rise, although other criteria can be used, such as a 10 or 15°C temperature rise. The criterion can be applied to both ac and dc current.

Current rating depends on contact size, contact pitch, contact type, and heatsinking capability. A large contact size generally assures a high current rating. A small contact pitch for socket contacts generally limits the applicable current rating. A high-conductivity contact can be adopted to compensate for a reduction in contact size and pitch. A socket contact, with high electrical conductivity, not only generates less heat, but generally dissipates heat more effectively.

Joule heat can be dissipated through conduction to the PCB traces. It can also be dissipated through airflow around contacts. The shielding effect of the socket housing can reduce the heat dissipation, causing a great difference between free-air and in-housing current ratings. However, the current rating performance can be improved greatly if a heat sink is attached, as a heat sink can enlarge the area of heat dissipation significantly.

Some standards for measuring current rating are listed below for reference.

- **EIA 364-TP70A**: temperature rise versus current test procedure for electrical connectors and sockets
- **IEC 60512-3**: electromechanical components for electronic equipment; basic testing procedures and measuring methods; Part 3: Current-carrying capacity tests
- **IEC 60512-10-4**: electromechanical components for electronic components; basic testing procedures and measuring methods; Part 10: Impact tests, static load tests, endurance tests, and overload tests; Section 4: Test 10d, Electrical overload
2.1.7 Capacitance and Inductance

Capacitance results from interaction of the electric field around an active conductor with nearby conductors (mutual capacitance) or with ground (self-capacitance). It defines the induced current flow generated by the change of charge due to changing voltage. In the case of two nearby conductors, the induced current flow due to voltage changing is

\[ i_1 = C_{11} \frac{dV_1}{dt} + C_{12} \left( \frac{dV_1}{dt} - \frac{dV_2}{dt} \right) \] (2.9)

\[ i_2 = C_{12} \left( \frac{dV_2}{dt} - \frac{dV_1}{dt} \right) + C_{22} \frac{dV_2}{dt} \] (2.10)

where \( t \) is time, \( V_1 \) the voltage in conductor 1, \( V_2 \) the voltage in conductor 2, \( i_1 \) the induced current flow in conductor 1, \( i_2 \) the induced current flow in conductor 2, \( C_{11} \) the self-capacitance of conductor 1, \( C_{22} \) is the self-capacitance of conductor 2, and \( C_{12} \) the mutual capacitance of conductors 1 and 2.

Inductance results from interaction of the magnetic field around an active conductor with nearby conductors (mutual inductance) or with ground (self-inductance). Inductance determines the induced voltage generated by the change of magnetic flux due to a changing electrical current. Consider two adjacent conductors. The induced voltage due to current changing is

\[ V_1 = L_{11} \frac{di_1}{dt} + L_{12} \frac{di_2}{dt} \] (2.11)

\[ V_2 = L_{12} \frac{di_1}{dt} + L_{22} \frac{di_2}{dt} \] (2.12)

where \( t \) is time, \( i_1 \) the current in conductor 1, \( i_2 \) the current in conductor 2, \( V_1 \) the induced voltage in conductor 1, \( V_2 \) the induced voltage in conductor 2, \( L_{11} \) the self-inductance of conductor 1, \( L_{22} \) the self-inductance of conductor 2, and \( L_{12} \) the mutual inductance of conductors 1 and 2. The magnitude of the capacitance and inductance depends on the dielectric medium between contacts and on the contact and grounding geometry.

The following example illustrates how to calculate capacitance and inductance [12, 13]. Figure 2.7 shows two parallel conductors for the calculation of mutual capacitance and mutual inductance. The mutual capacitance and inductance are calculated as follows:

\[ C = \frac{\pi \varepsilon_r \varepsilon_0}{\ln \left\{ \frac{d}{2r} \left[ 1 + \sqrt{1 - \left( \frac{2r}{d} \right)^2} \right] \right\} l} \] (2.13)

\[ L = \frac{\mu_r \mu_0 l}{2\pi} \left\{ \ln \left[ \frac{l}{d} + \sqrt{1 + \left( \frac{l}{d} \right)^2} \right] - \sqrt{1 + \left( \frac{d^2}{l^2} \right)^2 + \frac{d}{l}} \right\} \] (2.14)
where $\varepsilon_r$ is the dielectric constant of the insulator, $\varepsilon_0$ the dielectric constant of vacuum: $8.84 \times 10^{-12}$ F/m, $\mu_r$ the permeability of the insulator, and $\mu_0$ the permeability of vacuum $= 4\pi \times 10^{-7}$ H/m. For example, for two pins of a PGA socket with dimensions $l = 5.5$ mm, $d = 1.27$ mm, and $r = 0.38$ mm, the calculated mutual capacitance is (for free air: $\varepsilon_r = 1$)

$$C = 0.14 \text{ pF}$$

The mutual inductance is (for free air: $\mu_r = 1$)

$$L = 1.51 \text{ nH}$$

If the insulator is not air, but for example, a thermoplastic, the value above should be multiplied by the relative dielectric constant and relative permeability of the insulating thermoplastic to yield the true capacitance and inductance. This calculation presents an initial estimation of the order of capacitance and inductance. However, in practice, a simple calculation may not yield accurate results, if there is a large pin count, complex contact configuration, multiple signal-to-ground ratios, and complicated contact geometry. Therefore, $C$ and $L$ are usually determined experimentally.

Another inductance parameter is called loop inductance. Consider that two pins can form a current flow loop because the current flow in one pin produces magnetic field lines around the other. The field lines around the entire loop can be calculated by considering the two pins together:

$$L = L_{s1} + L_{s2} - 2L_m \hspace{1cm} (2.15)$$

where $L_{s1}$ is the self-inductance of pin 1, $L_{s2}$ the self-inductance of pin 2, and $L_m$ the mutual inductance. If pins 1 and 2 are identical, the loop inductance can be calculated as

$$L = 2L_s - 2L_m \hspace{1cm} (2.16)$$

In general, the mutual inductance between two pins is only a small fraction of the self-inductance of either one and drops off very rapidly with the increase...
in contact pitch. Therefore, the loop inductance is determined largely by the self-inductance of contact pins.

Three phenomena are associated with capacitance and inductance: characteristic impedance, crosstalk, and propagation delay. **Characteristic impedance** is given by

\[
Z_0 = \sqrt{\frac{L_0}{C_0}}
\]  

where \( Z_0 \) is the characteristic impedance, \( L_0 \) the inductance per unit length, and \( C_0 \) the capacitance per unit length. For a linear homogeneous isotropic dielectric propagation medium free of electric charge, the characteristic impedance is calculated as

\[
Z_0 = \sqrt{\frac{\mu}{\varepsilon}}
\]  

where \( \mu \) is the magnetic permeability of the insulating medium and \( \varepsilon \) is the dielectric constant of the insulating medium.

Characteristic impedance is a critical parameter in the control of signal reflection at the contact interface. The reflection coefficient is given by

\[
\rho = \frac{Z - Z_0}{Z + Z_0}
\]

where \( Z_0 \) is the characteristic impedance of a contact and \( Z \) is the characteristic impedance of the PCB trace or package pin. If \( Z = Z_0 \), the reflection coefficient is zero, and no signal reflection results. A uniform line terminated in its characteristic impedance will have no standing waves, no reflections from the end, and a constant ratio of voltage to current at a given frequency at every point on the line. If \( Z < Z_0 \), the reflection is negative and the signal is reflected and inverted. If \( Z > Z_0 \), the reflection is positive; that is, the signal is reflected but not inverted. In both cases, the unmatched characteristic impedance produces signal reflection, causing signal distortion and attenuation.

**Crosstalk** is a term for signal interference, or coupled noise. It results from coupling the electromagnetic fields surrounding an active conductor with those of its adjacent conductors. Crosstalk is another important source, in addition to unmatched characteristic impedance, for signal attenuation and distortion. The significance of crosstalk depends on the mutual parasitic capacitance and inductance. In practice, crosstalk can be minimized by increasing the contact pitch, reducing contact cross section and length, keeping circuits at right angles, and using balanced lines and grounding pins or planes.

Crosstalk can be divided into capacitive crosstalk and inductive crosstalk. As literally implied, the former is due primarily to capacitive coupling between circuits, while the latter is due primarily to inductive coupling. The relative significance of capacitive and inductive crosstalk depends on the circuit impedance [14].

Crosstalk can be indicated in terms of signal integrity and attenuation. It can be specified as the ratio of the amplitude of coupled noise to the active-line signal
amplitude, or as the ratio of the output voltage of one channel (without signal input) to the output voltage of its nearby channel (with signal input) [14]:

\[ K = 20 \log \left| \frac{E_{oa}}{E_{ob}} \right| \]  \hspace{1cm} (2.20)

where \( K \) is the magnitude of crosstalk between circuits \( a \) and \( b \) in decibels, \( E_{oa} \) is the output voltage of circuit \( a \) due to crosstalk, and \( E_{ob} \) is the output voltage of circuit \( b \) with signal input.

Propagation delay is a measure of how long it takes for a wave to travel the length of a specific conductor. The propagation delay for a unit of length is expressed as

\[ \tau_d = \frac{1}{v} = \frac{\sqrt{\varepsilon_r}}{C_0} = \sqrt{L_0 C_0} \]  \hspace{1cm} (2.21)

where \( \tau_d \) is the propagation delay for a unit length, \( v \) is the traveling velocity, \( C_0 \) is the velocity of light, \( \varepsilon_r \) is the relative dielectric constant of the insulator, \( L_0 \) is the inductance per unit length, and \( C_0 \) is the capacitance per unit length. The interaction of parasitic capacitance and inductance causes the propagation to increase by a factor of \( (L_0 C_0)^{1/2} \).

Mutual capacitance and inductance can be measured between two adjacent pins with one of them grounded. Self-capacitance and inductance are usually measured with one pin with respect to all surrounding pins grounded. Self-inductance can also be measured in free air.

Some standards for measuring capacitance and inductance are listed below for reference.

- **EIA 364-TP30**: capacitance test procedure for electrical connectors
- **EIA 364-TP33**: inductance of electrical connectors (100 nH to 100 mH)
- **EIA 364-TP69**: low-level inductance measurement for electrical contacts of electrical connectors (10 to 100 nH)

### 2.1.8 Bandpass and Bandwidth

A band is the frequency spectrum between two defined frequency limits. A bandpass is a fixed band of frequencies that a device can support. There are several definitions of bandwidth. Bandwidth can be defined as the frequency band within which a device performs with respect to some characteristic attenuations. Bandwidth can also refer to the maximum frequency that a device can pass in which the responsivity is not reduced from the maximum response by more than 3 dB.

The high operating frequency and large bandwidth of electronic components put more stringent requirements on component sockets. At high operating frequencies, dielectric losses and skin effects become more pronounced. The dielectric loss results from the repeated atomic polarization imposed by the alternating electric field and is manifested primarily as dissipative heat. The skin effect
describes a phenomenon in which electrical conduction occurs within a limited depth at the contact surface. The skin depth decreases with an increase in operating frequency. The skin effect is manifested by an increase in contact resistivity as the conduction cross section is reduced. Therefore, dielectric loss and skin effect will cause signal attenuation. Furthermore, capacitance and inductance are functions of the operating frequency. Increasing the operating frequency inevitably causes an increase in capacitance and inductance, and thus causes increased opportunities for crosstalk.

For high-frequency testing, sockets with a high bandpass are required. To guarantee signal fidelity, the bandpass of a socket is usually several times larger than the operating frequency of the electronic components. Bandwidth is expressed in terms of signal attenuation at a given frequency. Signal attenuation is a reduction in the amplitude of a signal. The degree of attenuation is often measured in terms of decibels (dB), the standard unit for expressing transmission gain or loss and relative power levels. A decibel equals 10 times the log of the ratio of the power out ($P_o$) to the power in ($P_i$) [15]:

$$dB = 10 \log \frac{P_o}{P_i} \quad (2.22)$$

Bandpass is expressed as a range of applicable frequencies from dc to a maximum frequency. This maximum frequency is the frequency at which the signal attenuation is greater than 3 dB according to the second definition of bandwidth (as given above). However, the criterion pertaining to a particular device or a socket manufacturer could be arbitrary.

Bandpass and bandwidth are usually cited for test and burn-in sockets, as they are two critical parameters for maintaining signal integrity and thus making the test meaningful. Short contacts, special materials and grounding, and decoupling schemes are factors that expand the bandwidth and assure adequate signal fidelity.

Some standards relating to measurement of contact electrical performances are listed below for reference.

- *IEC 60512-23-4, Ed. 1.0*: electromechanical components for electrical equipment: basic testing procedures and measuring methods; Part 23-4: Test 23d, Transmission line reflections of connectors in the time domain
- *IEC 60512-25-1*: crosstalk ratio test procedure for electrical connectors, sockets, and cable assemblies
- *IEC 60512-25-2*: attenuation test procedure for electrical connectors, sockets, cable assemblies, or interconnection systems
- *IEC 60512-25-4*: propagation delay test procedure for electrical connectors, sockets, cable assemblies, or interconnection systems
- *IEC 60512-25-5*: return-loss procedure for electrical connectors, sockets, cable assemblies, or interconnection devices
2.2 SOCKET HOUSING

A socket housing functions to:

- Insulate contact members electrically
- Support contact members mechanically and maintain them in position
- Exert and maintain contact pressures
- Shield contact members from the operating environment
- Provide mechanical protection for the contacts
- Provide protection for contacts against flux and contaminants during assembly

The electrical and mechanical performance of a socket housing are evaluated in terms of the functions listed above. For safety assurance, flammability must also be evaluated.

2.2.1 Electrical Properties

The electrical performance of a socket is determined not only by the socket contact but also by the socket housing. The parasitic capacitance and inductance are proportional to the dielectric constant and magnetic permeability of the socket housing; large capacitance and inductance can cause propagation delay, signal attenuation, and integrity degradation. Dielectric dissipation is another factor contributing to signal attenuation. This becomes more serious at high operating frequencies.

The dielectric constant reflects the ability of a material to store electrostatic field energy. Under an electric field, a surplus charge will appear on the surface of an insulating material due to the induced electron, ion, or molecular polarization. A high dielectric constant means high polarization and more charge on the surface. The dielectric constant of an insulator is the ratio of the capacitance formed by two parallel metallic plates with the insulator in between, to the capacitance with air in between. A vacuum has a dielectric constant of 1; the dielectric constant of air is a little larger than 1; and plastic may have a dielectric constant from 2 to 10, depending on its structure and additives. For socket housings, plastics with a low dielectric constant are needed. A low dielectric constant indicates a low capacitance and thus a high degree of transmission transparency and low propagation delays. For high-frequency applications, a low dielectric constant is often necessary.

The dissipation factor is a measure of the dielectric loss of an insulator. For an ideal dielectric, the current flows 90° out of phase with the voltage; however, for a nonideal dielectric, the current leads the voltage by an angle less than 90°. Suppose that the phase difference is \( \delta \); the power loss is proportional to \( \tan \delta \), called the dissipation factor, loss tangent, or quality factor. Dielectric loss is manifested by heat dissipation. Dielectric loss will cause signal attenuation, especially at high frequencies, so a plastic with a low dissipation factor is preferred.
The dielectric withstanding voltage (DWV) is the maximum voltage that an insulator can withstand while maintaining its insulating property under a specific condition for a specific period of time. All insulations will break down at a specific voltage. Above this critical voltage, the current flow will increase catastrophically. Per MIL-STD-1344A, Method 3001.1, the dielectric withstanding voltage is 75% of the minimum breakdown voltage; it is suggested that the operating rated voltage should be one-third of the dielectric withstanding voltage. During measurement, an alternating potential is usually applied between the adjacent contacts; the voltage is increased from zero to the specified value as uniformly as possible at a specified rate; and the test voltage is maintained at the specified value for 1 minute to see if the material breaks down. This method is often called the step-by-step test. In another common method, the short-term dielectric withstanding voltage is obtained by applying the test voltage continuously from zero to breakdown. The magnitude of the test voltage is expressed as its root-mean-square (RMS) value. Since the barometric pressure greatly affects the withstanding voltage characteristics of the socket, the dielectric withstanding voltage is usually specified for sea-level applications.

The breakdown voltage is influenced by the dielectric strength of the insulator, duration of the voltage applied, thickness of the sample, temperature, surrounding medium, and frequency of the voltage applied. The dielectric strength is a property of an insulator, expressed as the maximum voltage gradient that causes insulator breakdown.

The insulation resistance (IR) is the resistance of the insulator between the socket contacts to leakage current flow, expressed as the ratio of the applied voltage on the electrodes to the total current between them. According to MIL-STD-1344A, Method 3003.1, the insulation resistance is measured between the most closely spaced contacts. Unless otherwise specified, the test voltage is 500 V ±10%.

The value of insulation resistance is influenced by the volume resistivity and surface resistivity of the insulator, distance between electrical terminals, cross section of the terminal, surrounding medium, frequency of applied voltage, and temperature. The volume resistivity represents the resistance of an insulator to the leakage current flow through the bulk of the material.

The surface resistivity represents the resistance of an insulator to the leakage current flow over its surface. The surface resistivity is influenced greatly by the surface conditions, such as moisture adsorption.

Some standards for measuring the electrical properties of sockets are listed below for reference:

- ASTM D 149: standard test method for dielectric breakdown voltage and dielectric strength of solid electrical insulating materials at commercial power frequencies
- EIA 364 TP20: withstanding voltage test procedure for electrical connectors
- MIL-STD-1344, Method 3001: dielectric withstanding voltage test method for electrical connectors
2.2.2 Mechanical Properties

To ensure that socket housing can provide the mechanical support necessary for socket contacts to maintain their stability, socket housing must be evaluated in terms of its mechanical properties: elastic modulus, flexural strength, tensile strength, compressive strength, impact resistance, deflection temperature, coefficient of thermal expansion, and hardness.

Elastic modulus is the ratio of stress to strain during the initial deformation of materials. At the initial deformation, the material usually deforms linearly with respect to the applied stress; upon unloading, the deformation is recovered. The elastic modulus represents the material deformation resistance to external loads.

Flexural strength is the resistance of a material to breaking if it is bent across its main axis [16]. The flexural strength can be obtained by three- or four-point bending. For three-point bending, the flexural strength is calculated as [17]

\[ \sigma_{fs} = \frac{3L}{8tc^2} P_f \]  \hspace{1cm} (2.23)

where \( P_f \) is the fracture load in the bending test, \( L \) is the length of the standard specimen (rectangular cross section), \( t \) is the width of the sample, and \( c \) is the thickness of the sample. The flexural strength of a plastic not only reflects its resistance to deformation, but also its resistance to fatigue [16].

Tensile strength is the stress applied to stretch a material to its breaking point. Brittle materials may break without plastic deformation; for ductile materials, yielding will occur before the tensile strength is reached. Materials with both high tensile strength values and high plastic deformation percentages are assumed to be tough.

Compressive strength is the highest stress needed to compress a material to its cracking point. Not all polymers have a definite compressive strength; in such cases, a compression strength value may be reported as a percentage of deformation [16].
Hardness is the resistance of a material to indentation. An indent is made by pressing a hard round ball or point against a surface with a controlled force. The characteristics of the indent can be taken as a measure of hardness. Several methods have been established for the hardness test. Among them, the Rockwell and Shore hardness tests are generally used to measure the hardness of polymers. The scales represent the type of point or ball indenter used. The hardness of a material may be correlated experimentally with its tensile strength and toughness [17].

Impact resistance is the resistance of a material to a sudden applied stress. The ability of a material to withstand a mechanical shock is closely related to the toughness of the material. The samples can be notched or unnotched. The most common test for a notched plastic sample is the Izod test.

The coefficient of thermal expansion (CTE) represents the dimensional change of a material when the temperature changes. The CTE of a plastic is usually several times larger than the CTE of a metal. The mismatch between the socket plastic CTE and the socket contact CTE can contribute to the relative contact motion, called thermal wipe or thermal wear.

The heat deflection temperature is a measure of a material’s response to a combination of mechanical and thermal stresses. It is an index that measures a plastic’s resistance to excessive softening and deformation due to load and heat. It also gives the applicable operating temperature range for a polymer. According to ASTM standard D648, the heat deflection test is performed by loading a plastic sample into a three-point bending fixture under constant preset stress; the temperature is increased until the deflection of the sample reaches a critical value [17].

Some standards for measuring the mechanical properties of sockets are listed below for reference.

- ASTM D790-98: standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials
- ASTM D648-98c: standard test method for deflection temperature of plastics under flexural load in the edgewise position
- ASTM D732-99: standard test method for shear strength of plastics by punch tool
- ASTM D785-98: standard test method for Rockwell hardness of plastics and electrical insulating materials
- ASTM D2583-95: standard test method for indentation hardness of rigid plastics by means of a Barcol impressor
- ASTM D882-97: standard test method for tensile properties of thin plastic sheeting
- ASTM D-256-97: standard test methods for determining the Izod pendulum impact resistance of plastics
- ASTM D1822-99: standard test method for tensile-impact energy to break plastics and electrical insulating materials
- ASTM D4812-99: standard test method for unnotched cantilever beam impact strength of plastics
• *ASTM D5420-98a*: standard test method for impact resistance of a flat, rigid plastic specimen by means of a striker hit by a falling weight (Gardner impact)

• *ASTM D-747-99*: standard test method for apparent bending modulus of plastics by means of a cantilever beam

### 2.2.3 Temperature Rating

There are a variety of operating environments that a socket may be subjected to during its lifetime. These environments have been classified in various ways. Table 2.2 shows one way to classify the operating temperature range of electronic parts according to their potential application, although temperatures could still be higher or lower than given in the table. Higher temperatures could also be experienced by a socket during assembly and assembly-level burn-in. If a socket is surface mounted to a PCB through reflow, the surrounding temperature could easily surpass 200°C, or even 260°C with lead-free solder, during assembly.

In burn-in, a socket may experience high temperature, since burn-in is intended to precipitate early failures by subjecting parts to accelerated loads. In recent years the burn-in temperature has increased from 125°C to above 170°C to reduce the burn-in time [18].

Temperature ratings are specified in two ways. The *operating temperature rating* is the range of temperatures over which the socket can operate within its datasheet performance and functional specifications for its lifetime. The *withstanding temperature rating* refers to the temperature that the socket can withstand for a very short time, usually seconds or minutes. For example, for a PGA socket assembly, Intel specifies that a socket must withstand temperatures above 183°C for a minimum of 60 s, with a peak temperature of 240°C for 30 s [19].

Sockets for the burn-in applications typically have a higher temperature rating than sockets for production.

Some standards for measuring the temperature rating of sockets are listed below for reference

• *UL 94 V0*: standard for safety, tests and flammability of plastic materials for parts in devices and appliances

<table>
<thead>
<tr>
<th>TABLE 2.2</th>
<th>Categorized Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Category</td>
<td>Temperature Range (°C)</td>
</tr>
<tr>
<td>Commercial</td>
<td>0 to 70</td>
</tr>
<tr>
<td>Industrial</td>
<td>−40 to 85</td>
</tr>
<tr>
<td>Automotive grade 2</td>
<td>−40 to 105</td>
</tr>
<tr>
<td>Automotive grade 1</td>
<td>−40 to 125</td>
</tr>
<tr>
<td>Military</td>
<td>−55 to 125</td>
</tr>
</tbody>
</table>
2.2.4 Flammability

Some plastics will burn at high temperatures. The flammability of plastics may involve a risk of fire, electric shock, injury, or other dangers. To ensure safety, all plastics used in electronic products should be evaluated for flammability.

UL 94 V0 has generally been accepted by the electronics industry as a standard for safety, testing, and flammability of plastic materials used in devices and appliances. The test methods described in this standard are intended to assure and describe the flammability of materials used in electronic devices in response to heat and flame, under controlled laboratory conditions. They provide a preliminary indication of the acceptability of the materials with respect to flammability for a particular application.

The oxygen index method is another way to test and rate the flammability of plastics. The oxygen index determines the relative flammability of plastics by measuring the minimum concentration of oxygen mixed with nitrogen that will just support combustion. The oxygen index is expressed as [3]

\[
\text{oxygen index} = \frac{100 \times V_O}{V_O + V_N}
\]  

A higher oxygen index number corresponds to a lower degree of flammability. Thus this method allows for rating plastics quantitatively on their ease of combustibility.

To curb flammability, flame retardants are added to socket plastics. These flame-retarding additives are usually halogen-based compounds. Some reinforcing additives, such as glass fiber, may also play a role. Because of environmental issues, halogen-based compounds will phase out and be replaced by substitutes that are being investigated. Some plastics, such as PPS and PEI, are inherently antiflammable, flame retardants are generally not needed for these plastics.

Some standards for measuring the flammability of socket plastics are listed below for reference.

- **UL 94 V0**: standard tests for flammability of plastics used for parts in electronic devices
- **IEC 60512-20-2, Ed. 1.0**: electromechanical components for electronic equipment, basic testing procedures and measuring methods, Part 20, Flammability tests
- **ASTM D2863-97**: standard test method for measuring the minimum oxygen concentration to support candlelike combustion of plastics (oxygen index)
- **ASTM G114-98**: standard practice for aging oxygen-service materials prior to ignitibility or flammability testing
• ASTM D4804-98: standard test methods for determining the flammability characteristics of nonrigid solid plastics
• EIA 364-81: combustion characteristics of connector housings

2.3 SUMMARY

In this chapter the performance characteristics commonly quoted for IC component sockets, including their principles, measurements, and related standards are presented. To ensure that the performance of a socket meets the requirements of its application, performance characteristics must be evaluated; these may include flammability, temperature rating, insertion and extraction force, contact retention, contact wipe, contact force and resistance, capacitance and inductance, bandwidth, dielectric withstanding voltage, and insulation resistance. Optimized performance of a socket can be achieved through proper socket design and materials selection.

REFERENCES

3 IC Component Socket Materials

To achieve the required performance and reliability, material selection is a key issue in socket design. A material must meet electrical, thermal, and mechanical requirements for its intended application. Properties of socket housings and contacts also depend on the process by which they are manufactured. The key materials and manufacturing processes are presented in this chapter.

A component socket is composed of many different parts. For socket housings, thermoplastics are normally used; for socket contact, metal alloys are common. Typical materials for socket housings and contacts are listed in Table 3.1.

3.1 SOCKET HOUSING

Key properties of socket housing materials include melting temperature, heat deflection temperature, glass transition temperature, mechanical strength, flammability, electrical resistivity, dielectric strength, dielectric constant, dissipation factor, dimensional stability, chemical and moisture resistance, and short- and long-term heat stability. The material should also provide ease of manufacturing in terms of its processing characteristics.

A variety of materials are available for socket housings. The majority of these materials are thermoplastic polymers. Fillers, such as glass fibers, are added in the polymer matrix to increase the mechanical strength and to enhance the heat resistance. Thermosetting polymers are seldom used, although they can deliver better electrical, mechanical, and thermal properties, but they are difficult to process.

3.1.1 Polymer Fundamentals

Polymers are macromolecules (large molecules) formed by the union of many identical small molecules (monomers). The number of repeated units of a polymer can range from several to tens of thousands. This number is called the degree of polymerization. The molecular chains may be composed of various combinations of elements; the most common are carbon, oxygen, hydrogen, silicon, chlorine, fluorine, and sulfur.

Depending on its macromolecular size, a polymer may have a variety of molecular weights. The molecular weight reflects the degree of polymerization. The
### TABLE 3.1 Common Component Socket Materials

<table>
<thead>
<tr>
<th>Socket Housing</th>
<th>Socket Contact</th>
<th>Contact Plating</th>
<th>Underplate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPS</td>
<td>Beryllium copper</td>
<td>Gold</td>
<td>Nickel</td>
</tr>
<tr>
<td>PET, PCT, PBT</td>
<td>Brass</td>
<td>Tin</td>
<td></td>
</tr>
<tr>
<td>LCP</td>
<td>Phosphor bronze</td>
<td>Tin–lead</td>
<td></td>
</tr>
<tr>
<td>FR-4</td>
<td>CuNiSi</td>
<td>Palladium</td>
<td></td>
</tr>
<tr>
<td>Polyimide</td>
<td>Conductive elastomer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The average molecular weight of a polymer is expressed in different ways [1]. One calculation is given as follows:

$$M_n = \frac{\sum n_i M_i}{\sum n_i} = \sum N_i M_i$$

(3.1)

where \(n_i\) is the number of molecules with molecular weight \(M_i\) and \(N_i\) is the number fraction of molecules with molecular weight \(M_i\).

The molecular weight and polymer distribution determine many properties of the polymer, such as viscosity, mechanical strength, chemical resistance, heat resistance, and dimensional stability. As a rule of thumb, the higher the molecular weight, the better the mechanical properties and dimensional stability. However, for polymers with very high molecular weight, the polymer liquids become viscous and crystallize very slowly, resulting in unacceptably long processing cycle times, especially for polymers to be used in injection molding applications [2]. Thus, the required molecular weight should be balanced between properties and processibility.

Crystallinity is related to how the polymer chains are organized. Depending on the crystallinity, polymers can be classified as amorphous, crystalline, or liquid-crystalline [3,4]. Amorphous polymers consist of polymer chains arranged in a purely random or disordered manner. Crystalline polymers are in fact only semicrystalline, containing both crystalline and amorphous regions. The degree of crystallinity depends on the polymer structure, the additives used, and how the polymer is processed. Although liquid-crystalline polymers are sometimes included in the category of crystalline polymers [3], they have some unique characteristics. The molecules comprising a liquid-crystalline polymer are stiff, rodlike structures organized in large parallel arrays or domains in both melted and solid states [4]. Typical crystalline and amorphous polymers are listed in Table 3.2. Table 3.3 compares properties of amorphous, crystalline, and liquid-crystalline polymers. Plastics for socket housing are mostly crystalline and liquid-crystalline polymers.

A common way to classify polymers is based on their processibility. Thermoplastic polymers are essentially linear or branched polymers, consisting of long polymer chains, or sometimes with side chains growing out of the major chains. A thermoplastic polymer can be melted or softened by heating; hardening is achieved by cooling. Thermosetting polymers are cross-linked structures.
### TABLE 3.2 Crystalline and Amorphous Polymers

<table>
<thead>
<tr>
<th>Crystalline Thermoplastics</th>
<th>Amorphous Thermoplastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetal</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Nylon</td>
<td>Acrylonitrile–butadiene–styrene</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>Styrene–acrylonitrile polymer</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>Polycarbonate</td>
</tr>
<tr>
<td>Polyester (PBT, PET, PCT)</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>Polyamide (PA)</td>
<td>Polyphenylene oxide</td>
</tr>
<tr>
<td>Polyphenylene sulfide (PPS)</td>
<td>Polysulfone (PPO)</td>
</tr>
<tr>
<td>Polytetether ketone (PEEK)</td>
<td>Polyanide-imide (PAI)</td>
</tr>
<tr>
<td>Polyimide (PI)</td>
<td>Polyetherimide (PEI)</td>
</tr>
</tbody>
</table>

*Source: Ref. 4.*

### TABLE 3.3 General Comparisons among Crystalline, Amorphous, and Liquid-Crystalline Polymers

<table>
<thead>
<tr>
<th>Property</th>
<th>Crystalline</th>
<th>Amorphous</th>
<th>Liquid-Crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>Higher</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Higher</td>
<td>Lower</td>
<td>Highest</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>Higher</td>
<td>Lower</td>
<td>Highest</td>
</tr>
<tr>
<td>Ductility, elongation</td>
<td>Lower</td>
<td>Higher</td>
<td>Lowest</td>
</tr>
<tr>
<td>Resistance to creep</td>
<td>Higher</td>
<td>Lower</td>
<td>High</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>Higher</td>
<td>Lower</td>
<td>High</td>
</tr>
<tr>
<td>Shrinkage and warpage</td>
<td>Higher</td>
<td>Lower</td>
<td>Lowest</td>
</tr>
<tr>
<td>Flow</td>
<td>Higher</td>
<td>Lower</td>
<td>Highest</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>Higher</td>
<td>Lower</td>
<td>Highest</td>
</tr>
</tbody>
</table>

*Source: Ref. 4.*

in which two or more chains are joined together by side chains. A thermosetting polymer cannot be melted or appreciably softened by heat after curing. Because of the difficulty in processing, thermosetting polymers, they are not in common use in the connector and socket industry.

### 3.1.2 Thermoplastics

Various thermoplastics used as socket housings are described in this section.

**Polyesters** Polyesters were the first synthetic condensation polymers, studied as early as the 1930s. Thermoplastic polyesters were commercialized in the
TABLE 3.4 Properties of Polyesters: PET, PBT, and PCT

<table>
<thead>
<tr>
<th>Name</th>
<th>Density (g/cm³)</th>
<th>Tg (°C)</th>
<th>Tm (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>1.36–1.38</td>
<td>70–80</td>
<td>265</td>
</tr>
<tr>
<td>PBT</td>
<td>1.31</td>
<td>40</td>
<td>224</td>
</tr>
<tr>
<td>PCT</td>
<td>1.22–1.23</td>
<td>60–90</td>
<td>290</td>
</tr>
</tbody>
</table>

Source: Ref. 5.

early 1950s [5]. All commercial polyesters have terephthalic acid as the major building block. Variations of the difunctional alcohols, as well as use of alcohol mixtures, yield many kinds of products. However, three major products dominate the market today: polybutylene terephthalate (PBT), polyethylene terephthalate (PET), and polycyclohexylenedimethylene terephthalate (PCT). These polyesters are made by a transesterification of the appropriate alcohol and ester monomers. Densities and thermal properties of these three polyesters are listed in Table 3.4.

PET, introduced as an engineering polymer in 1966, is a linear crystalline polymer with crystallinity over 40%. PET shows high strength, stiffness, dimensional stability, and chemical and heat resistance, and has good electrical properties. A highly crystalline PET with 30% glass reinforcement can achieve a high heat deflection temperature of 227°C at 264 psi. However, compared with PBT, PET is more sensitive to water, which can cause degradation of its properties. PET is also attacked by chlorinated solvents and strong bases at high temperatures.

PBT has been an engineering polymer since 1974. PBT shows high mechanical strength, a high heat deflection temperature, low moisture absorption, good dimensional stability, low creep, and excellent electrical properties. PBT also exhibits solvent resistance and is unaffected by water, weak acids and bases, and common organic solvents at room temperature. Compared with PET, PBT has better processibility. The continuous-use temperature of PBT ranges from 120 to 140°C. By reinforcing it with glass fibers (30%), the heat distortion temperature of PBT can increase from 70 to 210°C.

PCT is a linear high-temperature semicrystalline polymer with a melting temperature as high as 290°C. It shows an excellent balance of physical, chemical, electrical, mechanical, and thermal properties. PCT has the same percentage of crystallinity as PBT, but is much slower to crystallize, resulting in slower cycle times. It also has a narrow processing window, due to the small temperature span between its melting point and degradation [3].

**Polyimide (PI), Polyamide-imide (PAI), and Polyetherimide (PEI)** Polyimide, polyamide-imide and polyetherimide contain imide groups (-CONCO-). These three kinds of polymers are all high-temperature engineering thermoplastics. Although they can be regarded as belonging to the PI family, PAI and PEI are essentially amorphous polymers.
Polyimides are characterized by a high glass transition temperature, excellent radiation resistance, high toughness, and good electrical properties and flame resistance. Polyimides can retain a significant portion of their mechanical strength at temperatures up to 482°C in short-term exposures. For prolonged exposures, they can be used at about 260°C. The shortcomings of polyimides include high cost and processing difficulty. Polyimides have some variations; among them, Kapton is used most extensively.

Polyamide-imides were introduced in the 1970s. PAIs show excellent mechanical properties, low dielectric losses, low coefficients of thermal expansion, wear resistance, and radiation resistance. PAIs possess outstanding temperature resistance, have a $T_g$ value of 275°C, and can be used continuously from cryogenic temperatures to about 230°C. Polyamide-imides are inherently flame retardant with an oxygen index of 43 and a UL 94 V0 rating. The polymers produce very little smoke when burned. They are not attacked by aliphatic or aromatic hydrocarbons, halogenated solvents, or most acids and bases at room temperature. The PAIs can be attacked by hot caustic acid and steam [4].

Polyetherimides appeared initially on the market in 1982 under the commercial name Ultem (GE) [6]. By incorporating aromatic groups along the polymer chain, polyetherimides combine structural stiffness with easy flow and processibility. PEIs show high heat resistance and dimensional stability. They are UL-rated for 170°C continuous use, and are inherently flame retardant, with an oxygen index of 47. Polyetherimides are resistant to a wide variety of chemicals, such as mineral acids, aliphatic hydrocarbons, alcohols, and completely halogenated solvents. They are not resistant to partially halogenated solvents, aprotic solvents, or strong bases. Their electrical properties show very good stability under various conditions of temperature, humidity, and frequency. PEIs have a low dissipation factor even at gigahertz frequencies.

**Polyphenylene Sulfide (PPS)**  Polyphenylene sulfides are crystalline engineering thermoplastics. They can be used with good retention of their physical properties up to their melting temperature, around 300°C (short time). The glass transition temperature of PPS is 88°C. PPSs are inherently flame retardant and are not affected by most solvents except hot nitric acid and chlorinated and fluorinated hydrocarbon solvents. When PPSs are reinforced with glass fibers, continuous temperatures as high as 200°C can be achieved [3].

**Polyether Ether Ketone (PEEK)**  PEEK is a crystalline high-temperature thermoplastic polymer. It belongs to the family of polyether ketones. Developed in 1980 by ICI, PEEK is a superb engineering polymer, showing excellent mechanical properties that are retained at elevated temperatures. The glass transition temperature of PEEK is 145°C, and its melting temperature is 335°C. It has a continuous service temperature of 250°C. PEEK shows stability toward fire and chemicals but is sensitive to ultraviolet radiation. However, due to its extremely high price, PEEK is rarely used.
**Liquid-Crystalline Polymer (LCP)**  Liquid-crystalline polymers are aromatic polyesters. They are self-reinforcing polymers, which have highly ordered structures in the melted and solid states. The liquid-crystalline polymers are known for their good thermal, electrical, and mechanical properties. The liquid-crystalline polymers are inherently flame retardant and pass the UL 94 V0 flammability rating. During combustion, very little smoke is generated. The LCPs show a very high heat deflection temperature, in the range of 180 to 350°C [6]. Liquid-crystalline polymers show very broad chemical inertness and are resistant to acids, dilute bases, and organic solvents. The good flow behavior of liquid-crystalline polymers provides high processibility; they can be molded flash-free, and thin-walled parts can be produced with clean edges. However, because of the high degree of molecular ordering, liquid-crystalline polymers exhibit a high degree of anisotropy, which may cause excessive stresses in the transverse direction and result in part warpage. To overcome the problems of anisotropy, 30 to 50% glass fibers are usually loaded with liquid-crystalline polymers.

**Comparisons among Polymers**  A comparison of the key polymers used in sockets is given in Table 3.5. This comparison is just for general reference, as the properties of final products are also greatly influenced by other factors, such as fillers, additives, and manufacturing processes.

The passage of European Union legislation on banning lead from electronic products puts new challenges on the selection of socket housing materials if sockets are soldered to boards. Lead-free processing temperatures will be significantly higher than the current tin–lead processing temperature. Some of the thermoplastic materials, such as PBT, may not perform well in lead-free assembly environments. Figure 3.1 shows a comparison of different thermoplastic materials in terms of their thermal resistance performances (melting temperature and heat deflection temperature). LCP yields the best heat resistance. Materials such as PBT, PEI, and PET cannot survive the assembly process, considering a peak reflow temperature of 260°C.

**3.1.3 Thermosetting Polymers**

Thermoset polymers are seldom used in the production of IC component sockets. They cannot be reheated or softened after cooling from the melt state. Consequently, they provide little opportunity for regrind use. However, compared with thermoplastic polymers, thermoset polymers usually provide better mechanical and thermal properties, since the polymer chains are cross-linked. Thus, thermoset polymers are used where the shape of the socket housing is simple and easy to manufacture, as in DIP and PGA sockets.

Epoxy resins show very good chemical, mechanical, and electrical properties, such as inertness to chemicals, high mechanical strength, and impact resistance. A filled epoxy is the common thermoset polymer material used. The operating temperature for the standard bisphenol (a type of epoxy resin) is about 150°C; specialized resins can extend the temperature to above 200°C [4]. As the socket housing and the PCB are made of the same material, there are fewer problems
## TABLE 3.5 Comparisons among Thermoplastic Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene terephthalate (PET)</td>
<td>Good electrical properties, chemical resistance, good heat resistance, high heat deflection temperature</td>
<td>More sensitive to water (than PBT)</td>
</tr>
<tr>
<td>Polybutylene terephthalate (PBT)</td>
<td>Good electrical properties, good processibility, low moisture absorption, and chemical resistance</td>
<td>High shrinkage, low glass transition temperature</td>
</tr>
<tr>
<td>Polycyclohexylene-dimethylene terephthalate (PCT)</td>
<td>High melting temperature, good flow and chemical resistance</td>
<td>Britteness, narrow processing window</td>
</tr>
<tr>
<td>Polyimide (PI)</td>
<td>High glass transition temperature, excellent radiation resistance, toughness, good electrical properties and flame resistance, excellent heat resistance and wear resistance</td>
<td>High cost and difficulty to process, low impact strength</td>
</tr>
<tr>
<td>Polymide-imide (PAI)</td>
<td>Good temperature resistance, low dielectric losses, wear resistance, radiation resistance, chemical resistance, inherent flame retardancy</td>
<td>Poor processibility</td>
</tr>
<tr>
<td>Polyetherimide (PEI)</td>
<td>Good processibility, toughness, flame resistance, chemical resistance, low dissipation factor, high operating temperature</td>
<td>High cost</td>
</tr>
<tr>
<td>Polyphenylene sulfide (PPS)</td>
<td>Inherent flame retardancy, chemical resistance, good heat resistance</td>
<td>Britteness, flash, colorability</td>
</tr>
<tr>
<td>Polyether ether ketone (PEEK)</td>
<td>Heat resistance, high operating temperature, excellent mechanical properties, resistance to fire and chemicals</td>
<td>High price, sensitive to UV radiation</td>
</tr>
<tr>
<td>Liquid-crystalline polymer (LCP)</td>
<td>Good mechanical properties, high deflection temperature, chemical resistance, low thermal expansion coefficient, good flow behavior</td>
<td>High price, anisotropic behavior</td>
</tr>
</tbody>
</table>

*Source: Refs. 3 and 4.*
with CTE mismatches, which increases the solder joint reliability if a socket is soldered to a PCB.

3.1.4 Additives

The purposes of using additives in polymers are many. Additives can significantly reduce product cycle time and cost; improve the mechanical, electrical, and thermal properties of products; and enhance antiflammability. To achieve these purposes, careful selection of additives, their content, and their shape is very important.

For safety reasons, electronic equipment is required to achieve the UL 94 V0 flammability rating. To prevent ignition and combustion of materials, flame retardants are added to plastics, other than to polymers that are inherently flame retardant, such as PPS and PAI. The flame retardant may act by interrupting the radical reaction of combustion or by forming a barrier layer on the surface of the polymer [3].

There are basically two types of flame retardants: halogen- and nonhalogen-based compounds. Halogen-based compounds, especially those based on bromine, are now commonly used for flame retardants. The antiflammability of these flame retardants is usually enhanced by adding a synergist such as antimony trioxide. However, these antiflame agents are harmful to the environment. Moreover, bromine and antimony trioxide are major sources of corrosion. Efforts are under way to develop nonantimony and nonhalogen flame retardants [7]. New flame-retardant agents under investigation are hydrated metal compounds, boron compounds, phosphorus compounds, and antimony pentoxide.

Reinforcement agents are added to improve the mechanical properties of engineering polymers, although they also serve other purposes, such as enhancing...
antiflammability and resistance to heat and chemicals. Glass fibers or particles are used extensively as the reinforcement agent, with a common loading of 30 to 40%.

### 3.1.5 Housing Manufacturing

The performance of a final product depends not only on its inherent properties but also on the process by which it is made. The time–temperature profile, cycle time, and working pressure can have a significant effect on final performance. Injection molding is generally used for the production of socket housings. By filling a hollow cavity space built to the shape of the desired product with hot and soft plastic, plastic parts can be produced. An injection mold can have a number of cavities, and cavity layout has many variations. Figure 3.2 shows an eight-cavity mold with an H-style runner system.

Steps in injection molding are as follows:

- Close the mold.
- Inject the hot or fluid plastic into the cavity spaces under pressure.
- Keep the mold closed until the plastic is cooled and ready for ejection.
- Open the mold and eject the finished products.

To maintain high quality in final products, many factors need to be carefully controlled, such as mold temperature, injection pressure, injection time, injection hold time, cooling time, viscosity of molding materials, and mold design.

### 3.2 SOCKET CONTACT

Socket contact materials are evaluated in terms of their electrical conductivity, mechanical strength, resistance to stress relaxation or creep, solderability, and resistance to corrosion. Formability of contacts should also be taken into consideration. Socket contacts are usually made of metal alloys, predominantly copper alloys. By doping some concentration of impurities, properties of contacts can be optimized. Major copper alloys are brass, bronze, and beryllium copper. In some cases, nickel alloys are substituted for copper alloys for better performance. Other metal or alloy systems are gold, silver, or molybdenum; these metals are typically utilized for BGA and LGA socket contact designs, such as wire-button contacts and conductive elastomer contacts.
Copper has been used extensively in the microelectronics industry because of its high electrical conductivity and low cost. However, pure copper demonstrates low mechanical strength. To overcome this shortcoming, some impurities are doped to the copper atom lattice, although this reduces electrical conductivity. The principal doping elements are beryllium, zinc, silicon, tin, nickel, phosphor, and aluminum. Depending on the doped elements, concentration, and how the copper alloy is processed, different mechanisms may be responsible for the hardening or strengthening of the copper alloy. Solid solution strengthening is caused by the strain field, due to the atomic size mismatch between dissolved alloying elements and copper. If the concentration of impurities exceeds the limit of solubility of the base metal, the impurities will dissolve out from the base metal. The new phase causes the type of strengthening called dispersed second-phase strengthening. Precipitation strengthening is related primarily to the process of heat treatment.

**Unified Numbering System (UNS)** The Unified Numbering System (UNS) is the alloy designation system in North America for wrought and cast alloy products. The UNS is jointly managed by the American Society for Testing and Materials and the Society of Automotive Engineers. It provides a quick and easy way to cross-reference many different numbering systems used to identify the thousands of metals and alloys in commercial use. In the designation system, numbers from C10000 through C79999 denote wrought alloys. Cast alloys are numbered from C80000 through C99999. Commonly, only the first three or four digits are used. Within these two categories, the compositions are grouped into families of coppers and copper alloys as described below [3,9,10].

**Coppers (C10000–C15599 Series)** These metals have a designated minimum copper content of 99.3% or higher.

**High-Copper Alloys (C15600–C19599 Series)** For wrought products, these are alloys with designated copper contents of less than 99.3% but more than 96% that do not fall into any other copper alloy group. Most alloys in this group contain additives of beryllium, cadmium, chromium, or iron to improve mechanical strength, without significant reduction in electrical conductivity. They are used primarily in applications where thermal or electrical conductivity as well as strength is necessary for the finished product.

**Brasses (C20500–C28299, C3XXXX, and C4XXXX Series)** These alloys contain zinc as the principal alloying element, with or without other designated alloying elements, such as iron, aluminum, nickel, and silicon. The wrought alloys comprise three main families of brasses: copper—zinc alloys (C20500—C28299 series); copper—zinc—lead alloys (leaded brasses) (C3XXXX series); and copper—zinc—tin alloys (tin brasses) (C4XXXX series). For the copper—zinc alloy group, the zinc concentration can range from 3% (C20500) to 39% (C28000).
group combines ease of manufacture with fair electrical conductivity, excellent forming properties, and good thermal conductivity. The leaded brasses contain a zinc content of 32 to 39%, to which 1 to 3% lead is added. The lead is disseminated in small particles throughout the alloy, giving excellent machining qualities, such as ease of sawing and milling. The tin brasses contain zinc with the addition of 0.5 to 2% tin. This group exhibits good corrosion resistance and mechanical strength. The cast alloys comprise four main families of bronzes: copper–tin–zinc alloys (red, semired, and yellow brasses); manganese bronze alloys (high-strength yellow bronzes); leaded manganese bronze alloys (leaded high-strength yellow bronzes); copper–zinc–silicon alloys (silicon bronzes and bronzes); and cast copper–bismuth and copper–bismuth–selenium alloys.

**Bronzes (C5XXXX and C6XXXX series)** Broadly speaking, bronzes are copper alloys in which the major alloying element is not zinc or nickel. Originally, bronze described alloys with tin as the only or principal alloying element. Today, the term is generally used not by itself but with a modifying adjective. For wrought alloys, there are four main families of bronzes: copper–tin–phosphorus alloys (phosphor bronzes) (C5XXXX series); copper–tin–lead–phosphorus alloys (leaded phosphor bronzes) (C5XXXX series); copper–aluminum alloys (aluminum bronzes) (C6XXXX series); and copper–silicon alloys (silicon bronzes). The addition of small amounts of phosphorus eliminates oxides. The phosphor bronzes possess excellent tensile strength, high resiliency, good fatigue strength, and corrosion resistance. The leaded phosphor bronzes provide the same mechanical properties as the phosphor bronzes. Zinc may be added, as in C54400, to further enhance the strength and hardness. The aluminum bronzes consist of copper with 2 to 13% aluminum. These alloys have good strength and formability. The silicon bronzes contain 0.4 to 4.0% silicon.

The cast alloys include four main families of bronzes: copper–tin alloys (tin bronzes); copper–tin–lead alloys (leaded and high leaded tin bronzes); copper–tin–nickel alloys (nickel–tin bronzes); and copper–aluminum alloys (aluminum bronzes). The family of alloys known as manganese bronzes, in which zinc is the major alloying element, is included among the brasses. These alloys are also included in the category of C60000. They exhibit excellent corrosion resistance and mechanical strength.

**Copper–Nickels (C7XXXX Series)** These are alloys with nickel as the principal alloying element, with or without other alloys, designated commonly as nickel silvers. These alloys contain zinc and nickel as the principal and secondary alloying elements, with or without other designated elements. This type of alloy shows good forming qualities, high strength, and excellent corrosion resistance.

The other types of alloys covered in the C7XXXX series are the nickel silvers and leaded nickel silvers. The nickel silvers are copper–zinc alloys with the addition of nickel. They demonstrate high formability, tarnish resistance, and oxidation resistance. Compared with copper–nickel, they are stronger but less resistant to stress corrosion. The leaded nickel silvers are copper–nickel–zinc
alloys with added lead. Silicon is also one major alloying element to this group. CuNiSi (C7026) is used as socket contact material, since it can provide high mechanical strength and high resistance to stress relaxation.

**Properties of Copper Alloys** The dominant copper alloys used in the socket industry are beryllium copper, brass, phosphor bronze, and spinodal alloy (copper–nickel–tin alloy). The properties of these alloys are compared below in terms of their electrical conductivity, mechanical strength, resistance to stress relaxation or creep, formability, solderability, and resistance to corrosion.

**Electrical Conductivity** Because of its superior conductivity, annealed pure copper is the international standard to which all other electrical conductors are compared. In 1913, the International Electro-Technical Commission set the conductivity of copper at 100% in their International Annealed Copper Standard (IACS). This means that copper provides more current-carrying capacity for a given diameter of wire than does any other engineering metal.

Alloying inevitably reduces conductivity. The extent of reduction depends on the types and concentrations of impurities and how they are distributed in the alloy. A higher content of impurities is usually accompanied by lower electrical conductivity, and thus a lower IACS percentage. Figure 3.3 presents a comparison of the electrical conductivity of some copper alloys.

Accompanying the electrical conductivity is the thermal conductivity of copper alloys. Metals with high electrical conductivity usually have a high thermal conductivity. This relationship is described by the Wiedemann–Franz–Lorentz law:

\[
L = \frac{K}{\sigma T} \tag{3.2}
\]

![Figure 3.3](image-url)  
**Figure 3.3** Rank of electrical conductivity of copper alloys. (From Refs. 3 and 11.)
where \( L \) is the Lorentz constant: \( 5.8 \times 10^{-9} \text{cal.s.K.} \), \( K \) is the thermal conductivity, \( \sigma \) is the electrical conductivity, and \( T \) is the temperature. The thermal conductivity of a copper alloy can be roughly estimated from (3.2) if its electrical conductivity is known. In most cases, the increase in temperature will cause a decrease in electrical conductivity, but not necessarily the thermal conductivity. Usually, for coppers with very high electrical conductivity, the thermal conductivity decreases as the temperature is increased; for coppers with low electrical conductivity, the reverse situation will occur. The influence of temperature on both electrical and thermal conductivity has to be considered in the design of socket contacts.

**Mechanical Strength** Mechanical properties of copper alloys that are of importance include the modulus of elasticity, yield strength, hardness, tensile strength, and fatigue (see Chapter 2). These properties are dependent not only on alloy composition but also on the manufacturing process. Comparatively, precipitation-strengthened alloys demonstrate higher mechanical strength (tensile strength and yield strength) than do solution-strengthened alloys and dispersed second-phase strengthened alloys.

**Resistance to Stress Relaxation and Creep** To maintain a stable contact interface, a stable contact force is necessary. An adequate initial contact force does not guarantee stable contact force throughout the contact’s entire life. Contact force can decrease over time due to a phenomenon called *stress relaxation*. Stress relaxation is due to macroscale plastic deformation within contact materials. The rate of stress relaxation depends on the duration under load, temperature, applied stress (load), alloy, and temper. Temperature is a major factor in increasing the stress relaxation behavior of metals. Higher stress usually causes a higher stress relaxation rate. The choice of the initial contact force depends on the potential stress relaxation rate and contact stress boundaries.

The stress relaxation of metals is usually defined as the remaining stress after a specified period, usually 1000 h (five weeks). Copper alloys show very good resistance to stress relaxation at room temperature. Table 3.6 show the performance of stress relaxation of some copper alloys at room temperature after 100,000 hours (10 years). Increasing the temperature significantly degrades the resistance to stress relaxation of some copper alloys, which limits these copper alloys to high-temperature applications. Beryllium copper and spinodal alloys show the most excellent high-temperature performance, while the performance of brass is poor at high temperatures; only 53% stress remains after 1000 h of service at 125°C, and 65% remains at 105°C, limiting the application of brass alloys to temperatures below 100°C [3].

*Creep* is time-dependent plastic deformation under a constant load. The creep rate is dependent on the material type, manufacturing process, operating time, applied stress, and temperature. Gradual deformation or creep may occur at stress levels much lower than the yield strength of metal contacts. Temperature greatly accelerates the creep rate of metal contacts.
TABLE 3.6 Stress Remaining for Alloys at Room Temperature after 10 Years of Use

<table>
<thead>
<tr>
<th>Initial Stress (80% of 0.2% Yield Strength in ksi)</th>
<th>40</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>C194</td>
<td>94</td>
<td>82</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>C195</td>
<td>–</td>
<td>90</td>
<td>81</td>
<td>–</td>
</tr>
<tr>
<td>C260</td>
<td>–</td>
<td>91</td>
<td>88</td>
<td>–</td>
</tr>
<tr>
<td>C510</td>
<td>98</td>
<td>–</td>
<td>–</td>
<td>95</td>
</tr>
<tr>
<td>C725</td>
<td>–</td>
<td>–</td>
<td>95</td>
<td>–</td>
</tr>
<tr>
<td>C762</td>
<td>–</td>
<td>96</td>
<td>–</td>
<td>96</td>
</tr>
</tbody>
</table>

Source: Ref. 11.

Solderability In many cases, component sockets are to be assembled on a printed circuit board through a soldering process, such as wave soldering for through-hole sockets and reflow soldering for surface-mounted sockets. Solderability represents the ability of a metal surface to be wet with solder in the presence of a flux [12]. Solderability of an alloy is usually determined by visual examination of samples that are fluxed and subsequently dipped in solder for a specific time [13]. Based on visual inspection, the solderability of alloys can be rated and acceptance criteria can be established. A class 1 rating refers to complete wetting by solder, while for a class 3 rating the wetting area can be as low as 50%. A solderability rating of class 3 or higher is regarded adequate for most socket applications [3]. Table 3.7 lists solderability ratings of some copper alloys when a mildly activated flux is used. To ensure good solderability during assembly, precoating of tin or solder onto copper alloys is a recommended practice.

Corrosion Resistance In the presence of moisture, and contaminants, copper will oxidize and corrode. Corrosion generally proceeds by an electrochemical reaction, in which electrons flow between anodes and cathodes through a

TABLE 3.7 Solderability Rating of Copper Alloys

<table>
<thead>
<tr>
<th>Solderability Rating</th>
<th>Coating Characteristics (% wetting)</th>
<th>Alloy Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>100</td>
<td>C172, C1751, C194, C510, C521</td>
</tr>
<tr>
<td>Class 2</td>
<td>95</td>
<td>C195, C230, C638</td>
</tr>
<tr>
<td>Class 3</td>
<td>50–90</td>
<td>C260, C654, C770</td>
</tr>
</tbody>
</table>

Source: Ref. 3.
TABLE 3.8 Copper Alloys in which Stress Corrosion Cracking Was Observed

<table>
<thead>
<tr>
<th>Copper Alloy</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu–Zn</td>
<td>NH$_3$ vapors and solutions</td>
</tr>
<tr>
<td>Cu–Zn–Sn</td>
<td></td>
</tr>
<tr>
<td>Cu–Zn–Pb</td>
<td></td>
</tr>
<tr>
<td>Cu–Zn–Pb</td>
<td>NH$_3$ vapors and solutions</td>
</tr>
<tr>
<td>Cu–Sn</td>
<td></td>
</tr>
<tr>
<td>Cu–Sn–P</td>
<td>Air</td>
</tr>
<tr>
<td>Cu–Au</td>
<td>NH$_4$OH, FeCl$_3$, HNO$_3$ solution</td>
</tr>
<tr>
<td>Cu–Zn</td>
<td>Moist SO$_2$</td>
</tr>
<tr>
<td>Cu–Zn–Mn</td>
<td>Moist NH$_3$ atmosphere</td>
</tr>
<tr>
<td>Cu–Be</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ref. 12.

...The formation of anodes and cathodes depends on many factors, such as surface defects, orientation grains, impurities, and localized stresses. As a result, a layer of corrosion film grows on the surface of the copper.

...When copper alloys are in a highly stressed condition and exposed to an adverse environment, they are susceptible to stress corrosion. The combined effect of corrosion and stress may cause a catastrophic failure of contacts, commonly referred to as stress corrosion cracking or season cracking. For copper alloys, the most aggressive environments are those containing ammonia or ammonia compounds [12]. Table 3.8 lists some copper alloys in which stress corrosion cracking was observed in the environment specified. Stress corrosion resistance varies for different kinds of copper alloys. Brass, which contains high amounts of zinc, was shown to be most susceptible to stress corrosion [3]. Therefore, the use of brass is limited to benign environments. Beryllium copper and phosphor bronze are among the best copper alloys to resist stress corrosion.

...Oxidation or corrosion of contact surfaces inevitably results in an increase of contact resistance. Plating contact surfaces with noble or non-noble metals is generally practiced to improve the corrosion resistance of contacts and to enhance interface stability.

### 3.2.2 Nickel Alloys

Nickel alloys are seldom used in component sockets, since they are expensive. The unified numbering system for nickel alloys goes from N02016 to N99800. Of the alloys, beryllium nickel has been used in the socket industry [14]. Beryllium nickel shows very high resistance to stress relaxation, especially at elevated...
temperatures. Nickel alloys also show considerably higher mechanical strength than copper alloys, while their electrical conductivities are relatively lower.

3.2.3 Conductive Elastomers

Conductive elastomers have been developed for a variety of electronic applications, including IC component sockets, display panels, flat cables, and mother–daughter board connectors. Compared with metallic spring contacts, conductive elastomers provide many advantages, such as high compliance, fine pitch and high I/O applications, and a short electrical path.

A conductive elastomer is a rubber that is made conductive by embedding metal wires or metal powders within the elastomer matrix. An elastomer is defined by ASTM to be a polymeric material that at room temperature can be stretched to at least twice its original length and upon immediate release of the stress will return quickly to its original length [15]. Elastomers are sometimes referred to as rubbers, because of their resemblance in elasticity or resilience. A variety of rubbers are produced, such as natural rubber, isoprene rubber, neoprene, polysulfide rubber, polyamide, polyester elastomer, silicone rubber, fluorosilicone rubber, and perfluoroelastomer. Among them, silicone rubbers are widely used for conductive elastomers because of their excellent physical and mechanical properties and their resistance to corrosion and weathering.

Silicone rubbers, also known as polysiloxanes, are a series of compounds whose polymer structure consists of silicone and oxygen atoms, rather than a structure made of carbon skeletons. The basic unit of a silicone rubber is

$$[(CH_3)_2 - Si - O - Si - (CH_3)_2 - O]_n$$

Compared with other carbon-linkage rubbers, silicone rubbers are more stable. Silicone rubbers are among the most heat-resistant elastomers; they can be used for a wide temperature range, typically from −51 to 232°C. Silicone rubbers exhibit good compression set resistance and rebound properties in both hot and cold environments, and a low dielectric constant and dissipation factor. Typical electrical and mechanical properties of silicone rubbers are listed in Table 3.9. Silicone rubbers demonstrate excellent resistance to flame, sun, weathering, and ozone, and their properties are virtually unaffected by long-term exposure [15]. Silicone rubbers can be used in contact with dilute acids and alkalis, alcohols, animal and vegetable oils, lubricating oils, and aliphatic hydrocarbons. However, silicone rubbers demonstrate poor abrasion resistance, and they can be attacked by aromatic solvents such as benzene, toluene, gasoline, and chlorinated solvents, which will cause excessive swelling. Although they are resistant to water and weathering, silicone rubbers are not resistant to high-pressure and high-temperature steams [15].

To be used as socket contacts, metals are incorporated into rubbers to make them conductive. Metals can be in the form of powders or wires. Commonly used metal powders include nickel and silver. Nickel powders are usually coated with
TABLE 3.9 Physical and Mechanical Properties of Silicone Rubbers

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.05–1.94</td>
</tr>
<tr>
<td>Water absorption (%/24 h)</td>
<td>0.02–0.6</td>
</tr>
<tr>
<td>Dielectric strength (V/mil)</td>
<td>350–590</td>
</tr>
<tr>
<td>Dissipation factor</td>
<td></td>
</tr>
<tr>
<td>At 60 Hz</td>
<td>0.0007</td>
</tr>
<tr>
<td>At 1 MHz</td>
<td>0.0085–0.0026</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td></td>
</tr>
<tr>
<td>At 60 Hz</td>
<td>2.91</td>
</tr>
<tr>
<td>At 1 MHz</td>
<td>2.8–3.94</td>
</tr>
<tr>
<td>Volume resistivity (Ω.cm)</td>
<td>10^{14}–10^{16}</td>
</tr>
<tr>
<td>Tensile strength (psi)</td>
<td>1200–6000</td>
</tr>
<tr>
<td>Hardness, Shore A</td>
<td>20–90</td>
</tr>
<tr>
<td>Maximum temperature, continuous use</td>
<td>232°C</td>
</tr>
<tr>
<td>Compression set (%)</td>
<td>10–15</td>
</tr>
</tbody>
</table>

Source: Ref. 15.

gold and silver to enhance electrical conductivity. Silver is a more expensive choice but offers high electrical conductivity. Silver is also resistant to chemical attack, but may react with chlorine and sulfur. Metal wires include gold, stainless steel, and brass wires plated with nickel and gold. These wires can be straight or curved, used singly or in a bundle [16].

The conducting mechanism for metal-powder-filled elastomers can be described by the percolation theory. A minimum content of metal powder is required to establish the conductive network. The critical filler content is usually 70 to 80% in weight, depending on particle geometry, size, and size distribution. Once above the critical filler content, the conductivity of conductive elastomers increases by several orders. Filler particles may come in various shapes: spheres, fibers, flakes, or granules. Among them, flakes, due to their high aspect ratio, provide the minimum critical filler concentration for low resistance and the strongest adhesion to elastomers. Small particles are considered to be better than large particles, providing more particle-to-particle contact and thus, higher conductivity [17].

A polysiloxane elastomer was prepared by incorporating approximately 30% volume fraction of foam into the elastomer [18]. The compressibility of the elastomer interconnects can be tailored by controlling the volume fraction of the foams. The use of foamed elastomers improves the compressibility of BGA socket interconnects, and avoids damage to solder balls during engagement.

3.2.4 Contact Manufacturing

Properties of socket contacts are not only dependent on contact materials but are also greatly affected by how they are manufactured. For metal alloys, the manufacturing process can impart improved properties, especially mechanical properties, to socket contacts by optimizing their macrostructures.
Figure 3.4 Manufacturing process for metallic spring contacts.

The manufacturing process for metallic alloys is illustrated in Figure 3.4. The steps comprise the *stamp process* of making socket contacts. In the stamp process alloys are formed to a required shape and configuration with progressive dies, and then heat-treated to achieve required spring properties.

*Formability* is related to the ease of bending alloys to a required configuration. Good formability is usually achieved at the sacrifice of mechanical strength, and vice versa. A common way to measure formability is to determine the minimum radius of bending that produces fracturing. This minimum radius is always almost proportional to the alloy thickness, so the ratio of the minimum radius over the thickness is usually characterized and reported. A smaller ratio denotes better formability. The formability of alloys is dependent not only on alloy type and treatment but also on bending directions. Better formability is achieved when the bending axis is perpendicular to the direction of rolling; this formability is also called *longitudinal formability*, in contrast to *transverse formability* (along the direction of rolling).

Some alloys are not suitable for stamping, such as leaded brass (C312–C385, C482–C465). These alloys are formed to a required shape through machining. They are utilized primarily to form shells or sleeves for multifinger contacts for DIP and PGA sockets.

The commonly used treatment terminologies from ASTM B601–98a [19] are listed below

- *Annealing*: a thermal treatment to change properties or grain structures of a product.
- *Cold work*: controlled mechanical operations for changing the form or cross section of a product to reduce residual stress variations, thus reducing susceptibility to stress corrosion or season cracking without significantly affecting the tensile strength or microstructure of the product.
• *Hot working*: controlled mechanical operations for shaping a product at temperatures above the crystallization temperature.

• *Precipitation heat treatment*: thermal treatment of a product to produce property changes such as hardening, strengthening, and conductivity increase by precipitating constituents from the supersaturated solid solution. This method is also called *age hardening* and *precipitation hardening*.

• *Solution heat treatment*: a thermal treatment of a product to add alloying elements into the base metal lattice by heating the product above its solid solubility, followed by cooling at a sufficient rate to retain a supersaturated solid solution.

• *Spinodal heat treatment*: thermal treatment of a product to produce property changes such as hardening, strengthening, and conductivity increase by spinodal decomposition of a solid solution. This treatment is also called *age hardening*, *spinodal hardening*, or *spinodal decomposing*.

• *Drawn stress relieved (DSR)*: thermal treatment of cold-drawn product to reduce residual stress variations, thus reducing susceptibility to stress corrosion or seasonal cracking, without significantly affecting tensile strength or microstructure.

*Temper* is defined as the metallurgical structure and properties of a product resulting from thermal or mechanical processing. Different treatment processes produce different tempers. A standard practice has been constructed by ASTM for the designation of alloy tempers [19]. Before construction of the standard, another designation system had been commonly used. The terms applied to cold-rolled tempers are listed in Table 3.10; for each temper name, alloys must meet a specific tensile strength requirement.

The ASTM designation is practiced by using letters followed by numbers. The letter is related to a specific mechanical or thermal treatment experienced by an alloy, while the number represents an achieved temper; for annealed tempers, it is an indication of grain size. Some tempers and their symbols and definitions are listed below:

<table>
<thead>
<tr>
<th>Temper Name</th>
<th>Tensile Strength Requirement (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 hard</td>
<td>49–59</td>
</tr>
<tr>
<td>1/2 hard</td>
<td>57–67</td>
</tr>
<tr>
<td>3/4 hard</td>
<td>64–74</td>
</tr>
<tr>
<td>Hard</td>
<td>71–81</td>
</tr>
<tr>
<td>Extra hard</td>
<td>83–92</td>
</tr>
<tr>
<td>Spring</td>
<td>91–100</td>
</tr>
<tr>
<td>Extra spring</td>
<td>95–104</td>
</tr>
</tbody>
</table>

*Source*: Ref. 10.
• **Annealed tempers (O)**: tempers produced by annealing to meet mechanical property requirements.

• **Cold-worked tempers (H)**: tempers produced by controlled amounts of cold work.

• **Heat-treated tempers (T)**: tempers that are based on heat treatments followed by rapid cooling.

• **Solution heat-treated temper (TB)**: tempers produced by solution heat treating of precipitation- or spinodal-hardenable alloys.

• **Solution heat-treated and cold-worked tempers (TD)**: tempers produced by controlled amounts of cold work of solution heat treated precipitation or spinodal-hardenable alloys.

• **Precipitation heat-treated tempers (TF)**: tempers produced by precipitation heat treatment of precipitation-hardenable alloys.

• **Spinodal heat-treated temper (TX)**: temper produced by spinodal heat treatment of spinodal-hardenable alloys.

• **Cold-worked and precipitation heat-treated tempers (TH)**: tempers produced in alloys that have been solution heat treated, cold worked, and precipitation heat treated.

• **Cold-worked and spinodal heat-treated tempers (TS)**: tempers produced in alloys that have been solution treated, cold worked, and spinodal heat treated.

• **Mill-hardened tempers (TM)**: tempers of heat-treated materials as supplied by the mill resulting from combinations of cold work and precipitation heat treatment and spinodal heat treatment.

• **Precipitation or spinodal heat-treated and cold-worked tempers (TL)**: tempers produced by cold working the precipitation or spinodal heat-treated alloys.

• **Precipitation or spinodal heat-treated, cold-worked, and thermal stress-relieved tempers (TR)**: tempers produced in the cold-worked precipitation or spinodal heat-treated alloys by thermal stress relief.

### 3.3 SOCKET CONTACT PLATING

Contact plating provides corrosion protection for base metals, helps to optimize mechanical and electrical properties of contact interfaces, and improves solderability. Copper alloys are highly susceptible to corrosion. Contact plating can provide a shield from environmental attacks to the copper alloy-based metals, prohibiting the accumulation of an insulating layer on the contact interface and maintaining its electrical stability. As a protective layer is supplied by contact plating, the durability and wear resistance of socket contacts are improved. The mechanical and electrical properties of the contact interface can be managed through choosing the appropriate plating material and plating thickness.
Contact plating can be divided into two categories: noble metal plating and non-noble metal plating. This classification is based on the corrosion resistance of metals. A noble metal is virtually corrosion-free, while a non-noble metal may react with certain chemicals. Choices for noble metal plating include gold, palladium, and their alloys; non-noble metal plating materials include tin, solder, nickel, nickel boron, silver, and copper; among them, tin and solder are more commonly used, while nickel is a commonly used underplate.

Selection of contact plating depends on the cost, application parameters, application environments, and technical and reliability requirements. Figure 3.5 presents the selection guidelines based on contact force, insertion and withdrawal cycles, insertion force, and engagement wipe.

Noble metal plating is free of surface films; thus lower contact resistance can be achieved without exerting high contact forces. For non-noble metal plating, a higher normal force may be required to disrupt surface films to ensure a metal–metal contact. For test or burn-in sockets, the durability cycling number is usually above 100,000; in such a situation, noble metal plating is usually needed to endure the long-term contact wear during contact insertions and extractions. For production sockets, non-noble metal plating can be used, as the requirements are comparatively benign. Although they provide higher performance, noble metal plating is much more expensive than non-noble plating.

### 3.3.1 Noble Metal Plating

Noble metal plating includes gold, palladium, and their alloys. These noble metals resist corrosion and film formation. The noble metals can be alloyed, and plating thickness can be adjusted to balance cost, performance, and reliability. The usual plating thickness of noble metals is 10 (or less), 30, or 50 µin., with minimal 50 µin. of nickel as an underplate. A plating of less than 10 µin., often called flash, is often used in noncritical areas where no contact interface is established. An exception is when gold flash is used to cover palladium plating to prevent

![Figure 3.5](image-url)  
*Figure 3.5* Guideline for selecting contact plating material. (From Ref. 12.)
occurrence of friction polymerization on a palladium surface. A plating of 30 µin. is a standard plating thickness practiced in the connector industry and is recommended for general industry applications. For high-reliability applications, such as military and aerospace, a higher plating thickness is often required, typically 50 µin.

**Gold** Gold is the most extensively used noble metal because of its excellent electrical, mechanical, and thermal characteristics as well as its chemical inertness. Gold has high electrical conductivity, comparable with that of silver and copper. It is immune to almost all environmental attacks and can be used continuously in high-temperature (above 100°C) and high-humidity conditions. Gold is resistant to many pollutant gases, such as chlorine, hydrogen sulfur, sulfur dioxide, and base and acid solutions. Although pure gold is soft, it can be alloyed to increase its hardness, and consequently, its contact durability.

Gold platings can be classified into eight general classes according to their impurity, application, thickness, and manufacturing method [20].

- **Class A**: decorative 24 K gold flash (2 to 4 µin.), rack and barrel
- **Class B**: decorative gold alloy flash (2 to 4 µin.), rack and barrel
- **Class C**: decorative gold alloy, heavy (20 to over 400 µin.), rack
- **Class D**: industrial/electronic high-purity soft gold (20 to 200 µin.), rack, barrel, and selective
- **Class E**: industrial/electronic hard, bright, heavy 99.5% gold (20 to 200 µin.), rack, barrel, and selective
- **Class F**: industrial/electronic gold alloy, heavy (20 to 400 µin.), rack and selective
- **Class G**: refinishing, repair, and general, pure and bright alloy (5 to 40 µin.), rack and selective brush
- **Class H**: miscellaneous, including electroforming of gold and gold alloys

Gold plating for socket contacts belongs primarily to classes D and E. Gold flash is utilized primarily for noncritical parts of contacts, such as terminals or contact shells. The thickness of gold plating can be reduced when the intended application is mild and when the contacts see very few insertions and extractions.

Addition of impurities in gold plating is based on cost and the hardness of the gold plating needed to optimize contact durability. Gold alloy with an addition of 0.1% cobalt is called hard gold because of its improved hardness. However, alloying has an adverse effect on the electrical conductivity of contacts; for example, as little as 1% iron will increase the electrical resistance of gold over 1000%, so impurities and their levels must be controlled carefully. Alloying reduces the corrosion resistance of gold contact plating as well.

One of the functions of contact plating is to seal the base metal from unfriendly environments. However, a plated surface may not be as continuous as it appears. Pores in the plating layer expose base metal to pollutant attacks. **Plating porosity**
defines the number of pores per unit area (usually in square centimeters) in the plating layer.

Porosity is a function of substrate roughness and plating thickness. For a specific plating process and substrate roughness, porosity is given by

\[ P = AH^{-n} \]  

where \( P \) is the plating porosity (pores/cm\(^2\)), \( H \) is the plating thickness, and \( A \) and \( n \) are experimentally determined parameters. Figure 3.6 shows experimental data of porosity as a function of plating thickness and substrate roughness.

Substrate roughness and plating thickness have a first-order effect on the plating porosity. With an increase in plating thickness, porosity decreases. An “elbow” can be observed at around 15 to 30 µin., depending on the substrate roughness. Beyond 50 µin. the porosity curve becomes flat; however, pores cannot be removed completely. For general industry applications, a minimum 30 µin. of hard Au plating is required. For high-reliability applications, 50 µin. of Au plating is often necessary.

Some standards were established to examine plating porosity. EIA established an evaluation procedure for the acceptability of gold contact finishes whereby the contacts are exposed to nitric acid vapor (EIA 364–53B: Nitric Acid Vapor Test; Gold Finish Test Procedure for Electrical Connectors and Sockets). By examining corrosion products (usually in a circular shape) after exposure to the acid vapor, the porosity can be counted. Table 3.11 shows the counting method via the corrosion product size. This test procedure does not apply to gold flash plating. For a connector to be acceptable, a porosity of less than or equal to 1 (pore/cm\(^2\)) is required.

In general, Tyco (formerly AMP) established some guidelines for using Au plating in connectors and sockets [22]. However, to ensure the reliability of a

![Graph showing porosity as a function of plating thickness and substrate roughness.](image)

**Figure 3.6** Porosity as a function of plating thickness and substrate roughness. (From Ref. 21.)
TABLE 3.11  Porosity Counting via Corrosion

<table>
<thead>
<tr>
<th>Product Size</th>
<th>Assigned Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter ( \leq 0.05 ) mm</td>
<td>0</td>
</tr>
<tr>
<td>Diameter ( 0.05 ) mm &lt; diameter ( \leq 0.51 ) mm</td>
<td>1</td>
</tr>
<tr>
<td>Diameter ( \geq 0.51 ) mm</td>
<td>2</td>
</tr>
<tr>
<td>Coverage in excess of 50% of measurement area regardless of size</td>
<td>20</td>
</tr>
</tbody>
</table>

connector, specific applications and requirements should be taken into consideration, together with plating thickness and quality.

- Gold coatings are recommended for high-reliability applications.
- Gold coatings can be used in corrosive environments.
- Gold coatings can be used for applications requiring high durability.
- Gold coatings can be used with low normal force and low wipe.
- Thin gold coatings can establish a stable low-resistance contact.
- Gold is not susceptible to fretting degradation.
- Gold contact performance can be enhanced with lubrication.
- Gold coatings require the use of a suitable underlayer, such as nickel.
- Gold coating thickness depends on application requirements.
- Gold can be used for low-level circuit conditions.
- Gold contacts can be used at elevated temperatures.
- Gold contacts should not be mated to tin contacts.
- Gold contacts are not recommended for “hot make-and-break” applications.

**Palladium**  Palladium alloys are employed for plating contacts. The major palladium alloy is palladium (80%)–nickel (20%). It is most often applied with a gold flash (or “cap”) on top. This affords the highest tarnish resistance, along with superior durability. Palladium is harder than gold, improving contact durability. In the past, palladium plating was a much more cost-effective alternative to gold plating; this changed in the late 1990s. Compared with gold, palladium provides lower electrical and thermal conductivity and inferior corrosion resistance. Palladium also has the disadvantage of being a catalyst of polymer formation [3]. In the presence of organic vapors, condensed vapors will polymerize on a palladium surface under fretting conditions, resulting in a friction polymer or brown powder, which could cause an increase in contact resistance.

**Silver**  Silver is a relatively noble metal that shows inertness to atmosphere, steam, and both base and acid solutions, but silver reacts with chlorine and sulfur. The reaction between silver and sulfur causes the silver surface to tarnish.
Another problem with silver is *electromigration*, in which metal atoms transport from one conductive element to another across an insulating layer, under the influence of an applied dc potential and in the presence of moisture. The electromigration of silver causes the dissolution of silver atoms in one element and dendrite growth in the adjacent element. The dendrite growth of silver can result in short circuits between adjacent contacts. Although silver has high electrical conductivity and chemical inertness, it is rarely used in the socket industry because of its reliability problems.

### 3.3.2 Non-Noble Metal Plating

Non-noble metal contact plating differs from noble metal plating mainly in corrosion resistance. Non-noble metal plating is much less resistant to environmental attacks. An insulating film can develop when a fresh non-noble metal is exposed to air. This insulating film determines many properties of the contact interface, such as contact resistance, and many design characteristics, such as contact normal force, insertion force, and contact wipe.

Non-noble metal plating materials include tin, solder, nickel, and nickel–boron, in which tin and solder predominate. The solder composition ranges from 5 to 60% tin. The plating thickness is much greater than that of gold plating, ranging from 100 to 200 µin. Since there is a layer of oxide film on the contact surface, a higher normal force is required to disrupt it and ensure a metal–metal contact. The oxide layer on a tin or solder surface is very brittle and easy to disrupt. However, the reoxidation of exposed surfaces inevitably thickens the oxide layer, causing a problem called *fretting corrosion*. Tin and solder can be plated with or without nickel as an underplate.

Driven by legislative requirements and consumer interest in environmentally friendly products, the connector industry has been pursuing a substitute for solder plating. Tin is one of the premium choices to replace solder. Based on finish color, tin plating can be classified into bright tin and matte tin. The bright finish, with a lustrous appearance, has a grain size less than 0.5 µm; while matte finish, with a dull appearance, has a grain size larger than 1 µm. One major concern for using pure tin plating is a phenomenon called *tin whisker growth*, which is a spontaneous growth of single crystal structures. Tin whiskers are capable of causing electrical failures ranging from parametric deviations to catastrophic short circuits. One potential cause for whisker growth has been attributed to the residual compressive stresses in the tin resulting from the plating process. It was found that bright tin is more susceptible to whisker growth than matte tin finish because of smaller grain size, and use of underplate, such as nickel, can significantly reduce the likelihood of whisker growth. However, there are still substantial controversies [23,24]. There are ongoing industrywide efforts to understand the whisker growth mechanisms and develop test methodologies to effectively assess the propensity of whisker growth.

Nickel and its oxide layer show high hardness, so a much greater contact force is required to disrupt the surface oxide. Nickel is used as a contact finish when
TABLE 3.12 Comparisons among Contact Platings

<table>
<thead>
<tr>
<th>Contact Plating</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>Corrosion resistant in almost all environments</td>
<td>High cost</td>
</tr>
<tr>
<td></td>
<td>Excellent electrical and thermal characteristics</td>
<td></td>
</tr>
<tr>
<td>Palladium</td>
<td>High hardness (high durability)</td>
<td>Frictional polymerization</td>
</tr>
<tr>
<td></td>
<td>Corrosion resistance</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>High electrical and thermal conductivity</td>
<td>Reacts with sulfur and chlorine</td>
</tr>
<tr>
<td></td>
<td>Resistance to welding</td>
<td>Electromigration</td>
</tr>
<tr>
<td>Tin–lead</td>
<td>Ease of displacement of oxide film</td>
<td>Potential to fretting corrosion</td>
</tr>
<tr>
<td></td>
<td>Low cost</td>
<td>Contains lead</td>
</tr>
<tr>
<td>Tin</td>
<td>Ease of displacement of oxide film</td>
<td>Potential to fretting corrosion and whisker growth</td>
</tr>
<tr>
<td></td>
<td>Low cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lead free</td>
<td></td>
</tr>
<tr>
<td>Nickel boron</td>
<td>Self-limiting oxide film</td>
<td>High hardness of oxide film</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Susceptible to fretting corrosion</td>
</tr>
</tbody>
</table>

boron is added, but nickel is most commonly used as an underplate. The advantages and disadvantages of common contact platings are listed in Table 3.12.

3.3.3 Underplate

A contact finish is not always 100% complete. Pores and manufacturing defects expose the base metal to unfriendly environments. A contact underplate creates another barrier against the intrusion of environments and seals off the base metal. It also blocks the outward diffusion of base metal constituents, especially at elevated temperatures. If the underplate has a high hardness (such as for nickel), the contact durability can also be improved.

Nickel is the most commonly used underplate. Nickel underplating seals off the base of pore sites from the environment through its passive and self-limiting oxide film. Studies have shown that nickel provides an effective barrier against the migration of base metal and corrosion products, and contact durability is greatly improved because of its high hardness [3]. The effectiveness of the underplate is conditional upon its thickness. Tests indicate that nickel underplating performs best at a thickness of approximately 50 µin. A thicker nickel plating may not be helpful. As nickel thickness increases, the surface roughness increases. This may cause higher porosity and a decrease in wear resistance.

Some companies (e.g., Tyco) see palladium–cobalt as the next generation of contact finish. Tests demonstrate that palladium–cobalt offers both performance and processing advantages over palladium–nickel, which has been the
cost-effective finish of choice for about 20 years. Because its hardness is greater than that of palladium–nickel and hardened gold, palladium–cobalt has greater durability (hardness has a significant impact on durability). Durability is especially important for contacts that undergo numerous connect–disconnect cycles over their life-span. Other performance parameters, such as contact resistance and fretting corrosion resistance, are about the same for the two alloys. Another advantage is processing quality control. A higher degree of thickness control is achievable with palladium–cobalt, providing a smoother and more uniform finish [25].

3.3.4 Plating Process

Generally, there are four methods to apply the socket contact plating: electrolytic plating, electroless plating, cladding, and hot dipping.

Electrolytic Plating

Electroplating, the most commonly used method to apply contact finishes, can be used on copper, nickel, tin, gold, palladium, and silver. In this process, metals in ionic form migrate from a positive electrode (anode) to a negative electrode (cathode) under an applied dc voltage. The metal atoms are oxidized at the anode and dissolve into the electrolyte solution; they are reduced at the cathode, causing the cathode to be coated with a thin metal layer. The electrolyte solution contains dissolved salts of the metal to be plated. Precisely controlling the composition and concentration of the electrolyte solution, solution temperature, pH value, and current density is critical to obtain a high-quality contact finish. Depending on the formula of the electrolyte solution, the composition of the contact finish can be tailored. For example, the palladium nickel can be deposited as a homogeneous alloy over a composition range from approximately 30% to over 90% palladium by weight [20]. For an alloy composition of 75 to 85% of palladium nickel, one formula is as follows:

- Palladium as Pd(NH₃)₄Cl₂, 18–28 g/L
- Ammonium chloride, 60 g/L
- Nickel chloride concentrate, 45–70 ml/L (nickel metal 8–12 g/L)
- Ammonium hydroxide to pH 7.5–9.0
- Temperature, 30–45°C
- Current density, 0.1–2.5 A/dm²

The contact plating can be overall or selective. Overall plating is the complete coverage of the contact by the contact finish. Selective plating is applied only to the contact area instead of to the entire part. Selective plating is applied to noble metal plating for cost reduction.

Factors used to examine the quality of plating are residual stress, impurities, cracking, and porosity. These manufacturing defects can greatly influence the performance and reliability of the contact interface. For example, pore corrosion
results from the attack of an adverse environment on the base metal through pores in the contact finish.

**Rack Plating**  In the rack plating method, workpieces are attached to the cross bars on a rack by permanent or replaceable tips, which are known as *workstations*. Direct current from a rectifier is picked up by hooks from a work (flight) bar that travels down the rack’s conductive backbone, enters the solution at the workpiece (cathode), and leaves at the anode. Metal ions in solution plate out on the workpiece. Rack dimensions are established so that each rack carrying parts will fit between anodes of the smallest process tank in a line. All common types of plating can be done with the rack plating method, including zinc, cadmium, tin, copper, precious metals, nickel, and chromium. The amount of current carried by the hooks and spine is determined by multiplying the current density of the plating bath by the surface area of parts on the rack.

**Barrel Plating**  Barrel plating is one of the processes to electroplate large quantities of small parts. Barrel plating received its name during the birth of electroplating in the American civil war, when parts were loaded into wooden kegs or barrels for coating. With the advent of modern technology and plastic-coated barrels resistant to harsh chemicals, barrel plating gained widespread popularity as an economic method of coating bulk parts. Nowadays it is estimated that over 70% of all electroplating facilities use barrel plating.

During the barrel plating process, bulk parts are loaded into a drum and dipped into a solution containing the substance to be plated. An electric current is passed through the parts from an electrode in the middle of the drum to electrodes on the surface of the drum. While the drum rotates, the parts continuously make and break electrical contact with each other at random locations on the surface. This random contact leads to a much more uniform coating than is possible with rack plating. However, since the parts tumble and are in continuous contact with each other, barrel plating does not produce a good surface finish. One of the primary uses of barrel plating is to enhance corrosion resistance. Due to the need for parts to tumble and rotate in the process, barrel plating is best suited for finishing large quantities of small parts. Barrel plating is not well suited to long, cylindrical parts, due to their inability to tumble randomly.

The benefits of barrel plating are summarized as follows:

- Barrel plating is extremely versatile. Unlike rack plating, it does not require special fixtures. Many different materials can be finished using the same barrel.
- Barrel plating is labor efficient because it does not require manual loading or handling of individual parts. This makes it well suited to the bulk finishing of large quantities of parts. In addition, the bulk material may remain in the same barrel for cleaning, preparation, electroplating, and drying.
- The entire inside diameter of the drum acts essentially as one large cathode, allowing a much higher level of current to flow and hence a much faster production rate compared to rack plating.
The rotation of the barrel creates a mechanical tumbling action that tends to clean the parts and increase the uniformity of the coating.

Electroless Plating  

Electroless plating involves the autocatalytic or chemical reduction of aqueous metal ions plated to a base substrate. It is a self-catalytic process, without applied electrical current or voltage. Electroless plating is seldom used for contact finishes; it is applied only when the contact shape is very complicated and electrodeposition could cause significant nonuniformity of contact finishes.

Various mechanisms have been proposed for deposition reaction in an electroless nickel plating bath. The principal reactions are

\[
3\text{NaH}_2\text{PO}_2 + 3\text{H}_2\text{O} + \text{NiSO}_4 \leftrightarrow 3\text{NaH}_2\text{PO}_3 + \text{H}_2\text{SO}_4 + 2\text{H}_2 + \text{Ni} \quad (3.4)
\]

\[
\text{Ni}^{2+} + 2\text{H}_2\text{PO}_2^- + 2\text{H}_2\text{O} \leftrightarrow \text{Ni} + \text{H}_2 + 2\text{H}_2\text{PO}_3^- + 2\text{H}^+ \quad (3.5)
\]

\[
3\text{H}_2\text{PO}_2^- \leftrightarrow \text{H}_2\text{PO}_3^- + 2\text{P} + 2\text{OH}^- + \text{H}_2\text{O} \quad (3.6)
\]

using hypophosphite ions as a reducing agent. During the process, phosphorus is codeposited in the plating layer.

Immersion plating, sometimes called displacement plating, is the deposition of a more noble metal on a substrate of a less noble and more electronegative metal by chemical replacement from an aqueous solution of a metallic salt of the coating metal. This process differs from the autocatalytic method in both mechanisms and results. Displacement plating requires no reducing agents in solution. Immersion deposition ceases, thus allowing no further displacement of the metal salts and substrate, as soon as the substrate is completely covered by the metal coating, whereas autocatalytic (electroless) plating has no limit to the thickness of deposit that is obtainable. Therefore, the immersion method can produce a coating layer with only limited thickness, typically below 5 \(\mu\)in.

Electroless plating can be used to plate nonconductive surfaces, where flow of current is not accessible and electrolytic process cannot be employed. It can deposit a uniform plating layer, even on complex shape.

Cladding  

Cladding is a mechanical process. A cladding material is bonded to a carrier material (contact) by the application of high pressure. There are three types of cladding: overlay, toplay, and inlay [3]. Overlay provides complete coverage of the substrate; toplay covers only a selected area of the substrate, and inlay is a two-stage process. Gold and nickel contact finishes are first bonded together and the base metal grooved by skiving. The gold–nickel combination is placed in the groove, and the metals are roll-bonded together. Additional heat treatment follows to enhance the interface bonding.

Hot Dipping  

Hot dipping is applied only to tin and solders, which have low melting points. Hot dipping is applied by immersing the contacts or strip metals into a molten tin or solder bath for a specific duration. Tin or solder is coated on the contacts with thickness controlled by using air knives or wipers. Hot dipping
is used to improve the solderability of socket contacts (terminals). It is usually not applied for contact area finishes, as excessive intermetallics will grow at elevated temperatures.

3.4 SUMMARY

In this chapter the materials for socket housings, contacts, and contact plating are introduced. Socket housing materials are primarily thermoplastic polymers, including polyesters, PPS, PEI, LCP, and polyimide. Applicability of these materials is assessed in terms of their flammability, mechanical strength, heat resistance, and electrical properties.

Socket contact materials are dominated by copper alloys, which provide high electrical conductivity, high mechanical strength, low stress relaxation and creep, and good corrosion resistance. To protect socket contacts from environmental attack, a thin metallic film is often coated on the surface of base metal. Contact plating also aims to maximize contact interface properties by increasing electrical and thermal conductivity and improving contact durability. Selection of either noble or non–noble metal plating is dependent on application requirements and on financial considerations. For noble metal plating, an underplate nickel is commonly applied to provide a barrier against pore corrosion and to improve contact durability.

REFERENCES

Queries in Chapter 3

Q1. Please clarify if the change made from ‘precipitation-or’ to ‘precipitation or’ is fine or if it should be left as such.
Q2. Please clarify if the term ‘Spinordal’ should be retained as such or if it should be changed to ‘Spinodal’.
4 Component Sockets for PTH Packages

A socket can be classified according to the type of package that is to be socketed. For the most part, the socket contact designs depend on how the package terminals are configured; for example, the contact designs for DIP and PGA packages share many common characteristics, while they differ substantially from the contact designs for LGA packages. In this chapter, sockets for connecting PTH packages, including DIP and PGA sockets, are discussed.

4.1 DIP SOCKETS

A dual-in-line package (DIP) is the most traditional packaging style. DIP packages are a family of rectangular IC flat packages with one row of leads on each of the two longer sides. A DIP package can be made from either ceramics or plastics. DIP leads can be made of copper alloy or nickel–iron alloy. The common lead pitch for DIP packages is 2.54 mm with a pin count from 8 to 80. The most common package widths are 0.3, 0.4, 0.6, and 0.9 in. Other hybrid widths are also possible. There are two variations of DIP packages: shrink DIP (sDIP) and micro DIP (mDIP). The only difference lies in the lead pitch. For sDIP packages, the lead pitch is 1.78 mm; for mDIP packages, the lead pitch is 1.27 mm [1]. Applications for DIP packages include linear ICs, logic ICs, DRAMs, SRAMs, microprocessors, ROMs, PROMs, and gate arrays. In the past, DIPs were the most common IC package type, but they are becoming less available with the advent of higher-density surface-mounted technologies.

4.1.1 DIP Socket Designs

DIP packages can be assembled onto a PCB through either wave soldering or through socketing. In 2002, over 60% of DIP packages were socketed onto PCBs. Unlike a permanent solder joint, socketing provides many design, manufacturing, and reliability advantages. With limited I/Os, high-contact normal forces can be applied, ensuring excellent contact performance and reliability. Furthermore, a surface-mounted DIP socket provides a buffer to fit the traditional plated-through-hole (PTH) packages in today’s surface-mounted era.
Detailed design configurations for DIP sockets are specified in MIL-STD-83734, including the dimensions of socket and contact, contact terminations, visual polarization, ramped edge, standoff, and so on. MIL-STD-83734 covers DIP sockets from 6 to 64 pins. Besides socket contact design, many other factors must be taken into consideration. A socket must provide a standoff from the PCB after assembly to allow flux to be cleaned from the board after soldering. A minimum standoff of 0.15 in. is usually required. During assembly, the socket body should shield the contacts from entering the contact cavity by capillary action (wicking). A closed-bottom design is generally utilized to achieve this function. A socket should have pin 1 identification to assist the orientation of packages, usually with an indentation on the socket body. To facilitate easy insertion of a DIP package, a socket contact design must provide features to guide lead insertion and avoid damage to package leads due to incorrect insertion. Faulty insertion of package leads causes overstress and even destruction of socket contacts. A closed-entry design and other overstress protection features are also desirable to protect socket contacts. To facilitate solder-joint inspection and repair after assembly, an open-frame structure may be designed for the socket body, with knock-out bars in the body center.

Per MIL-STD-83734, there are three types of socket body designs: solid body without mounting holes, open frame, and solid body with mounting holes. The three configurations are shown in Figure 4.1 for six-lead DIP sockets (dimensional data not shown).

Figure 4.1 Configurations of DIP sockets per MIL-STD-83734: (a) DIP socket configuration type 1: solid body without mounting holes; (b) configuration 2: open frame; (c) configuration 3: solid body with mounting hole.
Design flexibility adds much versatility to the DIP socket inventory. The sockets can be designed as either a PTH or as a surface-mounted type. Surface-mounted capacitors and a circuit assembly can be built in to create a full line of integral decoupling. Socket housing can be designed as a removable type (the contact carrier can be removed after assembly). Socket contacts can also be press-fitted into a PCB without soldering. A zero-profile solderless socket can be created by press-fitting discrete socket contacts completely into the plated through-hole of a PCB. Four contact designs are discussed here for DIP sockets: dual-beam contact, single-beam contact, multifinger contact, and ZIF contact. The dual-beam and multifinger contact designs are the most popular.

4.1.2 Dual-Beam Contact Design

The dual-beam contact design provides double-face contacts between the package leads and the socket contacts, enlarging the contact area and ensuring a low and constant contact resistance. Of the two beams, one is usually designed to be active; deflection of the contact spring causes the exertion of contact normal forces. The other beam is designed to be more passive. Figure 4.2 shows the DIP sockets with side-bearing stamped contacts. In another type of dual-beam contact design, the contact springs are symmetrically distributed [2], as shown in Figure 4.3. Contact normal forces are exerted due to equivalent deflection of both contact springs.

There are two ways of inserting DIP leads into the socket contacts. Edge-bearing contacts are designed to bear contacts on the shear edges of package leads, so narrower, lower-cost sockets can be achieved. By bearing on a larger surface

![Figure 4.2](attachment:image.png)  
(a) DIP sockets; (b) close-up of the contacts.
of the DIP leads, the side-wipe contact design provides better electromechanical performance. Longer usable life can be achieved since the configuration makes contact on the wide, smooth surface and damage to the contact plating can be minimized. Furthermore, side-bearing contacts provide better device retention than do edge-bearing contacts [2].

### 4.1.3 Single-Beam Contact Design

Figure 4.4 shows a DIP socket with single-beam contact design. The contacts are made by pressing the package leads against the socket housing wall. Compared to dual-beam contact design, the single-beam contacts are much less expensive. However, since the contact area is restricted to one side of the package leads, the contact resistance may be higher and long-term reliability may be reduced. To achieve comparable contact resistance, a larger contact normal force should be expected.
4.1.4 Multiple-Finger Contact Design

Another commonly used DIP socket contact is the multifinger contact, also called a cylindrical contact. The contact design consists of two pieces: a multifinger contact (clip) and a contact shell or sleeve in which the multifinger contact clip fits. The number of fingers can be two, three, four, five, or six, with the four-finger design most common. Figure 4.5 shows multifinger contacts.

The multifinger clip is usually made of beryllium copper, which is stamped to its final configuration; since it does not contact the package lead directly, the contact sleeve is usually made of brass, which performs worse than beryllium copper but is much cheaper. However, the contact sleeve is a screw-machined part, a much more expensive process than stamping. Screw machining contributes significantly to the total price of the contacts, making them much more expensive than dual-and single-beam contacts. Moreover, although high reliability can be assured with multifinger clips, moisture and dust can be entrapped, causing electrical interference and corrosion if the contact receptacle is designed with a closed bottom.

Depending on the contact design, the multifinger contact can accommodate package leads with different configurations, such as round pins, rectangular pins, and square wrap posts, and with a range of pin diameters. Figure 4.6 demonstrates the finger configurations after inserting rectangular, square, and round contacts. A compliance factor ($\delta$) is defined to specify the reconfigured operating range after initial insertion of the largest permissible mating pin [3]. For example, if a contact has an initial operating range from 0.032 to 0.047 in. in diameter, and a compliancy of 0.010 in., after insertion of a 0.047 in. pin, the contact size is enlarged, and the minimum pin acceptance becomes 0.047 in. − 0.010 in. = 0.037 in. Thus, the new operating range is 0.037 to 0.047 in. [3].

The insertion of package pins with different diameters causes different contact spring deflection, so different contact normal forces are exerted on the contact interface, and different insertion and extraction forces are required. An operating range of mating pin diameters can be selected, corresponding to a range of contact normal forces and insertion and extraction forces.

![Figure 4.5 Multifinger contact design. (From Ref. 3.)](image-url)
4.1.5 Low-Force Contact Design

As specified above, the insertion–extraction force increases with an increase in mating lead diameter; accordingly, for a specific contact design, an operating lead-diameter range can be defined. A lower insertion force can result from a smaller lead diameter. A low insertion force reduces the contact wear and thus improves contact durability. However, a low insertion force is accompanied by a reduction in the contact normal force, thus potentially sacrificing contact performance and reliability. In compensation, a large contact area is usually employed to reduce contact resistance and to provide electrical and mechanical stability. Other techniques may also be used to hold down DIP packages mechanically against shock and vibration.

4.1.6 ZIF Contact Design

One way to exert a large contact normal force without causing contact wear due to lead insertion and extraction is the zero-insertion-force (ZIF) design. The ZIF design features movable contacts and a mechanical actuator (or cam). Before insertion of a DIP package, socket contacts are in the open position; when the package leads are inserted, the actuator closes the socket contacts, which applies a normal force to retain the leads. To remove the package, the process is simply reversed. This not only improves contact durability but also facilitates package insertion and extraction and avoids damage to the package leads. However, this design is more expensive than any other type of socket design; furthermore, the addition of a mechanical actuator requires more real estate and a high profile. Contact reliability is also reduced if there is insufficient wiping action during contact mating and unmating. The ZIF design is used primarily for component test and burn-in.

A DIP socket with a ZIF contact design is shown in Figure 4.7. The actuation lever in the vertical orientation indicates that the socket contacts are in the open position; pushing down the actuation lever clockwise causes the contacts to close.

4.1.7 Insertion and Extraction Tools

DIP packages can be assembled into sockets manually or automatically. Except for ZIF designed sockets, a special tool kit is typically needed to do the assembly.
The tools help exert an insertion or extraction force on the package, while keeping the force evenly distributed, thus preventing bent leads and damaged contacts.

4.2 PGA SOCKETS

The pin grid array (PGA) package is a high-density through-hole chip package in which the connecting male pins are located on the bottom in concentric squares. PGA packages exist in both plastic and ceramic forms, with a standard pitch of 2.54 mm. The PGA package pins can be designed in two arrangements: in matrix elements or in staggered rows. In the latter, also called an interstitial pin grid array (IPGA), pin rows are typically staggered by 1.27 mm and the pitch between rows is 1.27 mm. For IPGAs, the pitch can be written as $1.27 \text{ mm} \times 2.54 \text{ mm}$. A simple calculation indicates that higher pin density can be achieved through the IPGA design than with the standard pin arrangement; thus, for very high I/O counts, IPGA design reduces the package size. PGA packages are particularly designed for modern microprocessors that have many terminals, such as the Intel Pentium, Celeron, and the AMD Athlon.

4.2.1 PGA Socket Designs

Although they belong to the same category of sockets, PGA sockets must meet more stringent requirements than DIP sockets. High I/O counts and density, a versatile footprint, and small pin diameter pose a challenging task for PGA socket design. High I/O number could require an upper limit on insertion and extraction forces, since excessive force makes it very difficult to mount or de-mount PGA
packages. An operating force range has been recommended, depending on the pin count, as follows [3]:

- **Low force** (recommended for pin counts up to 150): typical insertion force 50 g per pin, typical extraction force 30 g per pin
- **Ultralow force** (recommended for pin counts up to 250): typical insertion force 25 g per pin, typical extraction force 15 g per pin
- **Ultralight** (recommended for 250 pins or more): typical insertion force 12.5 g per pin, typical extraction force 7.5 g per pin

If the pin count is too large, even a small insertion or extraction force may become excessive, causing mounting difficulties and damage to package pins. In such cases, ZIF sockets are needed.

One complexity for PGA socket manufacturers and customers is the large inventory of PGA pin footprints. Even for a specific terminal number, there are a variety of footprint configurations to choose from. The footprint can be in the standard or interstitial arrangement; the pins can be in a full array or with an open window. For PGA packages with a large-volume design, such as computer microprocessors, the I/O count number and footprint patterns have been conventionalized to facilitate custom selection. Figure 4.8 shows some footprint patterns for PGA sockets commonly used to mate microprocessors. Conventional terms are used to represent these socket designs (socket 1, socket 2, socket 3, PGA 370, etc.). Each is associated with a specific pin count number and footprint

![Some footprint patterns for PGA sockets.](image-url)
COMPONENT SOCKETS FOR PTH PACKAGES

pattern. Table 4.1 lists the corresponding I/O number and cross-references. Some of them are interchangeable; for example, sockets 2 and 3, and sockets 5 and 7, can be used to mount the same type of PGA packages. Socket 8 is a hybrid type, with both a standard pin footprint arrangement and an interstitial arrangement.

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<tr>
<th>TABLE 4.1</th>
<th>Customized Terms, Related Pin Counts, and Cross-References</th>
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*Source: Ref. 5.*
The polarizing features for PGA sockets can vary: chemfered corner, locating pins, or embossed marking on the socket frame. Sometimes, a PGA substrate has lead standoffs at various locations. A PGA socket should have corresponding counterbore locations. PGA socket contacts can use a dual-beam contact design, multifinger contact design, Fuzz Button contact design, or ZIF contact design. These will be described below.

4.2.2 Dual-Beam Contact Design
The dual-beam contact design for PGA sockets is similar to the side-bearing contact design for DIP sockets. The PGA pins are inserted into symmetrically distributed contact cavities. However, to reduce the insertion and extraction forces, the contacts are designed with staggered heights. At the initial insertion stage, only a fraction of the socket contacts are mated; as the full deflection is achieved for these contacts, the remaining contacts are mated.

4.2.3 Multiple-Finger Contact Design
The multifinger contact socket has a multifinger beryllium copper contact inserted into a brass machined shell. Figure 4.9 shows a PGA socket with contact shells embedded in the plastic housing. The contact reliability is ensured by the multiple contacts. By tailoring the contact cavity diameter and contact geometry, a range of insertion and extraction forces can be produced. However, the multifinger contact design is not applicable for ZIF insertion and extraction.

4.2.4 Fuzz Button Contact Design
The Fuzz Button contact is especially designed for surface-mounted packages, such as BGAs, LGAs, and CSPs (chip-scale packages). Tecknit applied this technology to making PGA sockets. The proprietary Fuzz Button contact pins are

![Figure 4.9 PGA socket with contact shell arrays.](image-url)
made from a single length of gold-plated wire. The wire is compressed into a cylindrical shape to produce contact elements. Connection is made to each individual button upon insertion of the pin grid device, and a gentle piping action ensures optimum pin contact [6].

Figure 4.10 schematically shows the insertion of a PGA package into Fuzz Button sockets. Fuzz Button design provides many advantages over traditional contact designs. It offers reduced signal path length, and thus low impedance and inductance. Fuzz Button contacts are easily replaceable as required, and costs for test and burn-in can be reduced by replacing a single contact instead of the entire socket. The main drawback for this design is that buttons may fall out during the package insertion process.

4.2.5 ZIF Contact Design

The large pin count of PGA packages requires a ZIF design for easy, safe, and reliable insertion of packages. The ZIF contact design features movable dual-beam contacts. The contacts can be kept in either the open or closed positions by built-in actuation mechanisms, which can be a spring-loaded plastic socket cover, or a free-moving cam. The actuation tool can be affiliated with the sockets or an external tool. For the single-lever actuation, no external tool is required; simply lowering or raising the actuation handle will cause package leads to mate or unmate. However, the actuation handle takes more space. With screwdriver actuation, no extra space is occupied.

4.2.6 Insertion and Extraction Tools

Tools are needed for PGA package mounting and demounting, except for some ZIF designs. Tools apply insertion and extraction forces, prevent uneven insertion and extraction and consequent bending of package pins, and actuate the actuation mechanism.

Actuation becomes much simpler with ZIF socket design. For screwdriver-actuated ZIF sockets, a screwdriver is the only tool needed. Since the tool action is in a horizontal direction rather than being transmitted vertically to the PCB, the PGA packages and the PCB are protected from mating and unmating forces.
Before inserting a package, it is essential to make sure that the orientation of the package is correct. Polarization features or markings guide the proper insertion of a package into a socket.

4.3 SUMMARY

Contact designs for DIP and PGA sockets are varied. For DIP sockets, the contact technology can be single-beam contact design, dual-beam contact design, multifinger contact design, or ZIF contact design. For PGA sockets, the contact technology can be dual-beam contact design, multifinger contact design, Fuzz Button contact design, or ZIF contact design. These sockets can be press-fitted or wave-soldered to the plated holes of a PCB, or surface mounted onto a PCB through the reflow process, transforming a PTH package into a surface-mounted package.

To obviate the difficulties of package insertion and extraction, different force ranges can be selected, depending on the package pin count. Low-insertion-force (LIF), ultralow-insertion-force, and zero-insertion-force (ZIF) designs are more common for PGA sockets than for DIP sockets because of their high pin count.

To facilitate package orientation and avoid faulty insertion, sockets incorporate polarization features such as notches, locating pins, and embroidered markings on the socket frame. These features must be identified before mounting packages.

Selection of a socket will depend on cost, performance, reliability, and assembly. Generally, a ZIF socket is the most expensive of all sockets, but a ZIF design offers the advantages of easy insertion and extraction and protection of package terminals and socket contacts from damage. A single-beam contact design may be less reliable than a dual-beam design, but it offers a lower material cost.

REFERENCES

6 Component Sockets for Gull-wing Packages

The gull-wing-leaded package family includes the small-outline package (SOP) and the quad-flat package (QFP). The SOP package is a plastic-molded leadframe-based package with leads extending from two sides of the package in the shape of a gull wing. The typical pitch for SOP is 1.27 mm, and the typical lead count can be 8, 14, 16, 20, 24, 28, 32, 40, or 48. For shrink SOP (SSOP) and thin SOP (TSOP), the lead pitch can be 1.27, 0.8, 0.65, or 0.5 mm.

The quad-flat pack (QFP) is similar to the SOP except that its leads extend from four sides of the package. The typical pitch for QFPs is 0.4, 0.5, 0.65, 0.8, or 1.0 mm. The typical lead count can be from tens to several hundreds. The most common pin counts for plastic QFPs (PQFPs) are 84, 100, 132, 164, and 196. For the PQFP, four bumps are usually extended from the four corners of the package to facilitate alignment of the package in a socket and to protect its delicate leads. This type of package is also called a bumper-packed QFP.

The SOP and QFP lead configurations require a zero-insertion-force (ZIF) design of socket contacts. Typical contact technologies include single-pin, dual-pin, Fuzz Button, cantilever, S-type, and microstrip contact. These contact designs usually utilize socket housing to apply the contact normal force synergically.

6.1 SOCKET DESIGNS

To protect the delicate leads of gull-wing-leaded packages, ZIF must be ensured in the design of socket contacts. ZIF is usually achieved through the synergic function of the socket housing, in which it may act as a generator of contact normal forces or as a built-in actuator. There are various ways to place a normal force on the gull-wing leads. Figure 6.1 shows some possible positions where a contact interface can be constructed: shoulder, tip, foot, or ankle of a lead, or at both sides of a lead foot.

6.1.1 Shoulder Contact Design

Figure 6.2 shows an SOP socket with a top-actuation ZIF mechanism. The contacts are designed to pinch package leads on the shoulder area near the package
body. This design aims to protect lead integrity and solder tail compliancy. The contacts are usually designed with an easy hold-down cap. This top-actuation ZIF mechanism helps to deal with a large lead count and to facilitate easy package insertion and extraction. At the end of travel, a locking mechanism will be activated to hold contacts in position.

### 6.1.2 Tip Contact Design

A schematic drawing of a lead-tip contacting socket is shown in Figure 6.3. For this design, the body and leads of a package are supported by the socket housing, with the contact tips touching the socket contacts. A top actuation mechanism is utilized to ensure zero insertion and extraction force.

Figure 6.3 Schematic drawing of a lead-tip contacting socket. (From Ref. 1.)
6.1.3 Foot Contact Design

The lead-foot contact design is the most pervasive design style for QFP and SOP sockets. The socket contacts touch package leads from the bottom, and contact forces are exerted through the socket housing from the top. Representative contact designs include cantilever spring, S type, Fuzz Button, and microstrip contacts. The cantilever contact design is the most traditional style (Figure 6.4), but it is being replaced by other contact designs to reduce signal propagation delay.

**S Contact**  The S-type contact design is a surface-mounted socket with contacts formed in the shape of the letter S. The contacts are embedded in an elastomer matrix, the compression of which provides contact biasing forces [2]. Compared with the traditional cantilever contacts, S-type contacts provide a shorter electrical length and thus improve electrical performance. Figure 6.5 shows the S-type contact design versus a cantilever contact design.

**Fuzz Button Design**  Figure 6.6 shows a socketing configuration for the Fuzz Button contact design [3]. This design consists of two parts: a Fuzz Button and a hard hat. The Fuzz Button, made from a wire of beryllium copper plated with gold, acts as a miniature spring, while the gold-plated hard hat provides a solid contact base for interconnection to the gull-wing leads. Upon compression by the socket positioning lid, the Fuzz Buttons are compressed and interconnection can be constructed between the hard hats and package leads.
Microstrip Contact Design  Figure 6.7 shows a schematic of the microstrip contact design. Upon assembly, the microstrip contacts lie flat against the PCB pads. Typically, the microstrip contacts add only 0.178 mm of signal path to the component. Minimal signal loss in high-bandpass applications is assured for this contact design due to the short signal path.

6.1.4 Ankle Contact Design

The lead-ankle contact design features a contact interface on the inner side of a package lead, as demonstrated in Figure 6.8. To simplify the handling and insertion of QFP packages, a two-piece socket housing has been designed. Spring latches in the four socket corners secure the cover to the socket housing. The socket cover not only exerts pressure on the contact interface, but also separates and protects package leads and ensures proper lead-to-contact registration. A
6.1.5 Dual-Pinch Contact Design

Figure 6.9 shows a schematic diagram of the dual-pinch contact design. The contact interfaces are constructed at both the top and bottom of a package lead foot. A top-actuation mechanism is built in to the socket housing to facilitate zero force insertion.

6.1.6 Insertion and Extraction Tools

SOP and QFP sockets involve ZIF design, and thus in most cases, no special tools are needed to insert and extract packages. Before inserting a package, polarization features must be recognized. Common polarization features are chamfered corners, embossed (or dented) marks, and positioning pins.
6.2 SUMMARY

In this chapter, socket designs for mounting gull-wing-leded surface-mounted packages are discussed. Because of the configuration of package leads, zero-insertion force (ZIF) is required to protect delicate package leads. Contact designs include lead-shoulder, lead-tip, lead-foot, and lead-ankle contacts. Among these, the lead-foot contact design is the most common. The contact interface can be constructed either on the bottom of a lead foot with retention pressure from the socket housing, or on both sides of the lead foot by clipping contact pinches.

REFERENCES

7 Component Sockets for BGA Packages

The demand for high I/O density has promoted the popularity of BGA packages. Unlike peripheral leaded packages, BGA packages contain arrays of solder balls attached to the bottom of the packages. The BGA package family can be categorized according to either packaging material or assembly style. A BGA package can be a ceramic BGA (CBGA), a metal BGA (MBGA), a tape BGA (TBGA), or a plastic BGA (PBGA). Among these, PBGA is a cost-effective solution when pin count is between 250 and 500. The BGA family can also be grouped according to package size or pitch between solder balls. Fine-pitch BGA (FP-BGA) or micro-BGA (μBGA) is a subclass of chip-scale packages (CSPs) with pitches less than 1.0 mm, with typical pitches of 0.8, 0.75, 0.65, 0.5, or even 0.25 mm. For CSP packages, the solder ball can be as small as 0.3 mm. Super-BGA is a low-profile, high-power BGA package type, with package sizes from 13 mm × 13 mm to 45 mm × 45 mm, I/O counts from dozens to over 600, and a typical pitch of 1.27 mm.

In this chapter, IC component socket designs for mounting ball grid array packages (BGAs) are introduced. The fine pitch and high I/O density, as well as plasticity and oxidation of BGA solder balls, pose challenges to socket contact design. These challenges in turn, lead to a variety of solutions, especially to meet demands for burn-in and electrical testing.

7.1 SOCKET DESIGNS

A number of issues need to be considered for BGA socket design. Socketing a BGA package is more critical than socketing other types of packages, as the contact interface is constructed of solder balls instead of more rigid leads or pins. The greatest challenge is to avoid damage to the solder balls while maintaining a stable contact interface. Solder balls are susceptible to plastic deformation, especially at high temperatures and high forces; excessive load and heat may cause permanent deformation of solder balls, which may consequently result in contact failure or assembly difficulties, especially when deformation occurs on the bottom of the solder balls [1].

IC Component Sockets, by Weifeng Liu and Michael Pecht

100
Die

No-damage zone (NDZ)

**Figure 7.1** Schematic diagram of a no-damage zone (NDZ). (From Ref. 1.)

Deformation on the bottom of solder balls could degrade coplanarity of solder balls, imposing difficulty in the soldering process and causing imperfect solder-joint formation. Moreover, contacting the bottom of solder balls can cause contamination entrapment, affecting the solderability of solder balls in the final assembly. A no-damage zone (NDZ) is conventionally set aside to protect the bottom of the solder balls from deformation [1]. An NDZ is shown in Figure 7.1.

The fine pitch and small diameter of solder balls pose another challenge. For traditional BGA packages with a grid pitch of 1.27 mm and a solder ball diameter of 0.75 mm, it may not be a difficult task for socket contact designers. However, when the packaging technology shifts toward fine pitches, it proves formidable. Fine pitches of solder balls (as low as 0.25 mm) and tiny microballs (as small as 0.3 mm) push conventional contact designs to their limit. Pitch reduction of solder balls causes a decrease in package size. CSPs can be as small as 5 mm × 5 mm, with a thickness as low as 1 mm (including the solder ball). The small form factor of CSPs adds to the difficulty of package handling, which needs to be considered in socket design.

Another challenge for socket contact design is the oxidation of solder balls. A metallic contact should be constructed by piercing the oxide layer of solder balls or through wipe action to reduce contact resistance. Contact piercing and wipe action should be mild to minimize damage to the solder balls. However, even though metallic contacts can be constructed, reoxidation of solder balls remains a concern.

To summarize, the following factors need to be considered in a BGA socket design:

- Avoid damage to solder balls
- Control load pressure precisely
- Penetrate the oxide layer of solder balls
- Stay out of the no-damage zone
- Use zero insertion and extraction force
- Achieve low contact force
- Maintain high mechanical precision
TABLE 7.1 Contact Technologies for BGA Sockets

<table>
<thead>
<tr>
<th>Position of Contact Interface</th>
<th>Contact Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom contact design</td>
<td>Cantilever-spring contact</td>
</tr>
<tr>
<td></td>
<td>Wire-in-elastomer contact</td>
</tr>
<tr>
<td></td>
<td>Fuzz Button contact</td>
</tr>
<tr>
<td></td>
<td>DendriPlate contact</td>
</tr>
<tr>
<td></td>
<td>Plated metal bump on flex contact</td>
</tr>
<tr>
<td></td>
<td>Etched silicon pocket contact</td>
</tr>
<tr>
<td></td>
<td>Conductive epoxy bump contact</td>
</tr>
<tr>
<td>Single-sided contact design</td>
<td>S-type contact</td>
</tr>
<tr>
<td></td>
<td>Wiggle-wire contact</td>
</tr>
<tr>
<td>Double-sided contact design</td>
<td>Y contact</td>
</tr>
<tr>
<td></td>
<td>Cantilever bifurcated contact</td>
</tr>
<tr>
<td></td>
<td>Tweezer contact</td>
</tr>
<tr>
<td></td>
<td>Dual-pinch contact</td>
</tr>
<tr>
<td></td>
<td>Dual-plate contact</td>
</tr>
<tr>
<td>Multiple-point side contact</td>
<td>Four-point crown contact</td>
</tr>
<tr>
<td>Ringed contact</td>
<td>Ring pad on flex contact</td>
</tr>
</tbody>
</table>

BGA socket designs include cantilever spring, pinch, beam, Fuzz Button, metal-bump-on-flex, and conductive elastomer contacts. Table 7.1 lists the key designs in terms of contact position, categorized according to where the contact interface is constructed. Some contact technologies are compared briefly in Table 7.2.

Due to plasticity, oxidation, and high cost of solder balls, BGA sockets are used predominantly for functional test and burn-in applications. Test sockets may undergo more insertions and extractions than burn-in sockets. However, burn-in sockets need to endure a higher temperature for much longer durations. For test sockets, Fuzz Button and Pogo contacts are more commonly used; for burn-in sockets, beryllium–copper spring contacts are usually a better choice. Test and burn-in sockets are compared in Table 7.3.

7.1.1 Solder Ball Bottom Contact Design

Cantilever Contact Design  The cantilever-spring contact is the most traditional design for BGA sockets. The socket contacts are held in a nest that is part of the socket body, which also helps align BGA packages. The contact pads are supported by bent metallic springs to ensure high compliance and contact tolerance. This contact design may have a solderable tail that is wave-soldered onto the PCB. Figure 7.2 shows a BGA socket with the cantilever contact design. The socket design features a clamshell structure, which is favored for low-volume manual load and unload. After a BGA package is put into a socket, closing the latch
TABLE 7.2 Comparison of BGA Socket Contact Technologies

<table>
<thead>
<tr>
<th>Contact Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever spring contact</td>
<td>Conventional technology</td>
<td>Limited pitch capability</td>
</tr>
<tr>
<td></td>
<td>Low force relaxation</td>
<td>Long contact path</td>
</tr>
<tr>
<td></td>
<td>Replaceable contact</td>
<td>Contacting solder ball bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No penetration action</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z-axis loading</td>
</tr>
<tr>
<td>Fuzz Button contact</td>
<td>Replaceable contact</td>
<td>No wipe action due to straight compression</td>
</tr>
<tr>
<td></td>
<td>Short electrical path</td>
<td>No penetration action</td>
</tr>
<tr>
<td></td>
<td>High-frequency application</td>
<td>High normal force</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contact force relaxation</td>
</tr>
<tr>
<td>Wire in elastomer contact</td>
<td>High compliance</td>
<td>No single contact replacement</td>
</tr>
<tr>
<td></td>
<td>Fine-pitch capability</td>
<td>Elastomeric creep or stress relaxation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solder ball bottom contact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z-axis loading</td>
</tr>
<tr>
<td>Tweezer contact</td>
<td>Penetration through the oxide layer</td>
<td>Long electrical path length</td>
</tr>
<tr>
<td></td>
<td>Double-sided contact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal contact force</td>
<td></td>
</tr>
<tr>
<td>Crown contact</td>
<td>Multipoint contact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine-pitch capability</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 7.3 Comparisons of Requirements on Test and Burn-in Sockets

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Test Socket</th>
<th>Burn-in Socket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertions</td>
<td>100 k to 1 million</td>
<td>10,000 typical</td>
</tr>
<tr>
<td>Electrical</td>
<td>High frequency (GHz range)</td>
<td>Low frequency (&lt;250 MHz)</td>
</tr>
<tr>
<td></td>
<td>Low inductance (&lt;=4 nH)</td>
<td>High inductance (5-13 nH)</td>
</tr>
<tr>
<td>Production method</td>
<td>Machined</td>
<td>Injection molding</td>
</tr>
<tr>
<td>Contact technology</td>
<td>Pogo, particle interconnect, Fuzz Button</td>
<td>Stamped or formed BeCu spring contact</td>
</tr>
<tr>
<td>Device insertion time</td>
<td>3 s to 5 min</td>
<td>8-1000 h</td>
</tr>
<tr>
<td>DUT board type</td>
<td>Surface mounted</td>
<td>Through-hole</td>
</tr>
<tr>
<td>Typical order size</td>
<td>1-50 sockets</td>
<td>300-20k sockets</td>
</tr>
<tr>
<td>Typical cost (each)</td>
<td>$1000-$6000</td>
<td>$4-$200</td>
</tr>
<tr>
<td>Market size</td>
<td>$80 M-$100 M</td>
<td>$250 M-$300 M</td>
</tr>
</tbody>
</table>

Source: Ref. 1.

will align solder balls to their positions automatically and apply simultaneous contact pressure.

**Fuzz Button Contact Design** The Fuzz Button contact design consists of two parts: a hard hat and a Fuzz Button [2]. The Fuzz Button is made from a wire of
beryllium copper plated with gold, which is randomly routed into the shape of a cylinder. The Fuzz Button acts like a miniature spring, providing much contact compliance. The hard-hat tip is encaved to hold the entire bottom of the solder ball, ensuring "perfect" mating.

**Wire-in-Elastomer Contact Design** Elastomeric materials with metal wires embedded in the polymer matrix are conductive in the thickness direction and are being used to provide high-density interconnections between packages and PCBs. The metal wires can be gold, steel, or brass; the latter two are gold- or nickel-plated. The wires can be used singly or in a bundle. Figure 7.3 shows an IBM elastomeric design using gold wires as the conducting medium.

The gold-wire-embedded system provides z-axis interconnection through a clamping fixture. When the screw bolts are driven in, elastomers are compressed to exert a constant contact pressure. Through the alignment pins, solder balls can be aligned to ensure proper registration. Elastomers, especially silicone rubbers, are known for their high compliance, which ensures minimum damage to solder balls during package engagement and also helps accommodate noncoplanar solder balls. Gold wires exhibit high electrical and thermal conductivity and inertness to environments. Less than 50 g (typically, 12 to 50 g) per contact is usually applied.
to achieve low contact resistance. One of the advantages of this elastomeric-contact design is its fine pitch and high I/O capability; BGA sockets for very large modules (e.g., 44 mm × 44 mm, 1100 I/Os) and for modules with high I/O densities and pitches of less than 20 mils were developed. This contact design can be used for production, test, and burn-in applications. It is said to be capable of performing burn-in testing at temperatures higher than 150°C for a prolonged time in air. However, the elastomeric materials susceptible to creep and stress relaxation, and high temperature will accelerate these processes.

**DendriPlate Contact Design** Although palladium dendrite plating has been in use at IBM since the 1970s, it was not until 1990 that it was applied to the connector system [4]. A dendrite is a plating phenomenon that results in a needlelike structure attached to the base metal. Dendrites can be plated on any surface that is electrically conductive. The IBM Flexiposer contact comprises an interposer using a carrier (FR4 or polyimide) with copper pads on both sides. Pads are connected with a plated through-hole and are plated with dendrites. During contact engagement, the electroplated palladium dendrites can penetrate the oxide layer or film contamination, providing a gastight, reliable, and wipeless metallic contact interface.

**7.1.2 Single-Sided Contact Design**

**S-Type Side Contact Design** Figure 7.4 shows the Johnstech S-type side-contact design. The metallic contacts, in the shape of the letter S, are embedded through an elastomeric sheet. Although the short metallic contacts are very rigid, contact compliance is provided by the elastomer sheet to accommodate nonplanar solder balls and maintain a stable contact interface. The contact interface is constructed at the lower hemisphere of solder balls but outside the no-damage zone.

**Wiggle-wire Contact Design** Figure 7.5 shows a schematic of the wiggle-wire contact design. It features zero-force package insertion and through-hole socket assembly. After package insertion, the socket contacts touch the solder balls at the upper hemisphere without z-axis loading. Solder balls may be backed up
by socket housing walls for pressure balance. A T-bar entrapment secures the
contacts in the socket housing and prevents the contacts from assuming bad
positions, thus preventing excessive force.

Before a BGA package is loaded into a socket, the cam handle has to be
rotated to open the socket contacts. Then the BGA package is placed into the
socket with the correct orientation. The cam handle is rotated again to close the
contacts so that the solder balls are mated. Unloading a BGA package from a
socket requires that the socket contacts be opened first, then the package picked
up using vertical force.

7.1.3 Double-Sided Contact Design

Y Contact Design  Figure 7.6 shows an open-top BGA socket utilizing a Y con-
tact design. This contact design provides double-sided contacts without touching
the bottom of the solder balls. A top actuation design facilitates manual or auto-
matic insertion of packages. The insertion of solder balls is accompanied by a
wipe action to penetrate the oxide layer.

Cantilever Double-Sided Contact Design  Figure 7.7 shows a diagram of the
cantilever double-sided contact design. This design is very similar to the cantilever-
spring design, except that the contacts are bifurcated at the top in order not to touch
the bottom of the solder balls [8]. The contacts are spring-loaded for high compli-
ance and minimization of damage to solder balls. They are usually replaceable to
minimize cost.

**Tweezer Contact Design**  The tweezer contact design utilizes two blade-type con-
tacts touching the opposite sides of the solder ball, as demonstrated in Figure 7.8.
The contacts touch the upper hemisphere of solder balls using horizontal forces,
thus avoiding z-axis compression on the package and minimizing coplanarity error
and solder ball damage. The tweezer contacts touch solder balls at a 45° angle,
leaving a larger space for contact movement on a standard footprint-array pack-
age. The contact ribs can pierce the oxide layer with a controlled force to ensure
a metallic contact interface.

**Dual-Plate Contact Design**  The dual-plate contact design features double-sided
contact on the upper hemisphere of the solder balls. Figure 7.9 shows the dual-plate
contact design. This double-arm contact provides balanced forces, reducing the shear stress on the solder ball. Moreover, the contact arms exert contact forces in a downward direction, enhancing package retention.

### 7.1.4 Four-Point Crown Contact Design

The four-point crown contact design features double-ended, spring-loaded contacts. The helical coil springs, kept in a metallic shell, are designed to provide a compliance of contacts, minimizing mechanical impact on solder balls and absorbing contact noncoplanarity. The contacts are made of four tips distributed symmetrically in a circle, piercing the outer portion of the solder balls while leaving the critical apex of solder balls untouched. Figure 7.10 shows a four-point crown contact design socket, contact probes, and contact positions. This design, also called a *Pogo contact*, is fine-pitch applicable. Sockets with pitches of 0.5, 0.65, 0.75, 0.80, 1.00, and 1.27 mm are in production. However, z-axis compression is required for construction of contact interfaces, causing stresses in components. By providing a four-point contact, contact pressure can be reduced to minimize stresses and achieve low contact resistance at the same time. The socket contacts are replaceable, greatly extending the life of sockets and reducing the cost of ownership.
7.2 SUMMARY

The oxidation, softness, and plasticity of BGA solder balls pose a challenge for socket design. A variety of solutions have been taken to meet the demand for a stable contact interface with low contact resistance and minimization of damage to solder balls. Damage to the bottom of solder balls could cause noncoplanarity of solder balls and consequently, result in low-quality solder joints during the final assembly. Thus, a no-damage zone (NDZ) is set aside conventionally, and contact at the NDZ should be avoided to protect the bottom of solder balls from damage and deformation. Socket contacts need to be designed to touch the upper hemisphere of solder balls and exert a horizontal or even downward stress on them instead of z-axis compression, as do tweezer and dual-plate contact designs.

REFERENCES

8 Component Sockets for LGA Packages

LGA packages are similar to ball grid array packages, but with flat pads on the bottom of the devices instead of solder balls. LGAs are either ceramic packages (CLGAs) with alumina or glass ceramic substrates and aluminum lids, or plastic packages (PLGAs) with laminate substrates. LGA pads are usually plated with a minimum 30 µin. of gold.

The introduction of LGAs aims to achieve higher pin counts with smaller packages. The increased functionality of electronic devices has caused a tremendous increase in the I/O count of packages. Figure 8.1 presents the I/O trends for high-performance packages as well as cost/performance packages, predicted by the Semiconductor Industry Association (SIA). To account for these trends, the package I/Os tend to be relocated from the periphery to the package bottom. Pin grid array (PGA) packages were the earliest packages that had I/O pins attached to the package bottom. However, as through-hole components, PGAs are not suitable for fine-pitch applications (pitch ≤ 1.0 mm). Therefore, the I/O count is limited for PGA packages, typically below 1000 I/Os. Furthermore, because of long pins, the electrical performance of PGA packages cannot meet more demanding electrical requirements.

Another package style is ball grid array (BGA) packages, with solder balls attached to the package bottom. This was discussed in Chapter 7. BGA packages provide benefits of high I/O density, fine-pitch capability, ease of assembly, and low cost. However, for packages with high I/O count and large size, the CTE mismatch between the die, package substrate, and circuit board raises a serious concern for solder-joint reliability. Therefore, the I/O count of BGA packages is most commonly in the range 50 to 500. The maximum pin count for BGA packages, as reported, is the IBM hyperBGA with an I/O count of 1657 [2]. Furthermore, assembly yield and rework also raises concerns for using high I/O BGA packages.

Column grid array (CGA) packages attracted much attention because of their high I/O and fine-pitch capability. The high standoff between package and board make the CGA packages more robust to resist the stresses generated due to CTE mismatch during temperature cycling [3]. The I/O count can be up to 2577 for a 1-mm pitch and a package size of 52.5 mm [4]. However, the column is made of...
high–lead–solder alloy, which is eventually subjected to phase out due to lead-
eliminatation legislature. Its substitution is still under investigation. Furthermore,
the permanent attach characteristics of this package style puts it in an unfavorable
position to compete against LGA packages for high performance devices.

In comparison, LGA packages provide many advantages by overcoming the
shortcomings of the forgoing package styles and providing many benefits associated
with separable interconnection. The benefits of LGA packages can be
summarized as follows:

- **High I/O count and density.** LGA packages can achieve a much higher pin
count than can leaded packages. For PGA packages, the pitch is generally
limited to 2.5 mm, for a 42.5 mm nodule footprint, PGA design can achieve
only 289 pins. However, for an LGA device with a 1-mm pitch, 1681 pads
can be attached to the substrate.

- **Improved electrical performance.** For a PGA package assembled on PCB
via a ZIF socket, the added signal path length can be around 5 mm. For a
state-of-the-art LGA package, the added signal path length can be as little
as 0.7 mm.

- **Separable interconnection.** This characteristic of LGA assembly makes it
ideal for debug during system-level testing as well as for field replacement
and upgrade. By leaving the high performance (CPUs and CECs) in the
last step for attachment, use of LGA packages is in accordance with the
build-to-order business model.

It is expected that LGA packages will become a more popular packaging
style, and its market share will show a high growth rate. Although microPGA
is still being used by Intel to encapsulate its microprocessors, it is believed that
PGA packages will eventually be replaced by LGAs, driven by performance
improvement opportunities.
In this chapter, IC component sockets for interconnecting land grid array (LGA) packages are introduced. LGA packages have gained popularity because of their increased performance and high I/O density and field upgradable capability. All LGA packages are connected to circuit boards through an LGA socket (also often called an interposer), in which contact interfaces are created through z-axis compression. Various technologies are presented and compared.

8.1 LGA SOCKET DESIGNS

All the LGA packages need to be connected to circuit boards through sockets or interposers. LGA sockets have arrays of contacts, populated in correspondence to the LGA or PCB pad footprint and carried by an insulator. The sockets usually have plastic pins on the insulator to insert corresponding PCB holes for socket-board alignment and polarization features for proper socket-package orientation. They usually have built-in plastic springs (often called center beams) to align and hold LGA packages in the right place.

Full-stop features are sometimes employed to prevent contact overstress during assembly. Use of full stop is dependent on the potential failure mechanisms to which a socket contact design is most susceptible. For most metallic designs, a full stop is required, since overstress instead of stress relaxation is a big concern. For a design with stress relaxation as the biggest concern, use of a full-stop feature may make the design more susceptible to contact failures.

Once a PCB, socket and package are stacked together, a force is used to clamp the sandwich: heat sink, backing plate, and metal springs. Figure 8.2 gives a cross-sectional view of the stackup, in which four metal springs are used on the four corners of the assembly. The clamping force is applied by tightening the screws and compressing the metal springs; its required value can be achieved by counting the screw turns or reaching a preset torch. Considering a socket with 2000 contacts and a required force of 100 g per pin, the total compression force may reach up to 450 lb. A backing plate (or the bolster) is needed to provide mechanical support to the circuit board and prevent excessive deformation.
Designing a backing plate with sufficient strength is a necessity to ensure the stackup long-term reliability.

To be successful, a socket design must meet certain baseline requirements. The generic requirements are as follows:

- **Electrical performance**: With the increase in device electrical performance, the role of LGA socket interconnect becomes more important. The contributions from the contact signal path to crosstalk and propagation delay cannot be omitted. A socket design should demonstrate not only low inductance and capacitance as required by its intended application, but also have enough margin to enable future technologies.

- **Mechanical performance**: The circuit board and LGA package are usually not perfectly coplanar. An LGA socket contact should have enough working range to accommodate variations in the z stackup. The working range of a socket contact is defined as the deflection range within which the socket will perform reliably in its intended lifetime. Contact wipe and contact redundancy must also be evaluated.

- **Socket TP tolerance**: With an increase in the socket I/O count and size, socket contact true position (TP) control becomes more challenging. An out-of-spec socket TP may lead to contact open and/or short.

- **Reliability**: LGA sockets are mostly used in business critical applications, in which reliability is a high priority. The reliability of an LGA socket should be demonstrated before its implementation. Socket qualification is generally based on EIA standards. However, qualification may not in itself reveal socket reliability, especially for new designs or new technologies, for which there are no well-studied failure mechanisms or a field use reference is lacking. More stringent testing strategies should be used to understand the designs' reliability in their implementation conditions.

- **Manufacturability**: Manufacturability of a socket pertains to the socket assembly process. It defines inspection criteria for incoming materials, ease of socket handling and assembly, and assembly yield. It is related not only to socket design but also to vendor craftsmanship. An LGA socket should have features to enable easy handling and to prevent potential damage during assembly. Socket manufacturers need to demonstrate good and consistent quality control.

- **Business**: A socket manufacturer should be able to meet the cost (cents per pin) requirements of OEMs. They need to be responsive and provide necessary support in a timely manner.

Table 8.1 lists the general items that should be specified and evaluated for an LGA socket design. OEMs should provide a list of items and requirements to socket vendors. It is the vendors’ responsibility to supply data. Although specific values for some of these items depend on the potential implementation conditions,
TABLE 8.1 Items Generally Required for LGA Socket Design Evaluation

<table>
<thead>
<tr>
<th>Category</th>
<th>Evaluation items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket design</td>
<td>Socket materials and construction</td>
</tr>
<tr>
<td></td>
<td>Socket drawing and TP analysis</td>
</tr>
<tr>
<td></td>
<td>Compatibility with potential implementation conditions</td>
</tr>
<tr>
<td></td>
<td>Potential risk areas and corrective actions</td>
</tr>
<tr>
<td>Electrical performance</td>
<td>Signal path length</td>
</tr>
<tr>
<td></td>
<td>Self-inductance</td>
</tr>
<tr>
<td></td>
<td>Capacitance</td>
</tr>
<tr>
<td></td>
<td>Operating frequency</td>
</tr>
<tr>
<td>Mechanical performance</td>
<td>Working range</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
</tr>
<tr>
<td></td>
<td>Contact redundancy</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Operating temperature range</td>
</tr>
<tr>
<td></td>
<td>Current rating</td>
</tr>
<tr>
<td>Reliability</td>
<td>Potential failure mechanisms</td>
</tr>
<tr>
<td></td>
<td>Vendor qualification data</td>
</tr>
<tr>
<td></td>
<td>Field use reference</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>Socket quality</td>
</tr>
<tr>
<td></td>
<td>Assembly yield</td>
</tr>
<tr>
<td></td>
<td>Process sensitivity</td>
</tr>
<tr>
<td>Business</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td>Assurance of supply</td>
</tr>
<tr>
<td></td>
<td>Supplier support</td>
</tr>
</tbody>
</table>

some confidence may be established from prior experience, industry practice, and vendors’ testing data.

Dozens of companies produce LGA sockets. Many of them focus on burn-in/test sockets; only a few produce high-volume production sockets. In general, the LGA socket designs can be classified into four categories: metallic spring design, Pogo-pin style design, bundled-wire design, and conductive elastomer design. Each design style has its unique benefits and challenges. Table 8.2 provides a comparison of these design styles. In the following section, these styles of LGA socket designs are introduced, with some examples that are available in the marketplace.

8.1.1 Metallic Spring Design

The metallic spring design category has the most versatile LGA socket designs. The designs usually have stamped metal springs inserted into an injection-molded
TABLE 8.2 Comparisons among LGA Socket Designs

<table>
<thead>
<tr>
<th>Design Style</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic spring design</td>
<td>Contact wipe</td>
<td>Long signal path</td>
</tr>
<tr>
<td></td>
<td>Low contact force</td>
<td>No contact redundancy</td>
</tr>
<tr>
<td></td>
<td>Reliability assurance with a</td>
<td>Contact wear</td>
</tr>
<tr>
<td></td>
<td>long use history</td>
<td></td>
</tr>
<tr>
<td>Pogo-pin design</td>
<td>Low contact force</td>
<td>High cost</td>
</tr>
<tr>
<td></td>
<td>Reliability assurance with a</td>
<td>No contact wipe</td>
</tr>
<tr>
<td></td>
<td>long use history</td>
<td>No contact redundancy</td>
</tr>
<tr>
<td>Bundled wire design</td>
<td>Contact redundancy</td>
<td>Poor manufacturability</td>
</tr>
<tr>
<td></td>
<td>Reliability assurance with a</td>
<td>High contact force</td>
</tr>
<tr>
<td></td>
<td>long use history</td>
<td></td>
</tr>
<tr>
<td>Conductive elastomer</td>
<td>Contact redundancy</td>
<td>Elastomer stress relaxation</td>
</tr>
<tr>
<td>design</td>
<td></td>
<td>and creep</td>
</tr>
<tr>
<td></td>
<td>Elastic sealing effect</td>
<td>Complicated failure mechanisms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unknown reliability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limited field use history</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elastomer adhesion</td>
</tr>
</tbody>
</table>

plastic carrier. The contacts are formed more or less like a letter C or G, plated with \(30 \mu\text{in.}\) of gold and a minimum of \(50 \mu\text{in.}\) of nickel as an underplate. Examples include Teledyne Microconn design, Intercon CStack design, Molex G-Rocker design, Aries design, and Samtec Z-beam design. However, not all the designs use stamped metals. Tyco MicroSpring design (licensed from Formfactor on the contact technology) is one of the exceptions.

The benefits of metallic spring designs may include low contact force, large working range, contact wipe, known failure mechanisms, and long use history, depending on specific design characteristics. Because of the long use history of metallic springs in the connector industry, the contact behavior and failure mechanisms have been understood more clearly than other designs. Established industry standards, such as EIA 540 and EIA 360, are more applicable to this type of design. By tailoring the shape, length, width, and thickness of metal springs, socket manufacturers are able to adjust the mechanical and electrical performance of their designs, reaching a trade-off to optimize specific characteristics, depending on specific requirements.

Some designs provide very low nominal contact force, typically below 50 g per pin. However, because of the low contact force, the effectiveness of contact wipe is suspected, and the socket contact may not be able to disperse contaminants and penetrate the insulating layer on PCB and package pad surfaces. Furthermore, because of the wipe distance, the contact in-plane tolerance may prove more challenging than other designs without contact wipe. The contacts may have opportunities to start off or wipe off the pads. Coupled to the concern for wipe effectiveness, the metallic spring contact designs do not provide contact
redundancy. Therefore, for metallic spring designs, the assembly environment needs to be well controlled. PCB and package pads need to be covered to avoid exposure to dust settlement during storage and shipment and to prevent flux contamination during soldering nearby components. Before socket assembly, PCB and package pads need to be cleaned and inspected to make sure that there is no dust, fiber, or contaminants on their surface.

**Teledyne Microconn Design**  Figure 8.3 shows the Teledyne Microconn contacts on both the board and package sides. The contacts are gold/nickel-plated beryllium copper. They are inserted into a plastic carrier and bent in a letter C shape. The contacts are not floating; they are held rigidly in place by the plastic matrix (liquid crystal polymer). The contact beam and tip are bent to the required shape in the final assembly step. Between contact rows there are plastic ribs standing to a height that is dependent on the required magnitude of contact deflection. The main purpose of the plastic ribs is to provide a full stop to the contact springs. It may also serve as a barrier to intrusion of pollutants in the contact areas.

The design, performance, and reliability information of a Microconn socket (1369 I/Os, 1.12-mm pitch) are given in Table 8.3. The information and values are supplied here for reference purposes only.

**Intercon CStack Design**  Figure 8.4 shows the Intercon CStack LGA socket contact arrays. This design features a C-shaped beam, which is inserted in a cavity in its plastic housing. A retention feature is molded in the cavity to hold the contact and prevent contact fallout in the event of accidental drop. It is also designed to allow a certain freedom of contact floating. The housing body serves as a full stop, determining the maximum deflection the contact can reach. The contact is made from beryllium copper plated with gold over nickel [6].

To provide a contact redundancy, the socket manufacturer places two extra wings on both contact tips. Although the new design may provide a certain contact redundancy, it also creates a highly localized stress on the contact tips. This may increase the contact wear and thus reduce contact durability. Table 8.4
TABLE 8.3 Properties of Teledyne Microconn Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Beryllium copper</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>30 µ.in. of gold over nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>LCP</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1, 1.12, 1.27 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Could be above 2000</td>
</tr>
<tr>
<td></td>
<td>Contact full deflection</td>
<td>0.40 mm</td>
</tr>
<tr>
<td></td>
<td>Contact height at full compression</td>
<td>1.22 mm</td>
</tr>
<tr>
<td>Electrical</td>
<td>Self-inductance</td>
<td>&lt; 1 nH</td>
</tr>
<tr>
<td>properties</td>
<td>Mutual inductance</td>
<td>&lt; 0.1 nH</td>
</tr>
<tr>
<td></td>
<td>Capacitance</td>
<td>&lt; 2.0 pF</td>
</tr>
<tr>
<td></td>
<td>Propagation delay</td>
<td>&lt; 20 ps</td>
</tr>
<tr>
<td></td>
<td>Rise time, 20 ps input</td>
<td>29 ps</td>
</tr>
<tr>
<td></td>
<td>Bandwidth</td>
<td>− 0.03 dB at 600 MHz</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Contact force per pin</td>
<td>Min. 25 g (nominal 50 g)</td>
</tr>
<tr>
<td>properties</td>
<td>Contact wipe</td>
<td>0.07–0.13 mm</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>&gt; 15</td>
</tr>
<tr>
<td>Physical</td>
<td>Current rating</td>
<td>&gt; 1 A</td>
</tr>
<tr>
<td>properties</td>
<td>Operating temperature</td>
<td>− 55 to 105°C</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstanding voltage</td>
<td>1000 V ac for 1 min</td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>&gt; 1000 MΩ</td>
</tr>
<tr>
<td>Reliability</td>
<td>Mechanical shock according to EIA</td>
<td>LLCR change &lt; 15 mΩ</td>
</tr>
<tr>
<td></td>
<td>Random vibration according to EIA</td>
<td>Pass 1-ns glitch detection</td>
</tr>
<tr>
<td></td>
<td>Thermal shock according to EIA</td>
<td>LLCR change &lt; 15 mΩ</td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity according to EIA</td>
<td>LLCR change &lt; 15 mΩ</td>
</tr>
<tr>
<td></td>
<td>Mixed flowing gas according to EIA</td>
<td>LLCR change &lt; 20 mΩ</td>
</tr>
<tr>
<td></td>
<td>Temperature life according to EIA</td>
<td>LLCR change &lt; 15 mΩ</td>
</tr>
<tr>
<td></td>
<td>Accelerated temp. cycling</td>
<td>LLCR change &lt; 15 mΩ</td>
</tr>
</tbody>
</table>

Source: Ref. 5.

lists the properties of the Intercon CStack original design. These values are for reference purposes only.

**Aries LGA Socket Design** Figure 8.5 shows the Aries LGA socket design. Similar to the Teledyne design, the Aries contact is shaped like a letter C. The contact is held in place in the plastic housing; however, it does not count on the
plastic housing to provide a full stop. It has a built-in feature to prevent contact over stressing. Table 8.5 lists the design characteristics and properties of the design for reference purposes only. The manufacturer has done some qualification tests on the design.
TABLE 8.4 Properties of Intercon CStack Design (Original Design)

<table>
<thead>
<tr>
<th>Category</th>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Beryllium copper</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>30 μin. of gold over 30–70 μin. of nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>Glass-filled LCP</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1, 1.27 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>1657, 1088, and 937</td>
</tr>
<tr>
<td></td>
<td>Contact full deflection</td>
<td>11 mils</td>
</tr>
<tr>
<td></td>
<td>Contact height at full compression</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self-inductance</td>
<td>&lt;0.8 nH</td>
</tr>
<tr>
<td></td>
<td>Mutual inductance</td>
<td>&lt;0.1 nH</td>
</tr>
<tr>
<td></td>
<td>Capacitance</td>
<td>&lt;0.02 pF</td>
</tr>
</tbody>
</table>
|                           | Bandwidth                          | −1-dB loss at 7.3 GHz  
  \( S:G = 2:1 \)                                                      |
| Mechanical properties     | Contact force per pin              | ~50 g nominal                                                         |
|                           | Contact wipe                       | Not available                                                         |
|                           | Durability                          | Min. 100                                                              |
| Physical properties       | Current rating                     | >1 A                                                                  |
|                           | Operating temperature              | Not available                                                         |
|                           | Dielectric withstanding voltage    | 500 V ac for 1 min                                                   |
|                           | Insulation resistance              | >1000 MΩ                                                              |
| Reliability               | Mechanical shock (50 g, three axes) | Pass 2-ns glitch detection                                           |
|                           | Random vibration (7.3 g, three axes)| Pass 2-ns glitch detection                                           |
|                           | Accelerated thermal cycling (0–100°C, 3500 cycles) | LLCR change < 20 mΩ                                                 |
|                           | Temperature life (90°C, 2000 h)     | LLCR change < 20 mΩ                                                  |
|                           | Power cycling (20–90°C, 2000 cycles)| LLCR change < 20 mΩ                                                  |

Source: Ref. 7.

**Molex G-Rocker Design**  Figure 8.6 shows the Molex G-rocker LGA socket contact design. The design name was probably based on the fact that the contact is more like a letter G and the bottom of the contact looks like a rocking chair. The design was introduced at Gryphics, a Molex partner in Minnesota. It was intended for test and burn-in applications as well as production [9].

The contacts are inserted into the cavities of the socket housing. To prevent contact fallout, elastomers are injected into the cavities after contact insertion to hold the contacts in position. Figure 8.7 shows the contact cavities encapsulated by elastomers.
## TABLE 8.5 Properties of Aries LGA Socket Contact Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Beryllium copper</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>30µ in. of gold over 50µ in. of nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>LCP</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Could be above 1000</td>
</tr>
<tr>
<td></td>
<td>Contact full deflection</td>
<td>17 mils</td>
</tr>
<tr>
<td></td>
<td>Contact height at full compression</td>
<td>1.62 mm</td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self-inductance</td>
<td>Not available</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Bandwidth</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Contact force</td>
<td>15–25 g</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
<td>0.08 mm</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>Min. 25</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Current rating</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>−55 to 125°C</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstanding voltage</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>Not available</td>
</tr>
<tr>
<td>Reliability</td>
<td>ATC according to EIA 540B-0AE, 168 cycles</td>
<td>LLCR change &lt; 1.4 mΩ</td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity according to EIA 540B-0AE, 100 h</td>
<td>LLCR change &lt; 3.1 mΩ</td>
</tr>
<tr>
<td></td>
<td>Temp. life according to EIA 540-B0AE, 100 h</td>
<td>LLCR change &lt; 3.5 mΩ</td>
</tr>
</tbody>
</table>

*Source:* Ref. 8.

---

![Figure 8.6](image)  
Molex G-rocker contact design. (From Ref. 9.)
The contact material is CuNiSi, a high-performance copper alloy known for high resistance to stress relaxation. The properties of the design (version of 1.5 mm contact height) are presented in Table 8.6 for reference purposes only.

**Tyco MicroSpring Design**  Figure 8.8 shows the Tyco MicroSpring LGA socket design. The socket provides an LGA interface to the component to be socketed and a conventional SMT ball grid array interface to the motherboard. Formfactor, Inc., a company in California, invented the technology for use on semiconductor wafer-level testing. It licensed the technology to Tyco Electronics for making LGA sockets.
The process of producing a MicroSpring contact array is as follows [10]:

1. A PCB is fabricated with an appropriate array pattern of pads on the top and bottom surfaces. Each top pad is connected to the corresponding bottom pad with a plated via. The pads are configured according to the array pattern desired.

2. The PCB panel is loaded into a specially configured wire bonder, which creates a wire bond on the topside pads. Using software, the bonder creates a spring shape in free space and then cuts the wire at a precisely controlled height. It then indexes to the next pad location and repeats. When the wire bonder is finished, an entire panel of array spring shapes is created. The wire bond material currently being used is gold in either rectangular or round cross section. The wire bond process is fully automatic and runs at speeds of 2 to 12 bonds per second, depending on wire shape and bonder.

3. The fully populated panel then moves to the plating process, where the wire bond springs are heavily plated with a nickel alloy. After the nickel alloy, gold is plated as the top surface metal.

4. The next step is solder ball placement and attachment. This is performed using existing high-volume automated equipment.

5. Following ball attach, a MicroSpring array panel is singulated into individual arrays, and a molded contact protector is attached to each array. The contact protector functions to protect the contact array during packaging, shipping, pick and place, and so on, and also acts to align the component to be mated to the array contacts. When the component to be mated with the array is installed, the contact protector floats downward to allow the contact tips to mate with the component. The contact protector also acts as a positive compression stop.

6. The final step of the process is test and inspection for potential short and open circuits and for coplanarity.

The properties of the Tyco MicroSpring socket design are listed in Table 8.7. The vendor claims that a stable contact resistance can be achieved by a minimum normal force of 10 g. However, this spec needs to be a subject of long-term reliability testing and survivability testing during all kinds of field-use conditions, such as shock and vibration. Because of contact wipe, there is some amount of
friction force introduced during contact actuation. The force to assemble the sockets appears to be much higher.

### 8.1.2 Pogo Pin Socket Design

Figure 8.9 shows a Pogo contact design. It is composed of three components: a spring, a shell, and two plungers. The spring provides contact compliance, the two plungers provide contact interfaces, and the shell (also called the *barrel*) is to hold the spring and the plungers in position. The spring and plunger are usually made from beryllium copper. The barrel can be made of nickel–silver alloy. These parts are usually plated with nickel and gold, other platings are also used on the spring.

The Pogo pin socket design is used primarily for test applications, due to its excellent durability. Its mechanical actuation life can exceed 1 million cycles. Pogo pin design is also known for its high price. Compared to several cents per line for production sockets, the price for a Pogo pin can be 100 times higher.
TABLE 8.8 Properties of an ECT Bantam-Pak Socket Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>BeCu (stainless steel as spring)</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>Gold over nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>Polyamide-imide (PAI)</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>0.5, 0.65, 0.75, 0.8, 1.0, 1.27 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Could be above 2500</td>
</tr>
<tr>
<td></td>
<td>Contact full deflection</td>
<td>0.58 mm</td>
</tr>
<tr>
<td></td>
<td>Contact height at full</td>
<td>2.49 mm</td>
</tr>
<tr>
<td></td>
<td>deflection</td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>Self-inductance</td>
<td>&lt;0.8 nH</td>
</tr>
<tr>
<td>properties</td>
<td>Bandwidth</td>
<td>–1-dB loss at 10 GHz</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Contact force</td>
<td>~28 g</td>
</tr>
<tr>
<td>properties</td>
<td>Contact wipe</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Operating temperature</td>
<td>–50 to 150°C</td>
</tr>
</tbody>
</table>

Source: Ref. 12.

Besides LGA test applications, the Pogo pin socket can also be used to test other packages, such as BGA and CSP packages.

Many companies produce LGA sockets based on this type of design. Table 8.8 gives design and product information of an ECT socket (overall contact length: 3.0 mm) for reference purposes only. The Bantam-Pak contactor is designed according to the Pogo pin technology.
8.1.3 Wire-Button Contact Design

A wire-button (or Fuzz Button) interconnection is constructed of a random-wound metal wire that is formed into a cylindrical shape. It provides contact redundancy but without significant contact wipe involved. Figure 8.10 shows wire-button contacts. This interconnection can offer a compressed signal path length as short as 0.8 mm, a contact centerline spacing of 1 mm or greater, and custom I/O counts of over 1000. The operating frequency can be greater than 1 GHz. Furthermore, it can be used not only for mounting LGA packages, but also for interconnections between a flex circuit and a PCB or between PCBs.

Different metal wires can be used as contacts, such as beryllium copper, tungsten, monel, and molybdenum. Table 8.9 gives a comparison in operating temperature between these metal wires, as specified by Tecknit, a company producing wire-button sockets for test and burn-in applications.

Table 8.10 lists the properties of Cinch Fuzz Button LGA production sockets for reference purposes only. The nominal force required is around 100 g, which is higher than other types of designs. The design shows a short signal path, less than 0.8 mm on full compression. Compression is controlled by the insulator height serving as a full stop.

8.1.4 Conductive Elastomer Design

By incorporating conductive elements in its matrix, conductive elastomers are being used as an interconnection method. Silicone rubber is the most widely used elastomer because of its wide operating temperature range, inertness to most environments, and aging stability. There are generally two types of conductive elastomer design: wire-in-elastomer design and particle-in-elastomer design. The former is used to embed metal wires, such as gold, copper, nickel, gold, steel,
### Table 8.9 Operating Temperatures for Various Wire Types

<table>
<thead>
<tr>
<th>Wire Type</th>
<th>Applications</th>
<th>Operating Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-plated BeCu</td>
<td>General purposes</td>
<td>−55 to 105</td>
</tr>
<tr>
<td>Au-plated W</td>
<td>Military/commercial</td>
<td>−55 to 135</td>
</tr>
<tr>
<td>Au-plated NiCr</td>
<td>High temperature</td>
<td>−55 to 150</td>
</tr>
<tr>
<td>Au-plated Mo</td>
<td>Medium to high temperature</td>
<td>−55 to 135</td>
</tr>
<tr>
<td>Monel</td>
<td>Commercial</td>
<td>−55 to 85</td>
</tr>
</tbody>
</table>

*Source: Ref. 13.*

### Table 8.10 Properties of a Typical Cinch Fuzz Button Socket Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Molybdenum</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>Gold</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>LCP</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1, 1.27 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Could be above 1000</td>
</tr>
<tr>
<td></td>
<td>Contact height at full</td>
<td>0.8 mm</td>
</tr>
<tr>
<td></td>
<td>compression</td>
<td></td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self-inductance</td>
<td>&lt;1 nH</td>
</tr>
<tr>
<td></td>
<td>Propagation delay</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Bandwidth</td>
<td>20 GHz</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Contact force</td>
<td>~100 grams</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>25,000</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Current rating</td>
<td>1–3 A</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>~105°C</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstandning</td>
<td>900 VAC for 1 min</td>
</tr>
<tr>
<td></td>
<td>voltage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>&gt;25,000 MΩ @ 500 V dc</td>
</tr>
<tr>
<td>Reliability</td>
<td>Temp. life (200°C, 1000h)</td>
<td>Pass, but pass criteria not specified</td>
</tr>
<tr>
<td></td>
<td>Thermal shock (~−25–85°C,</td>
<td>Pass, but pass criteria not specified</td>
</tr>
<tr>
<td></td>
<td>2000 cycles)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity (30–80°C,</td>
<td>Pass, but pass criteria not specified</td>
</tr>
<tr>
<td></td>
<td>5000 cycles, 85% RH)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanical shock (100 g,</td>
<td>No discontinuity greater than 2 ns</td>
</tr>
<tr>
<td></td>
<td>6 ms)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vibration (20 g,</td>
<td>No discontinuity greater than 2 ns</td>
</tr>
<tr>
<td></td>
<td>10,000–20,000 Hz)</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Ref. 14.*
and their alloys, in the elastomer matrix; the latter to mix conductive particles with elastomer. The most common conductive particles are carbon, silver, and nickel. Carbon is the least expensive conductive filler but has the lowest conductivity. Silver has the highest conductivity but is much more expensive than other conductive fillers. For intermediate conductivity and price, nickel is the choice, and it also shows high corrosion resistance. The conductive elastomer design has found many applications in the electronics industry, such as edge connectors to connect a daughter board to a motherboard, display panel connectors, and IC component sockets.

**Tyco Metallized Particle Interconnection (MPI) Design**  
Figure 8.11 shows a Tyco MPI socket with 787 I/Os and a schematic of an MPI button construction. The button is made of silicone rubber embedded with silver particles. Once the button is compressed, the button’s electrical properties are improved and the particles form a percolation conductive network. To achieve high conductivity, a high percentage, typically 80% weight density, of metal particles are needed to fill in the elastomer. Once mixed, the composite is formed through injection molding into arrays of buttons supported by a polyimide flexible carrier.

The elastomer contact design is capable of fine-pitch and high-I/O applications. Elastomer sockets with as many as 5000 I/Os are under development. The button is only 0.7 mm in height under full compression. The short electrical path length makes it suitable for high-frequency applications. To prevent excessive deformation of the interconnects during assembly, transportation, and application conditions, a full-stop feature is built into the socket housing. However, the elastomers show a tendency to creep and stress relax. Once the elastomer buttons creep to the full stop, the failure mechanism will switch to stress relaxation. Therefore, both stress relaxation and creep and their transition should be well studied.

![Figure 8.11](image)

(a) Elastomer socket; (b) contact diagram.
Table 8.11 lists Tyco MPI socket properties. According to the manufacturer, the maximum operating temperature of the MPI contact is 90°C. This temperature is lower than that usually expected for metallic designs, typically 105°C. Temperature has a profound effect on elastomer contact behavior [16, 17].

**Elastomeric Conductive Polymer Interconnect (ECPI)** The ECPI was invented by AT&T Bell Laboratories (now Lucent) in the early 1990s [18]. The Bell team members later founded Paricon to produce this type of interconnect, called Pariposer. The market targets are for production as well as burn-in and test applications.

The ECPI is fabricated by aligning silver-plated nickel particles in a polysiloxane matrix through a magnetic field [19]. The process results in an elastomeric
film with columns of particles embedded that transverse the film thickness but are electrically isolated from each other in plane. Figure 8.12 shows the working principle of the ECPI design [18]. Pressure is required to compress the elastomer matrix and to make electrical contacts between adjacent particles within an individual column. Under low pressure, the metal particles will align on each other, with a pressure increase, because of the high rigidity of nickel particles, they will slide over each other and a certain distortion will occur. This may cause damage to the elastomer matrix. A maximum of 40% deformation is recommended by the manufacturer to avoid permanent distortion.

Table 8.12 lists the properties of Paricon Pariposer socket design. The polysiloxane film thickness can be in the range 0.2 to 0.375 mm. Because of its short signal path, the socket demonstrates excellent electrical performance. The operating frequency can be up to 40 GHz, according to the manufacturer. It has been used for semiconductor test purposes. However, because of its low thickness, this design may not provide enough working range to compensate for nonflatness of boards and components. Because of the characteristics of the manufacturing process, the thickness may not be increased further. Furthermore, this design does not allow for a built-in full-stop feature, and therefore, localized overstress may occur, causing permanent damage to the elastomer film and metal particles.

**HCD Superbutton** Figure 8.13 shows a schematic of HCD SuperButton design. The design is composed of silicone rubber, copper alloy wires, and a Teflon core. A certain number of copper wires, typically 6 or 12, route around a cylinder Teflon core and are embedded in the elastomer matrix. The contact tips are plated with some noble metals with nickel as an underplate.

Table 8.13 lists the properties of the HCD SuperButton socket design for reference. This design provides multiple advantages, including:
TABLE 8.12 Properties of Paricon Pariposer Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Nickel particles</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>Silver</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>Polysiloxane</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Contact height at full</td>
<td>&lt;0.3 mm (assume 20% deformation)</td>
</tr>
<tr>
<td></td>
<td>compression</td>
<td></td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self-inductance</td>
<td>&lt;0.1 nH</td>
</tr>
<tr>
<td></td>
<td>Propagation delay</td>
<td>&lt;2 ps</td>
</tr>
<tr>
<td></td>
<td>Operating frequency</td>
<td>40 GHz</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Contact force</td>
<td>50–100 psi</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>30,000 at 100 psi</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Current rating</td>
<td>1 A max. for 25-mil pad</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>−40 to 160°C</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstanding</td>
<td>8,00 V ac for 1 min</td>
</tr>
<tr>
<td></td>
<td>voltage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>&gt;1000 MΩ at 1000 V dc</td>
</tr>
<tr>
<td>Reliability</td>
<td>Thermal cycling</td>
<td>&lt;1% contact resistance change</td>
</tr>
<tr>
<td></td>
<td>(−20–100°C, 315 cycles)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity (1000h)</td>
<td>&lt;1% contact resistance change</td>
</tr>
<tr>
<td></td>
<td>according to EIA 540</td>
<td>Pass, but details not specified</td>
</tr>
</tbody>
</table>

*Source:* Ref.19.

Figure 8.13 Schematic diagram of HCD SuperButton design. (From Ref. 20.)

- The copper wires provide a continuous electrical path, there is no internal “secondary” contact interfaces, so it should be more robust and reliable than the particle-embedded design.
- Multiple wires provide redundant contact interfaces.
- The elastomer provides a gastight sealing of the contact interfaces, so this design can be potentially compatible with thin Au-plated boards.
### TABLE 8.13 Properties of HCD SuperButton Socket Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Copper wires in elastomer</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>Gold flash or palladium over nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>FR4</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>Could be above 2000</td>
</tr>
<tr>
<td></td>
<td>Contact height at full compression</td>
<td>~0.7 mm</td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self inductance</td>
<td>&lt;0.5 nH</td>
</tr>
<tr>
<td></td>
<td>Propagation delay</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Bandwidth</td>
<td>5 GHz</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Contact force</td>
<td>Min. 40 g</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
<td>~1 mil</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>20</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Current rating</td>
<td>&gt; 1 A (15°C increase)</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstanding voltage</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>&gt; 1000 MΩ at 1000 V dc</td>
</tr>
<tr>
<td>Reliability</td>
<td>Mechanical shock (50 g)</td>
<td>Pass, but details not specified</td>
</tr>
<tr>
<td></td>
<td>Vibration (4.24 g)</td>
<td>Pass, but details not specified</td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity (25–100°C, 80% RH)</td>
<td>Pass, but details not specified</td>
</tr>
<tr>
<td></td>
<td>Thermal cycling (0–100°C)</td>
<td>Pass, but details not specified</td>
</tr>
<tr>
<td></td>
<td>Temp. life (125°C)</td>
<td>Pass, but details not specified</td>
</tr>
</tbody>
</table>

*Source: Ref. 20.*

- The shorting between neighboring contacts can potentially be avoided, because of the elastomer insulation.
- The design utilizes a standard cable-fabrication process, so the cost is lowered.
- This design has a short signal path length.

However, there are some potential risks associated with this design:

- The long-term behavior of the elastomer is not well understood.
- If using a constant-load clamping mechanism (without using the full-stop design), creep will be a concern. The creep behavior of the design needs to be characterized.
• If using a full-stop feature, once the component reaches the full stop, no deformation will be allowed to occur. A gradual reduction of contact force causes instability of the contact interfaces.

• Different components will need to work synergically to ensure a stable contact interface.

**IBM Wire-in-Elastomer Design**  Figure 8.14 shows a schematic of IBM wire-in-elastomer design. Gold wires parallel to each other are embedded in the elastomer matrix at an angle. The elastomer provides contact compliance, and multiple wires touch the package and board pads to provide contact redundancy. This design is targeted primarily for burn-in applications.

Several other companies have similar designs. Fujipoly is one of them. Its wire-in-elastomer interconnect products have been used in LCD, MCM, and three-dimensional packaging applications [22]. To reduce cost, Ironwood uses brass wires as the contact material, with noble metal plating on the contact tips [23]. The company commercializes its products to burn in BGAs as well as LGAs.

**CCI ISOCON**  Figure 8.15 shows a schematic of CCI (Circuit Component, Inc.) ISOCON design. The design consists of flat S-shaped beryllium copper (nickel and gold plated) suspended in a high-stress-retention microcellular silicone rubber. As a force is applied, the conductors rotate and provide wipe at each contact interface. The elastomer provides support to the conductors and a gastight seal as well.

Table 8.14 lists the properties of CCI socket design. This design has a limited I/O capability, with a maximum of 400 I/Os achieved per socket. Although the design provides contact wipe, it also introduces contact wear. Since there is a certain gap (roughly 0.25 mm) between the elastomer surfaces and PCB and component surfaces, the elastomer may not be able to provide perfect gastight sealing. Therefore, the manufacturer recommends plating the contact pad with a minimum of 50 μin. of gold over 150 μin. of nickel.

![Diagram of IBM Wire-in-Elastomer Design](image)

**Figure 8.14** Wire-in-elastomer design. (From Ref. 21.)
Figure 8.15  CCI ISOCON design (a) before and (b) after loading. (From Ref. 24.)

TABLE 8.14 Properties of CCI ISOCON Socket Design

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket materials</td>
<td>Contact material</td>
<td>Beryllium copper</td>
</tr>
<tr>
<td></td>
<td>Contact plating</td>
<td>Gold over nickel</td>
</tr>
<tr>
<td></td>
<td>Insulator</td>
<td>Microcellular silicone</td>
</tr>
<tr>
<td>Socket design</td>
<td>Contact pitch</td>
<td>1.27 mm</td>
</tr>
<tr>
<td></td>
<td>I/O capability</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Contact height at full compression</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Electrical properties</td>
<td>Self-inductance</td>
<td>&lt;1 nH</td>
</tr>
<tr>
<td></td>
<td>Propagation delay</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Bandwidth</td>
<td>Not available</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Contact force</td>
<td>25–100 g</td>
</tr>
<tr>
<td></td>
<td>Contact wipe</td>
<td>9 mils for 80-mil-thick silicone</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>500</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Current rating</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Dielectric withstanding voltage</td>
<td>&gt;1800 V</td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
<td>&gt;2 × 10¹⁴Ω</td>
</tr>
<tr>
<td>Reliability</td>
<td>Thermal shock (−55 to 85°C, 50 cycles)</td>
<td>Average 2 mΩ increase</td>
</tr>
<tr>
<td></td>
<td>Temp. life (125°C, 6018 h)</td>
<td>Average 1.9 mΩ increase</td>
</tr>
<tr>
<td></td>
<td>Cyclic humidity (6–65°C, 90–95% RH, 1000 h)</td>
<td>Average 0.7 mΩ increase</td>
</tr>
<tr>
<td></td>
<td>Mechanical shock per MIL-STD-1344</td>
<td>No discontinuity greater than 2 ns</td>
</tr>
<tr>
<td></td>
<td>Vibration per MIL STD-1344</td>
<td>No discontinuity greater than 2 ns</td>
</tr>
</tbody>
</table>

Source: Ref. 24.
8.2 COMPARISON OF CONTACT RELIABILITY

A generic comparison of LGA socket designs is given in Table 8.2. In this section we compare reliability of different contact designs, with respect to the elastomer designs, especially particle-in-elastomer design. Compared to metallic spring and Fuzz Button designs, elastomer-based designs are relatively new. Their long-term reliability and contact behaviors are less well understood.

The elastomers, while having many advantages, are known for their high stress relaxation and creep rates, especially at elevated temperatures. The contacts may be subject to loss of contact force and/or excessive deformation, leading to contact failures. Elastomers also have a high coefficient of thermal expansion (CTE). During temperature cycling, contraction and expansion of elastomers may cause contact micromotion, and a short duration of contact separation can result in contact intermitiences.

Experimental data compared the reliability of a metal particle-in-elastomer design and a wire-in-elastomer design under thermal-cycling (−55 to 125°C) conditions [25]. Contact glitches started to show up at around 167 h for the ECPI particle-in-elastomer socket; the variation of resistance change was much less significant for the Fujipoly wire-in-elastomer design.

The reliability difference of the particle-in-elastomer and wire-in-elastomer designs can be attributed to the difference in their electrical conduction mechanisms. For a particle-in-elastomer contact, the electrical continuity is established through the metal particles embedded in the elastomer matrix. The multiple interfaces between the metal particles (called secondary interfaces as compared to the major interfaces between contact and pads) may be affected by the surrounding elastomers, resulting in a high level of sensitivity to micromotion due to pressure and temperature variation. The micromotion may arise due to the following factors [16]:

- **High CTE value of elastomers.** Expansion and contraction of elastomer under temperature-cycling conditions cause relative motion between metal particles, coupled with the high compliance of elastomer; contact glitches may be observed due to separation between metal particles if temperature increases sharply. CTE mismatch between socket contacts and other components may result in contact overstress and less stress, leading potentially to contact intermittent failures.

- **Lateral spreading (especially yielding at high load).** This can lead to a separation between particles.

- **Compression set and rebound.** The compression set of elastomers may result in an irreversible increase in contact resistance. However, elastomers are also known for their rebound property, but this rebound is time dependent, there is a springback hysteresis. This hysteresis may result in the nonconsistency of data measured at different time zones and conditions. For example, after
a certain number of compression cycles, an elastomer button may show a significant increase in contact resistance. However, after resting without load for a certain period of time, the contact resistance of the elastomer button may return to its original value.

- *Elastomer stress relaxation and creep.*
- *Dewetting of metal particles to the elastomer matrix.* The metal particles may lose support from the elastomer matrix.

### 8.3 FUTURE CHALLENGES FOR LGA SOCKET DESIGN

Although a variety of LGA socket designs are available on the market, it is still a challenge for OEMs to find a design that meets most requirements in terms of performance, reliability, manufacturability, working range, and price. In most cases, trade-offs need to be made.

In some cases it is essential for socket vendors and OEMs to work closely in the design and evaluation of new LGA sockets. Socket vendors should understand the application conditions that their design will potentially experience and also the specific requirements associated with the conditions. OEMs need to provide specific requirements on vendors’ socket design and guide them in the course of design and evaluation.

With the pursuit of lower cost and maximizing supply chain flexibility, there is a trend to switch from ceramic CGA packages to laminate LGA packages. With requirement on performance improvements, laminate PGA packages may also switch to LGAs. This creates a big challenge for implementing sockets as an interconnection method. Laminate packages may show more warpage than ceramic packages, and they can also tolerate much less compressive force. To interconnect laminate packages, new socket designs should have a large working range to accommodate the nonflatness of laminate packages and should provide a low contact force to ensure a stable contact interface.

### 8.4 SUMMARY

With LGA components, only z-axis compression contact designs are available; these designs can be classified into four categories: metallic spring, Pogo pin, Fuzz Button, and conductive elastomer. Among these, Pogo pin design is used primarily for test and burn-in purposes; other designs are being used for test and burn-in as well as for production applications. Further efforts are needed to characterize the long-term behavior of the elastomer contacts under a variety of environmental conditions; for this, socket manufacturers should work closely with OEMs to develop an effective assessment methodology, to define the operating window, and to extrapolate the acceleration factors for the elastomer designs.
REFERENCES

9 Failure Modes and Mechanisms

Failure mechanisms are the electrical, physical and chemical processes by which stresses (loads) can damage the materials used to build a socket. Investigation of the possible failure modes and mechanisms of a socket aids in developing failure-free and reliable designs. Failure mechanisms and their related models are also important for planning tests and screens to audit the nominal design and manufacturing specifications, as well as the level of defects introduced by excessive variability in manufacturing and material parameters. Finally, one must be aware of all possible failure mechanisms in order to employ sockets capable of performing properly over their intended lifetime. Numerous studies focusing on material failure mechanisms and physics-of-failure-based damage models and their role in obtaining reliable electronic products have been presented in a series of tutorials comprising many relevant wear-out and overstress failures [1–14].

Different sockets may experience different failure mechanisms, depending on the contact design, contact materials, contact platings, housing design, housing materials, manufacturing process and application environment. For example, for solder finish, the dominant failure mechanism may be fretting corrosion, while for gold-flash plating, pore or creep corrosion may dominate the degradation process. In some sockets, the contact may fail; in another socket, the socket housing may be the dominant failure concern. Table 9.1 summarizes many of the potential socket failure mechanisms.

Causes of socket failures can be categorized according to design (socket, circuit board, and component), socket manufacturing, component assembly, operation loads, and environmental conditions during shipping, storage, and application (see Figure 9.1). A socket failure may be caused by a combination of stresses (loads) in different categories. An understanding of life-cycle conditions experienced by a socket and system will help sort out the dominant stresses (loads) that cause a socket failure. A variety of factors can affect socket reliability, and socket users should be diligent in assessing this information.

Failures which occur due to stress events that exceed the destruct limit of a socket are termed overstress failures. Failures that occur due to the accumulation of incremental damage beyond the endurance limit of the socket are termed wear-out failures. Overstress failures are catastrophic sudden failures due to the occurrence of a stress event that exceeds the intrinsic strength of a material. Wear-out failures occur when the accumulation of incremental damage exceeds...
TABLE 9.1  Potential Failure Mechanisms of IC Component Sockets

<table>
<thead>
<tr>
<th>Overstress Mechanisms</th>
<th>Wearout Mechanisms</th>
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<tbody>
<tr>
<td><strong>Contact</strong></td>
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<tr>
<td>Buckling</td>
<td>Oxidation</td>
</tr>
<tr>
<td>Yielding</td>
<td>Corrosion</td>
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<tr>
<td>Fracture</td>
<td>Electrochemical</td>
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<tr>
<td>Bent pins</td>
<td>migration</td>
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<td></td>
<td>Intermetallic</td>
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<tr>
<td></td>
<td>formation</td>
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<td></td>
<td>Stress relaxation</td>
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<td>Creep</td>
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<td>Fatigue</td>
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<td>Friction polymerization</td>
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<td></td>
<td>Whisker growth</td>
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<td></td>
<td>Fungus growth</td>
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<td></td>
<td>Contact wear</td>
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<tr>
<td><strong>Housing</strong></td>
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<tr>
<td>Dielectric breakdown</td>
<td>Outgassing</td>
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<tr>
<td>Fracture</td>
<td>Leakage current</td>
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<tr>
<td>Cracking</td>
<td>Swelling</td>
</tr>
<tr>
<td></td>
<td>Creep</td>
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</tbody>
</table>

Figure 9.1  Potential causes of socket failures.

the material endurance limit. Unanticipated stress events or stresses can either cause an overstress (catastrophic) failure or shorten life by causing the accumulation of wear-out damage. In well-designed and high-quality sockets, stresses that cause failure should not occur within the useful life of the sockets.
OEMs should work diligently to investigate the potential risk areas of a socket design and analyze the compatibility of the socket design with its intended application conditions and if not compatible, recommend corrective action. In some cases, OEMs may also need to address their system design, making it compatible with the socket design in consideration. In the following sections, the failure mechanisms related to socket contacts and socket housings are discussed.

9.1 DRY OXIDATION

Except for the noble metals, such as gold and palladium, a thin oxide layer usually grows on the surface of metals when they are exposed to the air. Some oxide layers, like nickel oxide, are very dense and self-limiting. In these, the diffusion of corrosive gases through the oxide layer is limited, and further oxidation is usually prevented. For some metals, the oxide layer is a porous structure that permits the penetration of corrosive gases through the oxide layer; in these, the oxide layer will get thicker gradually. A typical example is copper.

The oxidation process can be regarded as a two-way process, as shown in Figure 9.2. On the one hand, the corrosive gases will diffuse to the oxide–metal interface and react with metals; on the other hand, the metal atoms will move to the surface and become oxidized. A higher activation energy is needed for the latter process; thus it usually occurs at a high temperature. In these processes, the oxide layer acts as an electrolyte [15].

To avoid oxidation of metal contacts, a thin layer of metal may be plated on the contact surfaces to act as a diffusion barrier. There are two types of metal platings: noble metal platings, such as gold and palladium, and non-noble metal platings, usually tin or tin–lead. For noble metal platings, the surface is free of an oxide layer, and thus a low contact force is enough to obtain the contact resistance required. However, the noble metal platings are expensive and they usually require a layer of underplate, such as nickel, to enhance the diffusion barrier. Noble metal platings are generally used when the application environment is harsh and high contact reliability must be ensured. To reduce cost, the thickness of noble metal platings can be reduced or non-noble metal platings can be used.

![Figure 9.2 Oxidation process.](image-url)
For tin or solder platings, the oxide layer is hard and brittle, and a higher contact force is required to break the oxide layer to ensure a metallic contact.

### 9.2 PORE CORROSION

The presence of precious metal plating on a contact surface does not itself guarantee a film-free surface. The platings must be continuous and thick enough to prevent diffusion of the base metal to the contact surface. Pores in noble metal platings, especially when the plating is thin, will expose the underplate and base metal to the environment, leading to corrosion. At elevated temperatures, base metal atoms may diffuse to the contact surface and react with oxygen and pollutant gases, allowing corrosion products to migrate out of the pores [16]. This phenomenon is called *pore corrosion*. The process is shown in Figure 9.3, and an example is given in Figure 9.4.

**Figure 9.3** Schematic diagram of pore corrosion process.

**Figure 9.4** Gold-plated phosphor bronze after 10-day MFG exposure.
9.3 CREEP CORROSION

For contacts with precious metal coatings, at pores and any other place (cracks, edges, scratches), where the base metal is exposed to the environment, corrosion products can be generated and they can spread over the protective precious metal coating without chemical reaction with the plating. This phenomenon is known as creep corrosion. Figure 9.5 shows the creep corrosion starting from a surface scratch and moving over a noble metal plating surface. The sample is a copper coupon with Ni/Pd/Au plating.

In some sense, creep corrosion over a noble metal-plated surface could be regarded as an extension of the pore corrosion process, especially when corrosion products from adjacent pores begin to merge with each other. However, it is believed that pore corrosion is driven primarily by chlorine ions, while creep corrosion is usually a sulfur-dominant process [17]. In mixed flowing gas (MFG) testing, an established accelerating corrosion test for qualification of connectors [18], creep corrosion is regarded as a separate failure signature than pore corrosion.

According to field observations [19], sulfide products creep at the highest rate, especially silver sulfide; other reacting products, such as chloride, do creep but at orders of magnitude lower than those of sulfides; creep of all products is highest across pure gold. In a study on creep corrosion phenomena of IC packages [20], creep corrosion may also occur on a plastic surface. Creep corrosion products for this case have been found to be a mixture of chloride and sulfide of the base metal (copper) and the diffusion-barrier plating layer (nickel).

The physics behind the phenomenon of corrosion products creep is not yet apparent. However, two propositions are available. One is a surface diffusion theory, which states that creep corrosion is driven by concentration gradients of

![Figure 9.5](image_url)  
*Figure 9.5* Creep corrosion from scratches on copper coupon with Ni/Pd/Au plating.
chemical species of the corrosion product [21]. A surface diffusion coefficient can be used to quantify the mobility of corrosion products over a surface under given environmental conditions. On the other hand, galvanic corrosion theory provides another interpretation [22]. Metallic ions move from anode (base metal) toward cathode (noble plating) and are deposited near the cathode, combining with other anions in the electrolyte. In this way, corrosion products propagate over a noble metal plating surface and have a tendency to cover more area of the plating surface.

The effect of creep corrosion on contacts is the degradation of performance by increasing the contact resistance. Once corrosion products begin to spread over a plating surface, the contact resistance of the surface will increase, due to the poor electrical conductivity of corrosion products. Noise in electrical signals or current leakage may occur.

In engineering design of contacts with noble metal plating, the resistance to creep corrosion is usually considered as an important characteristic. MFG tests are often conducted in the laboratory to reproduce creep corrosion phenomena to simulate field use, and contact resistance can be measured to evaluate the effect of creep corrosion. MFG testing is described in Chapter 10.

### 9.4 FRETTING CORROSION

Fretting corrosion of electrical contacts is caused by repeated micromotions between closed contacts, creating oxides or wear debris that can raise contact resistance [23]. Micromotion can result from vibration, shock, or differential thermal expansion of materials in contact. The degradation mode of the separable interface is an increase in contact resistance.

Fretting corrosion is the most prevalent failure mechanism of tin alloy-plated surfaces. For tin-and tin alloy-plated contact surfaces, the oxide layer is thin, hard, and brittle. Being supported by a soft substrate (tin or tin alloys), this oxide layer is easy to break, and its fragments can be pressed into the underlying matrix of soft, ductile tin or tin alloys. A normal force, higher than gold–gold contact, is required to disrupt the oxide layer to ensure a pure metallic contact. However, the sliding motion between contact surfaces, which could result from vibration, temperature cycling, durability cycling, or contact wipe action, breaks the brittle oxide film at a neighboring site and exposes the fresh metal at the original site to oxidation. If the sliding motion is repetitive, the continuous oxidation of the exposed tin or tin alloys results in the buildup of a layer of oxide debris at the contact interface. The accumulation of oxides can cause an increase in contact resistance and eventually lead to an open contact. Fretting corrosion is demonstrated schematically in Figure 9.6. Extensive studies have been conducted on the fretting corrosion of tin and tin–lead soldering coatings [24–35].

Due to the toxicity of lead, use of tin–lead solders is gradually being phased out completely. The lead-free movement, driven by both legislation and market
forces, is also expected to spread to the field of IC socket and electrical connector manufacturing; that is, lead-free solders will also be used for mechanical separable contact finishes. The National Electronics Manufacturing Initiative (NEMI) has suggested tin–silver–copper and tin–copper alloys as lead-free alternatives.

Studies were conducted to determine the fretting corrosion characteristics of lead-free solder alloy, tin–silver–copper and tin–copper coatings, to compare their behavior to those of current tin–lead solders and to assess the reliability of lead-free electrical contacts [36]. Fretting corrosion tests were conducted at the conditions of 20 g normal force, 25-µm fretting distance, and a fretting frequency of 0.5 Hz. Fretting corrosion behavior of lead-free and tin–lead solder coatings was investigated at various temperatures (25, 50, and 80°C). Test results show that fretting corrosion rate is temperature dependent. As temperature increases, fretting corrosion is accelerated. This may be due to the acceleration of the metal oxidation reaction at the contact interfaces.

At room temperature, SnAgCu alloy coatings show better performance in fretting corrosion resistance compared to SnCu and SnPb alloy coatings. As temperature rises, the time to failure of the SnAgCu alloy coating becomes closer to the time to failure of the SnPb alloy coating. When temperature reaches as high as 80°C, the lead-free solders and tin–lead solder coatings have similar values of time to failure [36].
9.5 **GALVANIC CORROSION**

Galvanic corrosion results when two dissimilar metals are coupled in the presence of a conducting electrolyte due to the difference in their electrochemical potentials. The more positive the metal potential, the more noble the metal is, and thus the least prone to oxidation and corrosion. When two dissimilar metals are connected, the less noble metal will corrode relative to the more noble metal in a specific environment.

9.6 **STRESS CORROSION**

Stress corrosion, often called *stress corrosion cracking* (SCC), is the formation of brittle cracks in a normally sound material through the simultaneous action of an external or residual tensile stress, and a corrosive environment. In most cases, SCC has been associated with the process of active path corrosion, whereby the corrosive attack or anodic dissolution initiates at specific localized sites and is focused along specific paths within the material.

9.7 **ELECTROCHEMICAL MIGRATION**

Electrochemical migration is the transport of an ionic species generated by electrochemical reactions from one electrical conductor to another separated by a dielectric medium under the influence of an applied potential, which could cause dendritic growth and an electrical short. For electrochemical migration to occur, three conditions must be met: sufficient moisture, presence of an ionic species, and an applied potential.

Typical metals that are vulnerable to electrochemical migration include silver and copper. Silver migration can be described by [23]

\[
\begin{align*}
2\text{Ag} (s) + \frac{1}{2}\text{O}_2 (g) &= \text{Ag}_2\text{O} (s) \quad (9.1) \\
\text{Ag}_2\text{O} (s) + \text{H}_2\text{O} (l) &= 2\text{Ag}^+ + 2\text{OH}^- \quad (9.2)
\end{align*}
\]

The silver oxide is electrically conductive and moderately soluble in water. Silver ions under the influence of applied voltage migrate toward the cathode and are reduced to the metal. Dendrites will be initiated at the cathode and grow toward the anode, potentially causing contact shorts.

9.8 **INTERMETALLIC FORMATION**

An *intermetallic compound* is a material consisting of two or more metallic elements combined in definite proportions with bonding that is partially ionic in character. Intermetallic compounds usually have very limited solubility on either side of this fixed composition. Interdiffusion of metal atoms across the
contact interface between dissimilar metals can result in intermetallic formation. Intermetallic compounds form when one of the metals has a significantly larger electronegativity than the other. In cases where the metals have similar electronegativities and are fully soluble in one another in the solid state, the interdiffusion results in the formation of an alloy mixture. High temperature accelerates the diffusion of metal atoms across the contact interface and thus can accelerate the formation of intermetallics.

Intermetallic formation can initially strengthen the bond between dissimilar metals, but intermetallic compounds typically have complex crystal structures with limited opportunities for slip, and as such, are quite brittle. The brittle nature of the compounds can, over time, weaken the interface between the metals, especially if voids are present to act as stress concentration and crack initiation sites. Such voids are formed when the interdiffusion rate of the first metal into the second metal is different than that of the second metal into the first. This process can leave voids behind in the faster diffusion metal [37, 38].

In component lead-to-socket interconnections, the use of coated metal leads can result in complete transformation of the coating layer to intermetallics. This occurs when tinned copper leads are exposed to elevated temperatures. For example, in power connectors using tinned–copper conductors, skin and proximity effects can induce high currents [39]. Joule heating in these paths will accelerate intermetallic formation, make the interface less smooth, and reduce the current-carrying cross-sectional area, thus increasing the contact resistance. This increase in contact resistance further heats these contacts, resulting in additional intermetallic formation and eventual failure.

Intermetallic formation can also occur between coated component leads and coated socket contacts. This behavior is seen in the contact system where tinned leads are mated with gold-plated contacts. In this case, intermetallic formation can cause bonding across the connector, leading to contact seizure, difficulty of component extraction, and damage to the package terminals and socket contacts during disassembly.

If two dissimilar metals are to be bonded, they should either be mutually soluble so that they do not create brittle intermetallics, or they should have low interdiffusion rates that prevent the formation of excess intermetallics within the operating life of the structure at normal operating temperatures [40]. The use of palladium–nickel and gold–nickel coatings provides resistance to intermetallic formation.

9.9 STRESS RELAXATION

Stress relaxation is a time-dependent decrease in stress (force) in a solid under given constraint conditions. The relaxed stress is the difference between the initial and remaining stress. It is usually expressed as a percentage of the initial stress and called percent relaxation.

The American Society for Testing and Materials (ASTM) has a standard for stress relaxation tests for materials and structures [41]. In the procedures, the
material or structure is constrained (deformed) initially by externally applied forces, and the change in the external force necessary to maintain the deformation is determined as a function of time. The loads can be tensile, compressive, bending, or torsional.

Empirical models can be used to model stress relaxation. For example,

$$\frac{\sigma}{\sigma_0} = 1 - \beta \ln \left( \frac{t}{t_0} \right) \quad (9.3)$$

where $\sigma$ is the stress at time $t$, $\sigma_0$ is the initial stress, $\beta$ is the slope of the best-fit line, and $t_0$ is the intercept of best-fit line [42].

9.10 CREEP

Creep refers to time-dependent deformation under a constant force, often at elevated temperatures. Creep may occur at stress levels well below the yield strength of the material. Typical creep mechanisms include dislocation climb mechanisms, polymer chain reorientation (self-diffusion), grain boundary sliding, and intergranular or transgranular void migration (grain boundary diffusion). The activation energy required for each of these creep mechanisms is a material property and depends on temperature.

The creep process is often categorized into three stages: primary creep (a stage of decreasing creep rate), secondary creep (a stage of constant creep rate), and tertiary creep (a stage of increasing creep rate). When the load is first applied, there is an instantaneous elastic elongation, then a primary stage of a transient nature during which slip and work hardening take place in the most favorably oriented grains. During this stage, the creep rate is high initially and slows gradually to a minimum value. After this, a secondary stage of steady-state creep during which the deformation continues at an approximately constant rate. There exists a balance during this stage between work hardening rate and softening rate. In particular cases, under moderate stresses, the creep rate may continue to decrease to a very slow rate, while the secondary stage may last for a long time. The third stage (tertiary stage) occurs when the stress is high enough that the creep rate accelerates until fracture occurs [43].

At moderate stress levels, the creep strain due to steady-state creep may be expressed by Weertman’s creep law:

$$\varepsilon = C_s S^p t \exp \left( \frac{-E_a}{k_B T} \right) \quad (9.4)$$

where $t$ is the elapsed time, $S$ is the stress, $k_B$ is Boltzmann’s constant, $T$ is the absolute temperature, and $E_a$ is the activation energy. $C_s$, $n$, and $E_a$ are parameters determined experimentally [44]. Creep is an important failure mechanism for sockets. Contact creep can cause excessive contact deformation, loss of contact
force and retention, or act as a precursor to creep rupture. Housing creep may lead to loss of contact normal force, excessive stress on contacts, or displacement of contact members from their normal positions.

9.11 FRACTURE AND FATIGUE

Fracture is the breaking, rupturing, or separation of a material into two or more pieces. There are two fracture types, brittle fracture and ductile fracture. From a micromechanical perspective, brittle fracture typically occurs at preexisting microscopic flaws due to nucleation and sudden propagation of cracks. Brittle fracture can occur in glass and ceramic housing or due to the formation of brittle intermetallics in otherwise ductile materials such as solder.

Ductile fracture is dominated by shear deformation, and occurs by nucleation and coalescence of microvoids, due to concentration (pile-ups) of dislocations at defects such as second-phase particles, impurities, and grain boundaries. Ductile fracture requires more energy than brittle fracture because of the large accompanying material deformations. Therefore, ductile materials exhibit greater resistance to fracture than brittle materials.

Previous research on fracture mechanics has shown that there are three primary factors that determine the brittle fracture in structures: material toughness, crack size, and stress level. Material toughness is the material ability to carry load or deform plastically in the presence of a notch. It can be described in terms of the critical stress-intensity factor under conditions of plane stress or plane strain for slow loading and linear elastic deformation. Even with good fabrication and inspection, discontinuities are unavoidable. By fatigue and stress corrosion, initial small discontinuities can grow to a critical size and cause fracture. Tensile stresses (nominal, residual, or both) are necessary for brittle fracture to occur [45].

Fatigue is the process of cumulative damage caused by repeated fluctuating loads [46]. Fatigue is related to the accumulation of incremental damage of materials under cyclic loads, including the initiation and propagation of a crack. Fatigue damage occurs in regions that deform plastically under the applied fluctuating loads. After some number of load fluctuations, the accumulated damage causes the initiation of crack(s). Subsequently, the crack(s) propagate in the plastically damaged regions. It is this process that causes the fracture of materials in many cases.

The factors that affect fatigue formation include stress (load), geometry and properties of the component and materials, and external environment. The primary factor is the fluctuation of localized stress or strain. Fatigue can be accelerated by temperature changes, vibration, moisture changes and corrosion.

9.12 FRICTION POLYMERIZATION

Friction polymerization is related to the thin insulating film growth on metal surfaces in the presence of organic vapors and micromotion. Palladium is a
catalyst for polymer formation. Such frictional polymers at the contact interfaces can result in an increase in contact resistance and contact open.

9.13 WHISKER GROWTH

Conductive whiskers present a failure risk to any closely spaced electrical conductors. Conductive whiskers have been found to grow from a variety of surface finishes. In particular, cadmium, zinc, and tin finishes are known to produce conductive whiskers. Of these finishes, tin (Sn), because of its widespread use by the electronics industry, has received the most study. This attention is particularly warranted based on the identification of tin (Sn) as a replacement for the tin (Sn) lead (Pb) plating by a majority of electronic parts suppliers [47].

Tin whiskers have been reported to reach lengths of 10 mm; however, the typical length is less than 1 mm. Whiskers appear to be extruded from finished surfaces and have typical diameters of 1 µm, but larger and smaller diameters have been reported. The protrusion from the surface can be nodular or needle-like, with the needlelike whisker growing to lengths that present the highest concern. Metallurgic analysis indicates that whiskers from tin finished surfaces are formed of pure tin. Due to the ability of tin to conduct electricity, whiskers can short closely spaced conductors, causing permanent and/or transient failure of electronic hardware.

It is generally agreed that whisker formation is a stress relief process in the finish. Tin-finished surfaces with compressive stresses measured by x-ray diffraction (XRD) were found to produce whiskers, while no whiskers were found on surfaces with a measured tensile stress. Although XRD is a good tool, the measurement of stress is considered to be subjective and may not be practical for screening terminal finishes. Furthermore, the stress state in the finish can change over time. Sources of stress in tin finish include [48]:

- Residual stresses in the tin resulting from the plating process
- Susceptibility of electroplated finishes to the high current densities involved in the plating process
- Compressive stresses, such as bending or mechanically fixing the plated structure
- Scratches or nicks in the plating introduced by handling
- Coefficient of thermal expansion mismatches between the plating material and the substrate
- Copper contamination in the plating bath
- Changes in lattice spacing that occur from the formation of intermetallic compounds, such as those between copper and tin

From previous studies it has been reported that matte tin finishes are less prone to whiskers than are bright tin finishes. As such, part manufacturers have generally focused on the matte tin finish. The distinction between matte tin and
bright tin is generally based on appearance. A more quantitative distinction is the grain size in the finish. Larger grain sizes, between 1 and 5 µm, produce a duller surface appearance (matte), while smaller grain sizes, between 0.5 to 0.8 µm, produce a shiny surface (bright). Organic additives are usually added to the tin plating bath to produce the bright finish. Despite the claim that matte tin is a more whisker-resistant finish, it should be understood that matte tin can also produce whiskers. It is clear that control of the plating process is critical for reducing the potential for whisker formation, and a simple specification of matte tin is not sufficient to reduce the potential for whisker growth.

Motorola [49] has presented a study comparing parts with Sn, SnCu, SnBi, and SnPb terminal finishes. In this study, the parts were subjected to a 60°C/95% RH condition. From this study, SnCu was found to have the shortest formation time and the maximum whisker growth. The next-longest whisker occurred on the tin finish followed by the SnBi and the shortest found on the SnPb finished terminal. Whiskers on SnPb-finished parts are not generally reported, and no failures associated with whiskers on SnPb finishes have been reported. Studies by Texas Instruments have also shown whisker grown on assembled matte Sn finished parts subjected to a temperature, humidity, and electrical bias [50].

Despite a sustained effort to find a standard accelerated test, no single test or tests have been identified to demonstrate whisker growth propensity. Although reported studies by some part manufacturers show periods of no whisker growth, there is no conclusive evidence that whiskers will not form eventually. In considering the potential failure risk posed by Sn, one should not only be concerned about the finish on electrical devices. Cover plates, RF shielding, bolts, washers, and other mechanical fasteners could also present a risk. A detailed description of potential strategies to mitigate the failure risk posed by tin whiskers has been published by CALCE [51].

9.14 FUNGUS GROWTH

*Fungus spores* and *bacteria* (often called *mold* or *mildew*) are in the air regardless of temperature and humidity. Under conditions of high humidity, warm atmosphere, and the presence of inorganic salts, fungus tends to develop on the surface of materials. Fungus growth can contribute to corrosion of contacts, open and short circuits.

Fungal growth can break down nonresistant materials and use them as nutrients, which results in deterioration and affects the physical properties of the material. Typical nonresistant materials include cellulosic materials, synthetic materials, and plastics that contain organic fillers of laminating materials.

Fungal growth on a surface may increase deposits of dust, grease, perspiration, and other contaminants. Metabolic waste products (i.e., organic acids) excreted by fungus can also cause corrosion of metals, etching of glass, or staining or degrading of plastics and other materials. Fungi can form undesirable electrical conducting paths across insulating materials, or may affect adversely the electrical characteristics of critically adjusted electronic circuits.
In Military Standard 810F, fungus growth testing is used to determine if fungal growth will occur and, if so, how it may affect use of the material. The purpose is to assess the extent to which material will support fungal growth and how fungal growth may affect performance or use of the material. Since growth rate is a function of temperature and humidity, it is most closely related to the conditions of a hot, humid environment [52].

9.15 CONTACT WEAR

Wear is a physical process caused by relative motion between the contact members, usually caused by contact mating/unmating, wipe, shock, vibration, or thermal cycling. Contact wear is affected by a variety of factors, including contact normal force, coefficient of friction, contact geometry, surface roughness, surface films, hardness of base metal, plating and underplating, thickness of plating and underplating, use of lubricants, surface particles and contaminants, mating distance, wear mechanism, and the quality of the contact surfaces.

Wear mechanisms include adhesive wear, burnishing wear, abrasive wear, delamination, brittle fracture, and fretting wear. **Adhesive wear** occurs when adhesive forces between two contact surfaces are greater than the cohesive strength of an individual surface, causing metal transfer between surfaces. Adhesive wear is more likely to happen between the sliding members of the same metallurgy. Cleanliness intensifies adhesive wear, whereas lubrication is effective in reducing it.

**Burnishing wear** is similar in principle to adhesive wear, but with much less metal transfer because of lower contact deformation (force), cold welding, and coefficient of friction. For example, for hard gold contact surfaces, the transition load between burnishing and galling wear occurs at approximately 10 g for clean surfaces and over 500 g for lubricated surfaces [53].

**Abrasive wear** is caused by plowing the contact surfaces by a mating member or by particles at the contact interface that have a higher hardness. Two-body abrasive wear occurs when the harder and rougher contact member abrades the other member and removes material from that member. Three-body abrasive wear describes wear due to foreign particles invading the interface. Sand particle contamination in the contact interface is a typical example of three-body wear. Lubrication cannot reduce abrasive wear significantly.

**Delamination wear** is fatigue cracking at the subsurface from cyclical movement. Delamination exposes the base metal to corrosion and metal flakes from the cracks can contribute to abrasive wear. Lubrication can be effective to reduce delamination wear when the reduced shear stress due to the lubrication is sufficient to prevent subsurface cracking.

In contrast to fatigue cracking, **brittle fracture** is caused with only one motion cycle. When base metals deform under mating forces, cracks develop in the brittle metal plating, exposing base metal to corrosion. Lubrication is not effective in reducing brittle fracture wear.
Fretting is a small-amplitude oscillatory motion, usually tangential, between two solid surfaces in contact. Fretting wear occurs when repeated micromotion between the mated contact members induces surface or subsurface breakup and loss of unwanted mixing of material. Mechanical vibration or shock and thermal cycling are common causes of fretting.

Contact wear affects the number of mating cycles that a socket can experience before failure. However, wear by itself is not usually a failure mode; rather, it causes exposure of base metals, enabling wet, dry, and fretting corrosion.

9.16 OUTGASSING

Outgassing is gaseous emission from a material when exposed to reduced pressure and/or heat [54]. Outgassing occurs at low pressures (high vacuum), where molecules with relatively low weight fraction are absorbed (on surfaces) and absorbed (in bulk) gases, or moisture evaporates. Outgassing of some plastics contains volatile residues with low-molecular-weight content, which evaporate at high temperature. This can lead to condensation of volatile materials onto sensitive surfaces. As an example, unwanted films can be deposited on optical surfaces of scientific instruments (such as mirrors and lenses). NASA requires that the total mass loss (TML) must be less than 1% and the collected volatile condensable material (CVCM) less than 0.1% when tested in accordance with ASTM E595-93. It is always advisable to check the molding compound outgassing properties prior to use [55].

Outgassing testing is used to identify and quantify volatiles emitted from samples according to an accepted standard such as ASTM E595. This test method covers a technique to determine volatile content of materials when exposed to a vacuum environment. This method describes the test apparatus and related operating procedures for evaluating the mass loss of materials being subjected to 125°C at less than $7 \times 10^{-3}$ Pa for 24 h. Two parameters are measured: total mass loss and collected volatile condensable materials [56].

9.17 LEAKAGE CURRENT AND DIELECTRIC BREAKDOWN

Leakage current is the uncontrolled (parasitic) current flowing across region(s) of a socket in which no current should be flowing. A leakage current is usually the undesirable current that flows through or over the surface of an insulator or insulating material. Usually, the presence of condensed water on insulators makes their surfaces more conductive. Surface ion effects, corrosion, electrical arcing, and partial short-circuiting can also result in overall degradation and leakage currents [57].

Dielectric breakdown is the short-circuit failure of dielectric materials used in capacitors, insulators, and encapsulants that stem from electric fields applied across them [58]. Ceramic oxides, glasses, ionic compounds, and polymers are all susceptible to such a failure. Manifestations of the damage include the pitting,
cratering, and melted regions. Breakdowns are classified as electronic breakdown and thermal breakdown.

Two common tests are generally performed to evaluate dielectric breakdown: the ramp voltage and constant-voltage tests. The ramp voltage test consists of stressing the dielectric to breakdown by applying a voltage and increasing it linearly with time. In constant-voltage tests the dielectric is exposed to higher-than-designed operating voltages and the time to failure (breakdown) is recorded.

9.18 SWELLING

A socket housing can absorb moisture when exposed to a humid environment. Moisture absorption is typically caused by the polymer–water affinity action that occurs due to the availability of hydrogen bonding sites along the polymer chains.

Hygroscopic stresses arise when the housing swells upon absorbing moisture, whereas the contacting nonpolymeric materials do not experience swelling [59–68]. The differential swelling that occurs between the housing and nonpolymeric materials (e.g., contacts) leads to hygroscopic mismatch stresses.

An equation used to relate hygroscopic swelling to moisture content can be defined as

$$
\varepsilon_h = \beta C
$$

(9.5)

where $\varepsilon_h$ is the hygroscopic swelling strain, $\beta$ is the coefficient of hygroscopic swelling (CHS), and $C$ is the moisture content percentage, defined as

$$
\text{moisture content (\%)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100
$$

(9.6)

The CHS is a material property of a polymer, and if known, the hygroscopic swelling can be determined by measuring the moisture content in the polymer.

An experimental procedure to measure hygroscopic swelling utilizes a real-time whole-field displacement measurement technique called moiré interferometry, which is used to conduct extremely accurate measurements [69]. The technique can also be used to investigate the stressed-induced deformation caused by the mismatch in hygroscopic swelling. In environments such as in automotive applications, where sockets may be subjected to both temperature excursion and relative humidity change, hygroscopic-induced strains must be considered for reliability assessment.

9.19 SUMMARY

In this chapter various failure modes and mechanisms of IC component sockets are discussed. An understanding of these mechanisms helps socket design engineers select appropriate materials and design properly. It is also essential for socket reliability investigation and helps reliability engineers select suitable accelerated tests and stress levels to identify the basic causes of failures.
REFERENCES

REFERENCES


REFERENCES


10 Socket Testing and Qualification

Conducting tests to uncover failure mechanisms of sockets under actual operating conditions is generally an ineffective means of assessing reliability, due to the length of time needed to obtain data. Accelerated testing and virtual reliability assessment are approaches to obtaining meaningful data in shorter time periods.

10.1 ACCELERATED TESTING

Accelerated testing involves measuring the performance of the sockets at loads that are more severe than would normally be encountered. The goal of such testing is to accelerate time-dependent failure mechanisms and the damage accumulation rate to reduce the time to failure. The failure mechanisms and modes in the accelerated environment must be the same as (or quantitatively correlated with) those observed under actual usage conditions, and it must be possible to extrapolate quantitatively from the accelerated environment to the usage environment with some reasonable degree of assurance.

Accelerated testing begins by identifying the possible overstress and wear-out failure mechanisms (see Chapter 9). The load parameters that directly cause the time-dependent failure are selected as the acceleration parameters and are commonly called accelerated loads. Common accelerated loads include thermal loads, such as temperature, temperature cycling, and rates of temperature change; chemical loads, such as humidity, corrosives, acid, and salt; electrical loads, such as voltage or power; and mechanical loads, such as vibration, stress cycles, strain cycles, and shock impulses. The accelerated environment may include a combination of these loads. Interpretation of results for combined loads requires a quantitative understanding of their relative interactions and the contribution of each load to the overall damage. Table 10.1 provides some of the potential socket failure mechanisms and associated accelerated tests.

Failure due to a particular mechanism may arise by several acceleration parameters. For example, corrosion can be accelerated by both contaminants and humidity, and creep can be accelerated by both mechanical stress and temperature. Furthermore, a single acceleration condition may induce failure by several wear-out mechanisms simultaneously. For example, temperature can accelerate
ACCELERATED TESTING

wear-out damage accumulation not only by electromigration, but also by corrosion and creep. Failure mechanisms that dominate under usual operating conditions may lose their dominance as the load is elevated. Conversely, failure mechanisms that are dormant under normal use conditions may contribute to socket failure under accelerated conditions. Thus, accelerated tests require careful planning to avoid introducing extraneous failure mechanisms or nonrepresentative physical or material behavior.

The degree of acceleration is usually controlled by an acceleration factor, defined as the ratio of the life under normal use conditions to that under accelerated condition. The acceleration factor should be tailored to the socket in question.

<table>
<thead>
<tr>
<th>TABLE 10.1 Potential Failure Mechanisms and Accelerated Stress Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerated Stress Testing</td>
</tr>
<tr>
<td>High-temperature aging</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Temperature (power) cycling</td>
</tr>
<tr>
<td>Thermal shock, mechanical shock</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Vibration</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Humidity</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Temperature, humidity, and bias</td>
</tr>
<tr>
<td>Salt spray, pollutant gases</td>
</tr>
<tr>
<td>Sand and dust</td>
</tr>
<tr>
<td>Durability cycling (usually, as preconditioning)</td>
</tr>
</tbody>
</table>
and should be estimated from a functional relationship between the accelerated stress and required life in terms of all the socket parameters.

Once the dominant failure mechanisms are identified, it is necessary to select the appropriate acceleration loads; to determine the test procedures; to determine the test methods, such as constant stress acceleration or step-stress acceleration; to perform the tests; and to conduct failure analysis and interpret the test data. Accelerated test results will be extrapolated to the useful-life operating conditions by using models and obtaining acceleration factors.

Acceleration factors cannot be applied universally for all contact systems. For example, acceleration factors for MFG testing may be valid only for traditional metal contacts. They may not apply to other contact designs, such as elastomer sockets. Figure 10.1 shows acceleration factors for a contact thermal aging study [1].

Common attributes to be monitored during reliability testing include contact resistance, contact normal force, insulation resistance, and dielectric breakdown voltage. Attributes can be monitored periodically; in some cases, continuous monitoring is required to avoid missing failure opportunities. The measurement of dielectric breakdown voltage is a destructive test that should be done on separate samples or at the end of the process.

A contact interface may be subject to incursion of a variety of pollutant gases, and an oxide film can build up gradually at the interface, causing an increase in contact resistance eventually leading to a contact open. The extent of this increase is not homogeneously paced; at some point an acceleration can be observed.

Usually, a socket is not tested to total loss of its functionality ("hard open") as specified by the system, but instead, a certain failure criterion ($\delta R_v a l u e$) is defined. Above this criterion, the remaining life of the contact system is very

![Figure 10.1](image-url)  
**Figure 10.1** Acceleration factors as a function of test and field temperatures for contact thermal aging. (Based on Ref. 1.)
minimal. In traditional qualification, a socket is regarded as “pass” if the increase in contact resistance is less than 10 mΩ, or “fail” if the increase surpasses the criterion. This “10 mΩ” criterion was set for some metallic contact designs, since it was found that their contact resistance showed a period of dormant time before increasing exponentially. However, other failure criteria for contact resistance are also used; for example, an increase of 5 mΩ in contact resistance is regarded as a failure. In the specification of AMP, a separable connection fails when the contact resistance becomes three times its initial value [2]. All of these failure criteria may not be applicable to all socket designs, since the change in contact resistance may have different results for different designs. It is necessary to have product-specific requirements in order to assess the lifetime of the sockets under test conditions.

10.2 ENVIRONMENTAL CLASSIFICATIONS

Environmental conditions should be measured to determine the field conditions and provide guidance for test development. Generic classifications are often inaccurate and in many cases, wrong. Table 10.2 lists environmental classifications

<table>
<thead>
<tr>
<th>Environment Category</th>
<th>Temp. (°C)</th>
<th>Humidity (%)</th>
<th>Marine Atmosphere</th>
<th>Pollutant Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benign</td>
<td>+25 to +65</td>
<td>40 to 60</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sheltered with air conditioning and humidity control</td>
<td>+25 to +65</td>
<td>40 to 75</td>
<td>No</td>
<td>Possible</td>
</tr>
<tr>
<td>Sheltered with air conditioning and no humidity control</td>
<td>+25 to +85</td>
<td>&lt;85</td>
<td>No</td>
<td>Possible</td>
</tr>
<tr>
<td>Sheltered with normal heating</td>
<td>+15 to +85</td>
<td>&lt;95</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sheltered with uncontrolled heating</td>
<td>+5 to +85</td>
<td>&lt;95</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Unsheltered, light industrial</td>
<td>−40 to 100</td>
<td>&lt;95</td>
<td>Possible</td>
<td>Yes</td>
</tr>
<tr>
<td>Unsheltered, industrial</td>
<td>−65 to 125</td>
<td>&lt;95</td>
<td>Possible</td>
<td>Yes</td>
</tr>
<tr>
<td>Application-specific</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automotive</td>
<td>−55 to +150</td>
<td>&lt;95</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Medical</td>
<td>−40 to +85</td>
<td>&lt;95</td>
<td>Possible</td>
<td>Yes</td>
</tr>
<tr>
<td>Aircraft</td>
<td>−65 to +200</td>
<td>&lt;95</td>
<td>Possible</td>
<td>Yes</td>
</tr>
<tr>
<td>Process control</td>
<td>−40 to +100</td>
<td>&lt;95</td>
<td>Possible</td>
<td>Yes</td>
</tr>
<tr>
<td>Military</td>
<td>−65 to +125</td>
<td>&lt;95</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: Ref. 1.
### TABLE 10.3 Environmental Classification per SMC

<table>
<thead>
<tr>
<th>Use Category</th>
<th>$T_{\text{min}}$ ($^\circ$C)</th>
<th>$T_{\text{max}}$ ($^\circ$C)</th>
<th>Cycles per Year</th>
<th>Years of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>0</td>
<td>+60</td>
<td>365</td>
<td>1–3</td>
</tr>
<tr>
<td>Computer</td>
<td>15</td>
<td>+60</td>
<td>1460</td>
<td>5</td>
</tr>
<tr>
<td>Telecommunication</td>
<td>−40</td>
<td>+85</td>
<td>365</td>
<td>7–20</td>
</tr>
<tr>
<td>Commercial aircraft</td>
<td>−55</td>
<td>+95</td>
<td>365</td>
<td>20</td>
</tr>
<tr>
<td>Industrial and automotive</td>
<td>−55</td>
<td>+95</td>
<td>185</td>
<td>10</td>
</tr>
<tr>
<td>passenger compartment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Military ground and ship products</td>
<td>−55</td>
<td>+95</td>
<td>265</td>
<td>10</td>
</tr>
<tr>
<td>Space products</td>
<td>−55</td>
<td>+95</td>
<td>8760</td>
<td>5–30</td>
</tr>
<tr>
<td>Military avionics</td>
<td>−55</td>
<td>+95</td>
<td>365</td>
<td>10</td>
</tr>
<tr>
<td>Automotive under hood</td>
<td>−55</td>
<td>+125</td>
<td>1000</td>
<td>5</td>
</tr>
</tbody>
</table>

*Source: Ref. 3.*

based on EIA Standard 364. Table 10.3 lists environmental classifications documented by the Surface Mount Council [3], presented for reference purposes only.

### 10.3 TEST CONDITIONS

This section provides an overview of the various socket test types and test conditions. In many cases the sockets are preconditioned and a sequence of tests is run.

#### 10.3.1 Preconditioning

*Preconditioning* involves subjecting the socket to a set of load conditions prior to testing. The purpose of preconditioning is to simulate the conditions (loads during screening, assembly, transportation, storage) that a socket will experience prior to use. In general, proper preconditioning should be based on the actual worst-case pre-use conditions. These may include soldering, repair, multiple insertion conditions, contamination and moisture, and various other aging conditions.

A common preconditioning process for connectors is durability cycling. For production sockets, the durability may be from 20 to 50, but it could be much lower. For metallic designs with contact wipe, durability cycling causes contact wear and may cause base metal exposure, accelerating contact corrosion.

Thermal aging is another common precondition. It usually lasts for about 24 h. The purpose of this exposure is to simulate the storage conditions and to assess early infant mortality of a socket.

#### 10.3.2 Shock and Vibration

A socket assembly may experience dynamic loads during its lifetime, especially during transportation, handling, shipping, and use. Figure 10.2 shows the dynamic
force spectrum during a typical product transportation from Washington D.C. to San Francisco and back [4]. In the plot, the g level is expressed in the root mean square (RMS) value, an average over time. A peak of 50 g was observed.

Shock and vibration introduce relative motion between two mated contact surfaces of a socket system. If the socket is not designed properly, a voltage drop, in a time scale of microseconds or even nanoseconds, may result across the contact interface, causing contact intermittent failures. There may be different causes for this contact intermittency (see Chapter 11). Dust, contamination, and surface films on the contact interfaces may result in surface discontinuities due to contact relative motion. Under a dynamic force, a contact, if not well designed, may experience overstress or less than required normal stress. The contact resistance may change accordingly, causing glitches. The contact glitches may also be caused by the deflection of components supporting contacts, such as a circuit board in an LGA socket assembly. It was observed that contact intermittency occurs more often with low contact forces [5].

To examine the susceptibility of contacts to intermittencies, shock and vibration testing is performed. Glitches, on a time scale of microseconds or nanoseconds, are usually monitored. Shock and vibration are also used to examine contact integrity and the susceptibility of the socket housing to potential damage.

For vibration, two types of testing are performed: sine sweep and random vibration. *Sine sweep* is to simulate periodic motions experienced by a socket assembly and to determine its fundamental frequency. Usually, *random vibration* is performed in the frequency range 5 to 500 Hz, but it is important to understand the actual life-cycle conditions. Mechanical shock is performed by dropping a product from a certain height a certain number of times in all axes. The attributes to be monitored during shock and vibration testing include contact glitches and visible damage, such as cracks in the socket housing, contact permanent deformation, and fracture.
10.3.3 Thermal Aging

_Thermal aging_ is also often called a _temperature life test_. It is performed at a constant elevated temperature. Typical testing temperatures include 85, 105, and 125°C, but other temperatures are also used, subject to the understanding of operating conditions and design and material properties. Degradation mechanisms activated by thermal aging include:

- **Dry oxidation and corrosion.** High-temperature aging will accelerate the diffusion of elements and quicken the process of insulating film formation on the contact interface.
- **Intermetallic formation.** Some metals are more prone to intermetallic formation, such as gold and tin.
- **Creep and stress relaxation.** Socket housing and contacts may be susceptible to creep and stress relaxation. It is usually recommended that contact members not rely on socket housing to provide contact normal forces.

10.3.4 Temperature Cycling

Temperature (or thermal) cycling is a process of cycling through two temperature extremes with a specified ramp and soak time. Although the proper test conditions must depend on the operational conditions anticipated and acceleration requirements, the temperature levels for testing are usually 0 to 75°C, 0 to 100°C, and −40 to 100°C. The duration of one cycle is usually 1 h or 40 min, with ramp time and soak time 15 or 10 min, respectively. The ramp and soak times must be selected to allow the contact interface to reach the temperature extremes required. In some cases a thermal couple needs to be attached to the contact area to determine if the test temperatures are obtained. A typical thermal cycling profile is shown in Figure 10.3.

![Figure 10.3](image-url) Temperature profile for a typical thermal cycling in connector testing.
Degradation mechanisms that are activated by thermal cycling include fretting corrosion, fatigue, fracture, wear, and general aging. Under thermal cycling conditions, thermal excursions, due to the mismatch of coefficient of thermal expansion of a socket assembly, cause a relative motion between mated contact surfaces. The plating can gradually be damaged and worn, and a high-temperature soak accelerates oxidation and corrosion. This may cause a buildup of insulating films at the contact interface, resulting in an increase in contact resistance and even contact glitches. To capture contact glitches, contact resistance needs to be monitored continuously during thermal cycling.

*Thermal shock* is thermal cycling at a very high rate of temperature change, typically 30°C/min or higher. It simulates rapid temperature changes during product transportation, assembly, and use. Thermal shock can also be used to examine the limits of the socket design and assembly.

### 10.3.5 Thermal Cycling with Humidity

In thermal cycling with humidity, temperature is cycled between extremes while at low or high humidity. Compared to thermal cycling, cyclic humidity has a milder temperature range, with the low temperature above the freezing point of water, typically at room temperature, and the high temperature below the boiling temperature, typically 65 or 85°C. Degradation mechanisms activated by combined cyclic humidity and temperature testing include:

- Fretting corrosion due to thermal cycling
- Contact wet oxidation due to humidity exposure
- Susceptibility of plastic housing materials to moisture adsorption and swelling

The attributes to monitor during combined cyclic humidity and temperature testing include contact resistance, insulation resistance, and dielectric breakdown voltage. The former is used to monitor the contact behavior during exposure; the latter two are used to evaluate the housing materials.

### 10.3.6 Mixed Flowing Gas Tests

Corrosive contaminants in the atmosphere are reactive elements in the corrosion process. Gaseous pollutants in the atmosphere are produced by natural events and human activities. Natural sources of air pollutants include forest fires, volcanic eruptions, and decay of dead plants and animals. Anthropogenic sources of air pollutants include emissions from automobiles, oil refineries, chemical plants, and power plants. A list of corrosive gases in the atmosphere includes CO₂, SO₂, NOₓ, H₂S, Cl₂, NH₃, ozone, minerals, and organic acids. For electronics working mostly indoors, the gaseous pollutants level around them varies with season, geography, and natural and human influences. The interaction of airborne contaminants, together with the ambient temperature and relative humidity levels, contributes to the corrosion phenomenon in electronics.
The purpose of the mixed flowing gas (MFG) test is to simulate a field-use corrosive environment for electronics due to gaseous pollutant exposure in the atmosphere. An MFG test is a laboratory test conducted in air that flows through a test chamber in which the temperature, relative humidity, concentration of gaseous pollutants, and other critical variables are carefully defined, monitored, and controlled. With regard to contacts and sockets, MFG testing has been widely accepted as a reliability test method.

Since the early 1970s, researchers at Battelle Labs (Columbus, Ohio), Telcordia (previously Bellcore), and IBM have carried out MFG tests to accelerate atmospheric corrosion and evaluate corrosion effects on electronics. In the early 1990s, professional organizations, including the American Society for Testing and Materials (ASTM), Electronic Industries Association (EIA), International Electrotechnical Commission (IEC), and Telcordia, began to standardize test methods and publish guidelines. These are presented below.

**ASTM MFG Test Standards** Among the current available MFG test standards, ASTM provides the most comprehensive list of documents, covering almost every aspect to perform a well-controlled MFG testing. These documents include:

- **ASTM B827-97**: Standard Practice for Conducting Mixed Flowing Gas Environmental Tests
- **ASTM B845-97**: Standard Guide for Mixed Flowing Gas Tests for Electrical Contacts
- **ASTM B810-01a**: Standard Method for Calibration of Atmospheric Corrosion Test Chambers by Change in Mass of Copper Coupons
- **ASTM B825-97**: Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples
- **ASTM B826-97**: Standard Test Method for Monitoring Corrosion Tests by Electrical Resistance Probes
- **ASTM B808-97**: Standard Test Method for Monitoring of Atmospheric Corrosion Chambers by Quartz Crystal Microbalances

The nature of ASTM is to publish voluntary consensus standards for materials, products, systems, and services. Therefore, ASTM standards are more likely a review of existing MFG practices rather than a mandatory procedure for individual situations. For industrial applications, Battelle Labs MFG Test Methods, EIA 364-TP65A, IEC 68-2-60 Part 2, and Telcordia GR-63-CORE Section 5.5 Indoor/Outdoor MFG Test Methods are less flexible and have been treated as standards.

**Battelle Labs MFG Test Methods** The classification and parameters for the Battelle Labs MFG Test Methods are listed in Table 10.4. The operational environments for electronic equipment are divided into four classes, from least corrosive (class I) to most corrosive (class IV). Class I represents a well-controlled office environment with continuous adjustment. Class II represents a light industrial
environment, such as business offices without effective or continuous environment control. Class III represents a moderate industrial environment, such as storage areas with poor environment control. Class IV represents a heavy industrial environment, such as locations adjacent to primary sources of atmospheric pollutant gases. Battelle claims that field data for class I indicate no precedent for corrosion effects on electronics reliability, and thus there is no accelerated testing for class I. The other three classes use a combination of three corrosive gases (NO₂, HS₂, Cl₂), to simulate the corrosion effect. The acceleration factor for such tests is stated as “two days exposure in chamber for one year field use” [7], but such a statement does not provide a scientific explanation or corresponding verification, so that up to now there is no widely accepted acceleration factor for a typical MFG test.

**EIA MFG Test Methods: EIA 364-TP65A** EIA has published its own specifications for MFG testing, shown in Table 10.5. Class II, III, and IV parameters come directly from Battelle research. Classes IIA and IIIA are adaptation to classes II and III by adding SO₂ along with the other three corrosive gases.

**IEC MFG Test Methods: IEC 68-2-60, Part 2** Table 10.6 shows the parameters for MFG testing by IEC 68-2-60. Test method 1 is for testing to be used in mild environments. Methods 2 and 4 are appropriate for products to be used in moderate corrosive environments. Such environments may be found in telecommunication centers, most office environments, and some industrial instrument rooms. Test method 3 is appropriate for more corrosive environments.

**Telcordia MFG Test Methods: Telcordia GR-63-CORE, Section 5.5** The MFG test methods developed by Telcordia are focused on electronic equipment in

### TABLE 10.4 MFG Test Conditions Specified by Battelle Labs

<table>
<thead>
<tr>
<th>Class</th>
<th>Temp. (°C)</th>
<th>RH (%)</th>
<th>H₂S (ppb)</th>
<th>Cl₂ (ppb)</th>
<th>NO₂ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>30 ± 2</td>
<td>70 ± 2</td>
<td>10 ± 0/− 4</td>
<td>10 ± 0/− 2</td>
<td>200 ± 25</td>
</tr>
<tr>
<td>III</td>
<td>30 ± 2</td>
<td>75 ± 2</td>
<td>100 ± 10</td>
<td>20 ± 5</td>
<td>200 ± 25</td>
</tr>
<tr>
<td>IV</td>
<td>50 ± 2</td>
<td>75 ± 2</td>
<td>200 ± 10</td>
<td>50 ± 5</td>
<td>200 ± 25</td>
</tr>
</tbody>
</table>

*Source: Ref. 6.*

### SOURCE

**TABLE 10.5 MFG Test Conditions Specified by EIA**

<table>
<thead>
<tr>
<th>Class</th>
<th>Temp. (°C)</th>
<th>RH (%)</th>
<th>H₂S (ppb)</th>
<th>Cl₂ (ppb)</th>
<th>NO₂ (ppb)</th>
<th>SO₂ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>30 ± 2</td>
<td>70 ± 2</td>
<td>10 ± 5</td>
<td>10 ± 3</td>
<td>200 ± 50</td>
<td>–</td>
</tr>
<tr>
<td>IIA</td>
<td>30 ± 2</td>
<td>70 ± 2</td>
<td>10 ± 5</td>
<td>10 ± 3</td>
<td>200 ± 50</td>
<td>100 ± 20</td>
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<tr>
<td>III</td>
<td>30 ± 2</td>
<td>75 ± 2</td>
<td>100 ± 20</td>
<td>20 ± 5</td>
<td>200 ± 50</td>
<td>–</td>
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<tr>
<td>IIIA</td>
<td>30 ± 2</td>
<td>75 ± 2</td>
<td>100 ± 20</td>
<td>20 ± 5</td>
<td>200 ± 50</td>
<td>200 ± 50</td>
</tr>
<tr>
<td>IV</td>
<td>40 ± 2</td>
<td>75 ± 2</td>
<td>200 ± 20</td>
<td>30 ± 5</td>
<td>200 ± 50</td>
<td>–</td>
</tr>
</tbody>
</table>

*Source: Ref. 8.*
### TABLE 10.6 MFG Test Conditions Developed by IEC

<table>
<thead>
<tr>
<th>Method</th>
<th>Temp. (°C)</th>
<th>RH (%)</th>
<th>H₂S (ppb)</th>
<th>Cl₂ (ppb)</th>
<th>NO₂ (ppb)</th>
<th>SO₂ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25 ± 1</td>
<td>75 ± 3</td>
<td>100 ± 20</td>
<td>–</td>
<td>–</td>
<td>500 ± 100</td>
</tr>
<tr>
<td>2</td>
<td>30 ± 1</td>
<td>70 ± 3</td>
<td>10 ± 5</td>
<td>10 ± 5</td>
<td>200 ± 50</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>30 ± 1</td>
<td>75 ± 3</td>
<td>100 ± 20</td>
<td>20 ± 5</td>
<td>200 ± 50</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>25 ± 1</td>
<td>75 ± 3</td>
<td>10 ± 5</td>
<td>10 ± 5</td>
<td>200 ± 20</td>
<td>200 ± 20</td>
</tr>
</tbody>
</table>

*Source: Ref. 9.*

### TABLE 10.7 MFG Test Conditions Developed by Telcordia

<table>
<thead>
<tr>
<th>Method</th>
<th>Temp. (°C)</th>
<th>RH (%)</th>
<th>H₂S (ppb)</th>
<th>Cl₂ (ppb)</th>
<th>NO₂ (ppb)</th>
<th>SO₂ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>30 ± 1</td>
<td>70 ± 2</td>
<td>10 ± 5</td>
<td>10 ± 3</td>
<td>200 ± 50</td>
<td>100 ± 20</td>
</tr>
<tr>
<td>Outdoor</td>
<td>30 ± 1</td>
<td>70 ± 2</td>
<td>100 ± 20</td>
<td>20 ± 5</td>
<td>200 ± 50</td>
<td>200 ± 50</td>
</tr>
</tbody>
</table>

*Source: Ref. 10.*

telecommunication applications. Two MFG test methods are available from Telcordia, which are known as indoor and outdoor. The parameters for these two methods are listed in Table 10.7.

**Selection of MFG Test Methods** All MFG test methods utilize a minimum of three corrosive gases (H₂S + NO₂ + Cl₂) at different levels. Some require a fourth gas, SO₂. All of them operate at humidity levels in the range 70 to 80% relative humidity and temperatures in the range 25 to 30°C. There is no consensus regarding the best MFG test, although many industry engineers favor the four-gas tests. Typical exposure times vary greatly; typically in the range 10 to 20 days, with occasional requirements up to 40 days. However, it is the responsibility of the test specifier to assure the pertinence of a given test condition to the application condition.

### 10.3.7 Particulate Tests

With a separable interface, sockets are susceptible to failures caused by particulate deposition. Sources of particulates include airborne sand and dust, debris from contact wear, corrosion products, debris from packing materials, and debris from the socket housing. Particulates can be conductive, such as zinc fiber (in floor tiles for ESD protection), carbon fiber; or nonconductive, such as rust, alumina, calcite, or quartz. They can be corrosive, such as KCl, or KNO₃; or inert, such as quartz, or alumina. They can be hydroscopic, such as MgSO₄, or CuSO₄; or hydrophobic, such as quartz.

The effects of particulates on contacts can be summarized as follows:

- **Loss of contact area**: Area of influence of a dust particle reduces the effective contact area. A particle lying outside the actual contact area may prevent
physical connection by holding the mating members apart. Increasing the load and reducing particle size and contact hardness are ways to raise the actual contact area; however, embedded particles in a soft metal can cause an accumulation of contaminants. Smaller, more pointed contacts are less affected by dust than are flatter, rounder contacts. Although some contact designs provide a wiping mechanism, the effectiveness of contact wipe needs to be examined. Some contacts may not have enough force to scrub dust away. Small particles are typically more difficult to wipe away than large ones.

- **Contact short:** Conductive particles can cause circuit shorting; the finer the pitch, the higher the probability of a short circuit.

- **Contact wear:** Dust particles can increase the contact wear rate during durability cycling; higher hardness (higher abrasive) of a dust particle can cause a higher contact damage.

- **Corrosion:** Some dust particles contain corrosive elements and are hygroscopic; dissolution of salt can form a conductive path for corrosion and electromigration.

- **Plating porosity:** For a plating environment not carefully controlled, dust contamination can cause a large number of pores during the plating process.

To prevent particulate accumulation on the contact interfaces and its impact on contact behavior and reliability, some practices need to be followed. For contact designs with wiping mechanism, a suitable wipe length is necessary to clear particles from interfaces. Without contact wipe, a design should provide contact redundancy. A multiple-point contact design may reduce the risk of contact opens due to particulate deposition. A closed structure socket housing can effectively shield the contact area from particulate deposition.

For system-level design, airflow can be used to prevent deposition of particulates, sealing or sheltering can be used for dustproofing, and filtering can also be used to reduce dust concentration and size. Before socket assembly, contact pads of circuit boards and packages need to be cleaned and inspected to ensure that there is no fiber or dust on the contact area.

A variety of test standards were developed to assess susceptibility of contact designs to dust exposure. EIA 364-91, “Dust test for electrical connectors and sockets,” and EIA 364-50A “Dust (fine sand) test procedures for electrical connectors,” are commonly used to evaluate contacts and connectors. These tests are intended to evaluate the sensitivity of contacts to dust exposure, contact wipe effectiveness, and socket housing shielding effectiveness.

An acceleration factor may be obtained by calculating dust exposures during test and during the socket’s intended lifetime. However, the validity of such an acceleration factor is suspect, since the dust exposure may not be equivalent to the dust deposition. To make it simple, the EIA test standards are more like a saturation test. They do not intend to simulate the real applications. If a socket can pass the EIA standard test, it is often regarded as “dust risk free.”
10.4 TEST SEQUENCING

A test program is usually comprised of a set of multiple tests. The sequence may include preconditioning, operational and environmental exposures. The purposes of subjecting sockets to a sequence of testing are many. In a socket lifetime, a socket will experience a variety of loads, in a sequence or simultaneously. A sequence of tests may reveal or accelerate failure mechanisms which otherwise cannot be observed by subjecting a socket to a single test.

A test program may be comprised of different test groups. The testing items and load levels are different for different groups, since each sequence will expose a socket to different types of failure mechanisms and modes.

10.5 FOUR-WIRE VERSUS TWO-WIRE MEASUREMENT

There are two ways to monitor the contact resistance: four-wire low-level contact resistance (LLCR) measurement and two-wire loop resistance measurement. A schematic of these configurations for an LGA socket testing is shown in Figure 10.4.

The two-wire measurement is not a very sensitive method. Contributions from measuring wires and internal traces may be equivalent to the resistance of contacts tested. It may be very difficult to differentiate the increase in electrical resistance of wires and traces from that in contact resistance. If a contact interface sees a high contact resistance increase, it may not be observable during the measurement (the milliohm compared to the ohm level). The magnitudes of current and voltage are not controlled during two-wire measurement; a large current and/or a high voltage may destroy the film built up at the contact interface, making the assessment invalid. Since two-wire measurement includes a large contact population, it is difficult to pinpoint the location of failures if they occur; comparatively, it is much easier to locate the failure sites and identify root causes if failures are observed during four-wire measurement.

Four-wire measurement is used to eliminate the test leads resistance as an error when measuring very low resistance. There are two wires connected to the ends of the resistance to supply test current. There are another two wires connected to the ends of the resistance to measure the voltage. The test current \( I \) is supplied by a current source. The voltage across the tested resistance \( R \)

![Figure 10.4](image_url)  
**Figure 10.4** Four-wire (left) and two-wire (right) measurements.
is measured by a voltage meter. The voltage measured by the meter, $V_M$, can be expressed as $V_M = IR + I_{sense}(R + R_{other})$. Since test current $(I)$ is on the order of milliamperes, and sense current $I_{sense}$ from the voltage meter is on the order of picoamperes, and the voltage across other resistance caused by testing wires and other contacts can be ignored. Therefore, the resistance of the testing wires and other contacts as an error source is eliminated.

As shown in Figure 10.4, with the four-wire measurement only two adjacent contacts are tested. The LLCR includes four contact resistances, two bulk resistances of the pins, and the resistance of a trace inside the package. The electrical resistance of the testing wires is excluded. For two-wire measurement, a much larger population of daisy-chained contacts is often tested. The measured resistance is a summation of the contact resistance and bulk resistance of multiple contacts, and the resistance of internal (PCB and package) traces and measurement wires.

In four-wire measurement, the current and voltage need to be controlled to prevent damage of interface films, which could cause invalid measurement. According to ASTM and EIA standards, the short current should be less than 100 mA and the open voltage should below 20 mV. This is called dry circuit conditions.

Comparatively, the two-wire measurement can capture a much larger population of contacts without using a lot of testing resources. If two daisy chains are interlaced with each other, it can be used to detect the contact shorting between neighboring contacts. The two-wire method is also better to detect glitches during shock and vibration. The use of header connectors for the four-wire method may make it more difficult to investigate contact behavior under shock and vibration conditions, since the connectors themselves may also introduce glitches.

10.6 PERIODIC AND CONTINUOUS MONITORING

In performing tests on sockets, contact resistance is often measured after a period of exposure to accelerated stresses. Samples are taken out of the chamber and the contact resistance is measured. By comparing the contact resistance at different durations, the performance of the socket can be evaluated. For some designs, the socket behavior at high-temperature conditions may be different from that at normal room-temperature conditions. Therefore, periodic monitoring may miss some failure opportunities and intermittents that can otherwise occur temporarily at high or low temperatures, changing temperature, high or low humidity conditions and during vibration and shock.

When temperature and humidity change, stresses will be introduced due to expansion mismatches of different components of a socket assembly. A contact micromotion will be created, potentially inducing contact open in a very short period of time. This micromotion may also result in contact wear and fretting corrosion, which will further accelerate the tendency toward contact glitches. Furthermore, the expansion and contraction of a contact with stress cycling can result in changes in normal force, which can also cause fluctuations of contact resistance and contact glitches. In-situ continuous monitoring may capture these
stress–induced contact failures, while a periodic monitoring at room conditions will miss intermittents. Continuous monitoring can capture the critical point when the contact interface begins to show instability.

Glitch detecting is used to capture nanosecond contact discontinuities, which ordinary data acquisition systems cannot. During the glitch detection, a threshold resistance should be preset by taking into account the failure criteria during normal resistance monitoring. A glitch detector does not record contact resistance variation if within threshold value, and it may be susceptible to external disturbances. These create some complexities on how to interpret the data if a “dubious” glitch is observed.

The main drawback of in-situ continuous monitoring is the cost of the data acquisition equipment. Comparatively, periodic monitoring does not require sophisticated equipment or glitch detection.

10.7 VIRTUAL RELIABILITY ASSESSMENT

Virtual reliability assessment is a process that ultimately requires significantly less time and money than accelerated testing to qualify a part for its life-cycle environment, especially if it is a process incorporated as part of the design process. Virtual reliability assessment is a simulation-based methodology to determine whether a socket can meet its life-cycle requirements based on its materials, geometry, and operating characteristics. This methodology can be used to:

- Identify and rank the dominant failure mechanisms associated with the socket
- Conduct trade-offs to obtain optimum design parameters for the part/product and thus ruggedize the socket
- Design-in reliability in the very early stages of socket development and assist in reducing time-to-market
- Simulate the effect of piece-to-piece variabilities in the socket and the effect of variabilities in the life-cycle loads on the part failure distribution to extract critical data, such as mean time to failure, failure-free operating period, failure percentiles, failure rates at different stages of the socket life cycle, and distribution variances
- Establish warranties and maintenance activities
- Indicate potential failure mechanism shifting
- Provide acceleration factors, enabling scientifically tailored accelerated tests

Each potential failure mechanism comprises of a stress analysis model and a damage assessment model. Chapter 11 provides the foundation of the mechanisms and models. The output is a ranking of different failure mechanisms, based on the time to failure. The stress model captures the socket architecture, while the damage model depends on a material’s response to the applied stress. This process can therefore be applicable to existing as well as new sockets. Although
the data obtained from virtual reliability assessment cannot always fully replace those obtained from physical tests, they can increase the efficiency of physical tests by indicating the potential failure modes and mechanisms that the operator can expect to encounter.

Some models have been established by constructing the relationship between degradation performance parameters and identified rate-determining factors. However, modeling of a contact system has the following difficulties [11]:

- The reliability of a contact system is not only application dependent but also design and material dependent; there are many socket designs on the market. Different failure mechanisms and degradation trends can occur for different combinations of socket designs and applications. There is no single universal reliability model for all socket designs.
- For an electromechanical device, reliability modeling needs to take into account not only mechanical performance but also electrical performance. The degradation of electrical performance ultimately determines the socket reliability.
- Performance degradation of a contact system may not be continuous. The degradation mechanisms of a socket, such as stress relaxation and corrosion, although they themselves may be continuous, may not lead to contact resistance degradation in the absence of contact interface motion. This discontinuity causes difficulty in making an accurate prediction of a socket lifetime. Furthermore, contact systems are very susceptible to intermittent failures.
- Performance degradation of a contact system may be caused by a combination of different failure mechanisms. For example, the degradation of a contact interface may be caused by oxidation and stress relaxation. Modeling one failure mechanism without considering another may result in misleading results.

10.8 SOCKET QUALIFICATION

Once a socket is designed, it will go through tests to verify the design capability. This may take several iterations before the socket design can be finalized and released to market. Qualification by socket vendors is usually performed based on industry standards without pertaining to a specified application. As a result, qualification itself may prove to be inadequate for some designs and technologies. This is why reliability testing needs to be employed.

Qualification includes all activities which ensure that the nominal design and manufacturing specifications will meet or exceed the desired reliability targets. Qualification tests should be performed during initial socket development, and immediately after any design or manufacturing changes in an existing socket. Qualification validates the ability of the nominal design and manufacturing specifications of the socket to meet customer expectations. The purpose of qualification
is to define the acceptable range for all critical parameters affected by design and manufacturing, such as geometric dimensions, material properties, and operating environmental limits. Attributes that are outside the acceptable ranges are termed defects, since they have the potential to compromise reliability [12, 13].

Detailed failure analysis of failed samples is a crucial step in the qualification program. Without such analyses and feedback to the design team for corrective action, the purpose of the qualification program is defeated. In other words, it is not adequate simply to collect failure data. The key is to use the test results to provide insights into, and consequent control over, relevant failure mechanisms and to prevent them.

10.9 SUMMARY

In this chapter, accelerated stress tests to assess the long-term performance of sockets, which include thermal aging, thermal cycling, humidity, MFG, shock and vibration, and dust test, were introduced. These tests can be done individually or in combinations, and usually in sequence. Many standards, such as EIA 364, are available for references. However, stress-based socket qualification may not establish the reliability of a socket. Understanding the application conditions and inherent socket failure mechanisms is a key to establishing a successful assessment program to obtain the lifetime of a socket in its intended application.

REFERENCES


Queries in Chapter 10

Q1. Please clarify if the change made from ‘Mutichip’ to ‘Multichip’ is fine or if it should be left as such.
11 Reliability Assessment

In this chapter we present contact reliability theory and the potential causes of intermittency. Then there is a discussion of reliability prediction, followed by the approach necessary to achieve high socket reliability.

11.1 CONTACT RESISTANCE THEORY

Early research in contact resistance was conducted by Holm in the 1930s [1]. Holm proposed that contact resistance consists of two parts, constriction resistance and film resistance.

\[ R_{\text{contact}} = R_{\text{constriction}} + R_{\text{film}} \]  \hspace{1cm} (11.1)

Contact interfaces are never perfectly flat, due to microroughness. Instead, the solid material contact areas are actually contact asperities on the two contact surfaces. The asperity contact is also referred to as an a-spot. When electrical current flows through the contact interface, the current lines are distorted and restricted to pass through the a-spots. The electrical contact is a small fraction of the apparent contact area. The reduced electrical conduction area due to the a-spots increases the electrical resistance. This increase in resistance is defined as the constriction resistance of the contact interface.

Usually, there are oxides or other electrically insulative layers covering the contact metal surfaces before mating the contacts. Surface films are another source of the increase in electrical resistance. Normal and insert forces are necessary to rupture or displace insulative films and to enable electrically conductive contact at surface asperities.

Consider a flat circular area of a conducting particle embedded in the surface of a semi-infinite composite button. Let \( a \) be the radius of the conducting particle, let its center be at the origin and its axis along the \( z \)-axis, and let \( \rho \) be the resistivity of the conducting particle. The resistance of the particle is

\[ R = \frac{\rho}{4a} \]  \hspace{1cm} (11.2)
If the two contact members have electrical resistivity $\rho_1$ and $\rho_2$, respectively, the constriction resistance is

$$R = \frac{\rho_1 + \rho_2}{4a} \quad (11.3)$$

As noted, an electrical contact consists of multiple-contact a-spots due to surface roughness, and not all the mechanical contacts are electrically conductive. Electrical conduction occurs primarily at the spots where the surface insulating layers are removed. The removal (fracture) of surface insulating layers such as oxide films depend on the deformation of the contacting asperities. An approximation for the contact resistance is given by Greenwood [2] as

$$R_c = \rho \left( \frac{1}{2na} + \frac{1}{2\alpha} \right) \quad (11.4)$$

where $a$ is the mean a-spot radius, $\alpha$ the radius of the cluster (also defined as the Holm radius), and $n$ the number of circular a-spots within a cluster.

When the electrical interface has a sufficiently large number of a-spots within the Holm radius $\alpha$, the contact resistance can be approximated as

$$R_c = \frac{\rho}{2\alpha} \quad (11.5)$$

Greenwood’s [2] calculation for the radius of equivalent single contacts and the Holm radius suggest that the number and spatial distribution of a-spots are unimportant to evaluate the contact resistance. If the electrical contacts are reasonably uniform over the nominal contact area and there are no electrically insulating surface films, the Holm radius may be estimated from the true electrical contact area $A$ to the first approximation as

$$\alpha = \left( \frac{A}{\pi} \right)^{1/2} \quad (11.6)$$

Based on the assumption that the normal force is supported by plastic flow, the true mechanical contact area $A_m$ is related to the normal force $F$ and the hardness of the softer material in contact:

$$F = A_m H \quad (11.7)$$

One can see that the true contact area is independent of the nominal contact area and the dimension of the contacting objects but depends only on contact force and the hardness of the contacting members. When there is no insulating film, the electrical contact area is equal to the true (mechanical) contact area $A_m$. Then the contact resistance can be expressed as

$$R_c = \frac{\rho}{2}\sqrt{\frac{\pi H}{F}} \quad (11.8)$$
Contact finishes are used to protect the base metal of the electrical contacts and to maintain a stable, low contact resistance. The contact resistance depends on the relative electrical resistivity of the plating to the base metal and on the ratio of the radius of the a-spot to the plating thickness. Nakamura and Minowa [3] used finite element methods to simulate the electrically conductive plating film resistance at a contact interface. They found that the contact resistance is a function of the relative electrical resistivity of the plating to that of the substrate and the thickness of the plating, while neglecting the effect of microasperity.

When the resistivity of the plating material is larger than that of the base metal and the a-spot radius is on the same order of magnitude as the film thickness, the electrical current emanating from the a-spot spreads out significantly more into the substrate than into the plating. In this case, the potential drop in the immediate vicinity of the a-spot in the substrate is negligible in comparison with the potential drop across the film in a direction normal to the film–substrate interface. Therefore, the film–metal interface defines a nearly equipotential surface. The current density in the film is approximately uniform across the a-spot. At the a-spot, the current passes the plating film of area $\pi a^2$, thickness $d$, and resistivity $\rho_f$. The additional film resistance is approximately

$$R_f = \frac{\rho_f d}{\pi a^2} \tag{11.9}$$

For the case where the film is sufficiently thin, the total spreading resistance of a coated surface becomes

$$R_t = R_s + \frac{\rho_f d}{\pi a^2} = \left( \frac{\rho}{4a} \right) \left[ 1 + \left( \frac{4}{\pi} \right) \left( \frac{\rho_f}{\rho} \right) \left( \frac{d}{a} \right) \right] \tag{11.10}$$

Under the conditions where the a-spot radius and plated layer thickness do not differ greatly, the spreading resistance increases approximately linearly with plating thickness. For a sufficiently thick film, the spreading resistance will, of course, deviate from (11.10) and approach the value of $\rho_f / 4a$. Equation (11.10) is useful in pointing out that the effect of constriction resistance is overshadowed by the film resistance whenever the ratio $(\rho_f / \rho)(d/a)$ is much larger than unity.

Whether the resistivity of the plating is smaller or larger than that of the substrate, the effect of the plating on contact resistance is often evaluated via a plating factor. Thus the total contact resistance is

$$R_c = \left[ \left( \frac{\rho_{b1} p_{f1} + \rho_{b2} p_{f2}}{2} \right) \right] \sqrt{\frac{\pi H}{4F}} \tag{11.11}$$

where $\rho_{b1}$ and $\rho_{b2}$ are the resistivity of the base metal in contact, and $p_{f1}$ and $p_{f2}$ are the plating factors, which are related to the resistivity of the base material and plating material, the thickness of the plating, and the dimensions of a-spots. Since the dimensions of a-spots are affected by normal force, the plating factor
is a function of the normal force. The plating factor $p_p$ can be obtained by the algorithm provided by Williamson and Greenwood [5].

When the base metal and plating material are the same for both contacting members, the constriction resistance becomes

$$R_c = \frac{\rho_b p_p}{2} \sqrt{\frac{\pi H}{F}}$$  \hspace{1cm} (11.12)

The resistivity of a contamination film is generally much larger than that of metals. The contamination film resistance can be expressed as

$$R_{\text{cont}} = \frac{\rho_{\text{cont}} d_{\text{cont}} H}{F}$$  \hspace{1cm} (11.13)

where $\rho_{\text{cont}}$ is thickness of the contamination film, and $d_{\text{cont}}$ is the resistivity.

It is difficult to predict the effect of electrically insulating oxide films on contact resistance because conduction primarily occurs through cracks or other openings in these films. Crack formation depends on normal load as well as local shear stresses and the conventional expression (11.8), for contact resistance (i.e., contact resistance varying inversely with square root of contact load) no longer applies. The expressions for contact resistance due to thin layer of conducting contaminant film, (11.12) and (11.13), where resistance is inversely proportional to contact load, also do not apply. Contact resistance for insulating surface films must be evaluated experimentally from laboratory measurements.

11.2 CONTACT RELIABILITY THEORY

The electrically conductive contact material properties and geometry (area) essentially determines the resistance of electrical contacts over the lifetime of a contact pair. Over the lifetime of an electronic system, the properties and geometry can be diminished by numerous failure mechanisms, such as stress relaxation and corrosion. Insulating corrosion films can grow from defect sites in the noble metal plated contact surface, spread over the surface of the noble metal, and seep gradually into the asperity points, thereby decreasing the electrically conductive area in contact.

To assess the contact area, consider the simplifying case where all of the conducting asperity spots are circular (radii $a_1$, $a_2$, $a_3$, etc.) and lie at distances from each other that are large compared to their radii. Also assume that the size and surface feature of the conducting asperities on the contact surface are sufficiently uniform. The initial constriction resistance can be calculated as

$$R_c = \frac{\rho_{1,2}}{2n a_c}$$  \hspace{1cm} (11.14)

where $n$ is the number of contact spots and $\rho_{1,2}$ is the average resistivity of the mated couple.
Only the fraction of the area that is known as a contact spot can conduct current within each circular area of the conducting asperity. As current flows through the particles, it is impeded, giving rise to the constriction resistance at time $t$; that is,

$$ R_c(t) = \frac{\rho_{1,2}}{2 \sum a_v(t)} \frac{\rho_{1,2}}{nA_t} $$

(11.15)

where $A_t$ is the particle contact diameter and $n$ the number of contact spots. Each $A_t$ can shrink radially due to the growth of any corrosion film on the contact area. The expression of initial contact resistance $R(t = 0)$ is

$$ R_c(t = 0) = \frac{\rho_{1,2}}{2 \sum a_v(t = 0)} \frac{\rho_{1,2}}{nA_0} $$

(11.16)

where $A_0$ is the initial diameter of asperity contact area. The diameter $A_t$ of the contact area after time $t$ is

$$ A_t = A_0 - 2\xi $$

(11.17)

where $\xi$ is the penetration depth of the corrosion or oxidation film into the contact area given by the parabolic law [6].

$$ \xi = \gamma^2 D_0^{1/2} e^{-\frac{(Q_a - \sigma a^3)}{2K_Ta}} t^{1/2} $$

(11.18)

where

$$ T_a = \sqrt{T_0^2 + \frac{U^2}{4L}} $$

and $\gamma$ is a dimensionless constant, $D_0$ is the frequency factor, $Q_a$ is the activation energy, $\sigma a^3$ is the work done by the stress on the atom ($\sigma$ is negative for compressive stress), $K$ is the Boltzmann constant, $T_a$ is the absolute temperature at the contact, $U$ is the contact voltage drop, $L$ is the Lorentz constant, and $T_0$ is the absolute temperature in the noncontact area.

The combination of equations above yields the expression for the contact resistance after time $t$ as

$$ \frac{R(t)}{R(t = 0)} = \frac{1}{1 - \eta t^{1/2} e^{-\frac{(Q_a - \sigma a^3)}{2K_Ta}}} $$

(11.19)

where

$$ \eta = \frac{4\gamma}{A_0} D_0^{1/2} $$

and

$$ T_a = \sqrt{T_0^2 + \frac{U^2}{4L}} $$
Equation (11.19) shows how the lifetime contact resistance is modified as a function of stress and voltage drop. Therefore, it is possible, in practice, to estimate lifetime contact resistance of sockets for a given contact system and operating environment.

Previously published studies on electrical contact physics [7–11] have demonstrated experimentally that corrosion film formation is controlled by diffusion either in the surface film or in the near-surface region. The correlation between the lifetime resistance of electrical contacts and the growth kinetics of corrosion film on the surfaces of noble metal–plated electrical contacts was also established [12], showing that the behavior of lifetime contact resistance depends on

**Figure 11.1** Increase in contact resistances subjected to three contact stress levels at a voltage drop of 140 mV.

**Figure 11.2** Behavior of lifetime contact resistances in contact voltage drops under $\sigma = 4 \times 10^8 \text{ N/m}^2$. 
the mechanical contact load, electrical voltage drop across the contact spot, and the environmental temperature.

Equation (11.19) shows that lifetime contact resistance depends not only on the temperature at the a-spot, but also the stress in the contact area. As shown in Figure 11.1, the higher contact force can result in a longer lifetime of electrical contacts since the compressive force can suppress the growth of insulated corrosion film at a-spots. Figure 11.2 shows the change of contact resistance as a function of voltage drops across the contact area. Analytical results for lifetime contact resistance versus environmental temperatures is shown in Figure 11.3. Lifetime contact resistance increases with elevated environmental temperatures.

11.3 INTERMITTENCES

There are two approaches to explain intermittences in contacts: the asperity model and granular interface model [13]. An increase in contact resistance is described by the asperity model due to a reduction in the conducting contact area. The oxidation of the contact surfaces fills the valleys with oxide debris. Eventually, the contacts are separated because the contact interfaces are covered with oxide and no conduction is possible. A short-duration high-contact resistance event occurs at a time when the valleys are only partially filled with debris. During relative motion of the contacts, there can be moments when no asperity pair is conductive, because all mechanical loads are underpinned by the oxide layer.

Some researchers argue that the asperity model cannot explain intermittences of nanosecond duration. In contrast, the granular interface model assumes that the contact interface is covered with debris and the conduction occurs through the debris. The mechanism behind this effect is called percolation conduction. The
debris may consist of metal particles coated with an oxide layer and fully oxidized material. An electrical path is formed by direct metal-to-metal contact between particles or by tunneling through the thin oxide layer between neighboring particles. As described here, tunnel junctions are very sensitive to the relative spacing of the particles. It is assumed that a relative movement between the contact interfaces of only 30 Å could result in a discontinuity of nanosecond duration.

Neither model can justify contact voltage drops far above the melting voltage of 130 mV. Such high voltages could be explained by another phenomenon that has not yet been investigated in the context of intermittences: the scattering of conduction electrons by the constriction boundary in an electrical contact. This effect is noticeable when the size of the constriction is smaller than the electron mean free path of the conducting medium (\(\sim 10 \text{ nm} \) for many metals). It is argued that the additional resistance caused by the scattering does not generate Joule heat within the conducting medium. This could explain the measured contact voltage drops above softening and melting voltage.

11.4 SOCKET RELIABILITY PREDICTION

The first reliability prediction and assessment specifications for electronic equipment is traced back to November 1956 with the publication of the US Rome Air Development Center’s (RADC) RCA release TR-1100, Reliability Stress Analysis for Electronic Equipment, which presented models for computing failure rates of electronic parts. This was eventually followed by the release of MIL-HDBK-217 [14], Reliability Prediction of Electronic Equipment, which became popular as a handbook. Subsequently, companies and organizations such as British Telecom, the Nippon Telegraph and Telephone Corporation, Siemens AG, the Reliability Analysis Center (RAC), Bell Communications (now Telcordia), and the Society of Automotive Engineers (SAE) adopted the MIL-HDBK-217 philosophy to develop their own reliability prediction handbook or software. Examples of these methods include RAC’s PRISM [15], Telcordia SR-332 [16], SAE’s PREL [17], CNET’s reliability prediction method [18], Siemens’ SN29500 standard [19], and British Telecom’s HRD-4 [20]. The handbooks are generally poor methods of reliability prediction, especially for sockets. The authors do not recommend that they be used. Other methods used for reliability prediction, which have significantly more merit, include using field and test data, and stress and damage analysis. A comprehensive history of the development of reliability prediction methods can be found in Ref. 21.

11.4.1 IEEE Reliability Prediction Standard 1413

IEEE Reliability Prediction Standard 1413 [22] was developed to identify the key required elements for an understandable and credible reliability prediction and to provide its users with sufficient information to select a prediction methodology and to use the results effectively. A prediction complying with this standard
includes sufficient information regarding the inputs, assumptions, and uncertainties associated with the methodology used to make the prediction, enabling the risks associated with the methodology to be understood.

According to IEEE 1413, the item for which the prediction is performed must be clearly identified. This identification should be performed using the following:

- Description of the product, electronic system, or equipment
- Product function, architecture, geometries, architecture, and materials
- Possible redundancy
- Hardware and software relationship and human factors
- System-level block diagram

The IEEE standard 1413 identifies the elements of a comprehensive reliability prediction process for electronic systems (products) and equipment. Since the reasons for performing a reliability prediction vary (e.g., feasibility evaluation, comparing competing designs, spares provisioning, safety analysis, warranties, and cost assessment), a clear statement of the intended use of prediction results obtained from an IEEE 1413–compliant method is required to be included with the final prediction report. Thus, an IEEE 1413–compliant reliability prediction report should include:

- Reasons why the reliability predictions were performed
- The intended use of the reliability prediction results
- Information on how the reliability prediction results must not be used
- Where precautions are necessary

An IEEE 1413–compliant reliability prediction report should also identify the method used for the prediction and identify the approach, rationale, and references to where the method is documented. In addition, the prediction report should include:

- Definition of failures and failure criteria
- Description of the process to develop the prediction
- Required prediction format

IEEE 1413 specifically identifies the reliability prediction inputs that must be addressed with respect to the extent to which they are known and can be verified or are unknown. These inputs include, but are not limited to, usage, environment, lifetime, temperature, shock and vibration, airborne contaminants, humidity, voltage, radiation, power packaging, handling, transportation, storage, manufacturing, duty cycles, maintenance, prediction metrics, confidence levels, design criteria, derating, material selection, design of printed circuit boards, box and system design parameters, previous reliability data and experience, and limitations of the inputs and other assumptions in the prediction method.
Besides prediction outputs, the prediction results section should also contain conclusions and recommendations. The output is required to include system figures of merit and their definitions and confidence levels. The report should indicate how the conclusions follow from the outputs and the report should justify the recommendations, where the recommendations are stated in terms of specific engineering and logistic support actions. Since the uncertainty (or the confidence level) is affected by the assumptions regarding the model inputs, the limitations of the model, and the repeatability of the prediction, the reliability prediction results should be presented and included in the report.

### 11.4.2 Guidebook for IEEE Standard 1413

The purpose of IEEE 1413.1, Guide for Selecting and Using Reliability Predictions Based on IEEE 1413, is to assist in the selection and use of reliability prediction methodologies satisfying IEEE 1413, and thus in making informed decisions regarding the compliance of various methodologies to IEEE standard 1413. The guidelines enable the industry to capitalize on the positive aspects of the available prediction methodologies and to benefit from the flexibility of using various methodologies, as appropriate during product development, installation, and use.

In the section on reliability prediction methods, the guide reviews the engineering information assessment that is critical for developing an IEEE 1413–compliant reliability prediction. The guide then describes reliability prediction methods such as handbooks based on historic data (MIL-HDBK-217, RAC’s PRISM, SAE’s reliability prediction method, Telcordia SR-332, the CNET reliability prediction model), predictions using field data and test data, and the stress and damage model approach. The similarity analysis approach is included within the field data–based reliability prediction approach. Each of these sections has been developed by industrial and academic users and developers of the methodologies and represents the latest understanding of those methods. Examples of their use are also provided.

All the methods described in the guidebook have been evaluated per the requirements established in IEEE 1413 as described. The criteria used for the evaluation of these methods consist of a list of questions based on IEEE 1413 concerning the inputs, assumptions, and uncertainties associated with each methodology, enabling the risk associated with the methodologies to be identified. The assessment results are shown in Table 11.1.

### 11.5 ACHIEVING SOCKET RELIABILITY

Achieving socket reliability over time demands an approach that consists of a set of tasks, each requiring total engineering and management commitment and enforcement. These tasks impact socket reliability through the selection of materials, structural geometries and design tolerances, manufacturing processes
<table>
<thead>
<tr>
<th>Does the methodology identify the sources used to develop the prediction methodology and describe the extent to which the source is known?</th>
<th>Field Data</th>
<th>Test Data</th>
<th>MIL-HDBK-217F</th>
<th>SAE’s Handbook</th>
<th>Tekvordia SR-332</th>
<th>CNET’s Handbook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?</th>
<th>Field Data</th>
<th>Test Data</th>
<th>MIL-HDBK-217F</th>
<th>SAE’s Handbook</th>
<th>Tekvordia SR-332</th>
<th>CNET’s Handbook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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</thead>
<tbody>
<tr>
<td>Can be</td>
<td>Can be</td>
<td>Can be</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Are limitations of the prediction results identified?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Are failure modes identified?</td>
<td>Can be</td>
<td>Can be</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Are failure mechanisms identified?</td>
<td>Can be</td>
<td>Can be</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Are confidence levels for the prediction results identified?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Does the methodology account for life-cycle environmental conditions, including those encountered during (a) product usage (including power and voltage conditions), (b) packaging, (c) handling, (d) storage, (e) transportation, and (f) maintenance conditions?

| Yes. As input to physics of failure-based models for the failure mechanisms. | No. It does not consider the different aspects of environment. Environmental inputs include operating and dormant temperatures, relative humidity, vibration, duty cycle, cycling rate, and power and voltage conditions. | No. It does not consider the different aspects of environment. Ambient temperature, application stresses, and duty cycle are used as factors in prediction equation. | No. It does not consider the different aspects of environment. Ambient temperature, vibration and shock, power, and voltage conditions are used as factors in prediction equation. | No. It does not consider the different aspects of environment. Requires a range of parameter values that define each environmental category.

(continued overleaf)
<table>
<thead>
<tr>
<th>Field Data</th>
<th>Test Data</th>
<th>Stress and Damage Models</th>
<th>Handbook Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the methodology account for materials, geometry, and architectures that comprise the parts?</td>
<td>Can be</td>
<td>Can be</td>
<td>Yes</td>
</tr>
<tr>
<td>Does the methodology account for part quality?</td>
<td>Can be. Not considered explicitly. Used implicitly from the quality of the parts in the system.</td>
<td>Can be. Not considered explicitly.</td>
<td>Yes. Considered through the design and manufacturing data.</td>
</tr>
<tr>
<td>Does the methodology allow incorporation of reliability data and experience?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*a* Some data sources are included in the accompanying case.

*b* Parameters include vibration, noise, dust, pressure, relative humidity, and shock.

*c* Quality is defined as a measure of a part’s ability to meet the workmanship criteria of the manufacturer. Quality levels for parts used by some handbook methods are different from quality of the parts. Quality levels are assigned based on the part source and level of screening the part goes through. The concept of quality level comes from the belief that screening improves part quality.
and tolerances, assembly techniques, shipping and handling methods, operational conditions, and maintenance and maintainability guidelines [23]. The tasks are as follows:

1. Define realistic product requirements and constraints determined by the life-cycle application profile, required operating and storage life, performance expectations, size, weight, and cost. The manufacturer and the customer must jointly define the requirements in the light of both the customer’s needs and the manufacturer’s capability to meet those needs.

2. Define the life-cycle environment by specifying all relevant assembly, storage, handling, shipping, and operating conditions for the fielded socket. This includes all stress and loading conditions.

3. Characterize the materials and the manufacturing and assembly processes. Variabilities in material properties and manufacturing processes can induce failures. Knowledge of the variability is required to assess design margins and possible trade-offs.

4. Select the materials required for the socket using a well-defined assessment procedure that ensures that the materials selected have sufficient quality and integrity, are capable of delivering the expected performance and reliability in the application, and will be available to sustain the socket throughout its life-cycle.

5. Identify the potential failure sites and failure mechanisms by which the socket can be expected to fail. Potential failure modes and mechanisms must be identified early in the design, and appropriate measures must be implemented to assure design control. Potential architectural and stress interactions must also be defined and assessed.

6. Design to the usage and process capability (i.e., the quality level that can be controlled in manufacturing and assembly), considering the potential failure sites and failure mechanisms. The design stress spectra, the socket test spectra, and the full-scale test spectra must be based on the anticipated life-cycle usage conditions. The socket must survive the life-cycle environment, be optimized for manufacturability, quality, reliability, and cost-effectiveness, and be available to the market in a timely manner.

7. Qualify the socket and end-product manufacturing and assembly processes. Key process characteristics in all the manufacturing and assembly processes required to make the part must be identified, measured, and optimized. The goal of this step is to provide a physics-of-failure basis for design decisions, with an assessment of all possible failure mechanisms for the anticipated end product.

8. Monitor and control the manufacturing and assembly processes addressed in the design so that process shifts do not arise. Each process may involve screens and tests to assess statistical process control.

In this chapter, contact theory is presented. The contact lifetime of a socket can be assessed based on the calculation of a-spot area reduction due to insulation film growth. However, as a separable system, a socket contact seldom sees the static conditions as used in the theory; it will experience constant micromotions during its lifetime induced by load (stress) cycling. As a result, intermittencies may be observed. Two models are discussed to address the physics of intermittencies. Finally, reliability prediction methodologies are presented.

REFERENCES

12 Standards and Specifications

In this chapter, standards and specifications for IC component sockets, connectors, and related areas are listed for reference. These documents are developed by standards organizations in the United States and internationally. The letters in each standard denote the organization that is responsible for the document:

- AEC Automotive Electronics Council
- ANSI American National Standards Institute
- ASTM American Society for Testing and Materials
- EIA Electronic Industries Alliance
- IEC International Electrotechnical Commission
- IPC Institute for Interconnecting and Packaging Electronic Circuits
- ISO International Organization of Standards
- JEDEC Joint Electron Devices Engineering Council of EIA
- UL Underwriters’ Laboratories, Inc.
- MIL U.S. Department of Defense (DoD)
- QQ U.S. Department of Defense

12.1 STANDARDS AND SPECIFICATIONS

Standards and specifications can also be classified according to their contents. In this chapter the standards and specifications are categorized as follows:

- Standard references for quality management and assurance
- General standards and specifications for IC component sockets
- Safety-related standards and specifications
- Standard references for socket manufacturing
- Standard references for socket material property characterization
- Standard references for socket performance qualification
- Standard references for socket reliability qualification
- Other standards and specifications
### Standard References for Quality Management and Assurance

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 9001/9002</td>
<td>Quality program requirements</td>
</tr>
<tr>
<td>MIL-STD-109C</td>
<td>Quality assurance terms and definitions (canceled; suggested substitution: ISO 8402, or ASQC A8402)</td>
</tr>
<tr>
<td>MIL-STD-105E</td>
<td>Sampling procedures and tables for inspection by attributes (canceled; substitution: ASQC Z1.4–1993)</td>
</tr>
<tr>
<td>MIL-STD-45662A</td>
<td>Calibration system requirements (canceled; suggested alternative: ISO 10012-1, or ANSI Z540-1)</td>
</tr>
<tr>
<td>MIL-I-45208A</td>
<td>Inspection system requirements (canceled; no replacements)</td>
</tr>
<tr>
<td>MIL-I-45607C</td>
<td>Acquisition, maintenance, and disposition of inspection equipment (inactive for new design and no longer used except for replacement purposes)</td>
</tr>
<tr>
<td>IPC QS-95</td>
<td>General requirements for implementation of ISO 9000 quality systems</td>
</tr>
</tbody>
</table>

### General Specifications for IC Component Sockets

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-S-83505</td>
<td>General specifications for sockets</td>
</tr>
<tr>
<td>MIL-S-83734</td>
<td>Sockets, plug-in electronic DIP or SIP packages</td>
</tr>
<tr>
<td>MIL-C-39029D</td>
<td>General specifications for contacts of electrical connectors</td>
</tr>
<tr>
<td>EIA 540 series</td>
<td>Sockets: detailed specifications for chip carriers and electronic equipment</td>
</tr>
<tr>
<td>EIA 5400000</td>
<td>Generic specifications for sockets for IC packages for use in electronic equipment</td>
</tr>
<tr>
<td>EIA RS-488</td>
<td>Sockets, individual lead types (for electrical and electronic components)</td>
</tr>
<tr>
<td>EIA 415-B</td>
<td>General standard for sockets for use with dual- and single-in-line electronic packages and other electronic components</td>
</tr>
<tr>
<td>EIA 415-1</td>
<td>Application guide for IC sockets</td>
</tr>
<tr>
<td>EIA 506</td>
<td>Dimensional and functional characteristics defining sockets for leadless chip carriers (0.050 spacing)</td>
</tr>
<tr>
<td>IPC C-406</td>
<td>Design and application guidelines for surface-mounted connectors</td>
</tr>
</tbody>
</table>

### Safety-Related Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL 94 V0</td>
<td>Standard for safety, tests, and flammability of plastic materials and for parts in devices and appliances; serves as a preliminary indication of acceptability of plastic materials with respect to flammability for a particular application</td>
</tr>
<tr>
<td>UL 746B</td>
<td>Standard for safety of polymeric materials, long-term property evaluation; measures temperature index of polymers</td>
</tr>
</tbody>
</table>
Standard References for Socket Manufacturing

**Socket Contact**

ASTM B16-92  Standard specification for free-cutting brass rod, bar, and shapes for use in screw machines

ASTM B194-96  Standard specification for copper-beryllium alloy plate, sheet, strip, and rolled bar

ASTM B139-95  Standard specification for phosphor bronze rod, bar, and shapes

**Contact Plating**

MIL-G-45204  Standard specifications for electrodeposited gold plating (cancelled; recommended substitution: AMS 2422 and ASTM B488)

ASTM B488  Electrodeposited coatings of gold for engineering use

MIL-P-45209  Standard specifications for electrodeposited palladium–nickel (canceled; recommended substitution: ASTM B679)

ASTM B679  Electrodeposited coatings of palladium for engineering use

MIL-T-10727  Standard specifications for electrodeposited or hot-dipped tin plating (canceled; recommended substitution: ASTM B545 (type I), ASTM B339 (type II))

ASTM B545  Standard specification for electrodeposited coating of tin

ASTM B339  Standard specification for pig tin

MIL-P-81728  Standard specification for electrodeposited tin–lead plating (canceled; recommended substitution: SAE-AMS P-81728)

QQ-N-290  Federal standard specifications for electrodeposited nickel plating

MIL-C-14550  Standard specification for electrodeposited copper plating (canceled; recommended substitution: AMS 2418)

**Plating Thickness**

ASTM B487  Standard test method for measurement of metal and oxide coating thickness by microscopic examination of a cross section

ASTM B567  Standard test method for measurement of coating thickness by the beta backscatter method

ASTM A754  Standard test method for coated weight of metallic coatings on steel by x-ray fluorescence

Standard References for Socket Material Property Characterization

**Socket Housing**

ASTM D150  Ac loss characteristics and permittivity of solid electrical insulation
ASTM D256  Determining the izod pendulum impact resistance of plastics
ASTM D495  High-voltage, low-current, dry arc resistance of solid electrical insulation
ASTM D570  Water adsorption of plastics
ASTM D638  Tensile properties of plastics
ASTM D648  Deflection temperature of plastics under flexural load in the edgewise position
ASTM D695  Compressive properties of rigid plastics
ASTM D696  Coefficient of linear thermal expansion of plastics between $-30^\circ C$ and $30^\circ C$ with a vitreous silica dilatometer
ASTM D732  Test method for shear strength of plastics by punch tool
ASTM D785  Rockwell hardness of plastics and electrical insulating materials
ASTM D790  Flexural properties of unreinforced and reinforced electrical insulating materials
ASTM D792  Density and specific gravity (relative density) of plastics by displacement

**Socket Contact**

ASTM B16  Standard specification for free-cutting brass rod, bar, and shapes for use in screw machines
ASTM B139  Standard specification for phosphor bronze rod, bar, and shapes
ASTM B194  Standard specification for copper–beryllium alloy plate, sheet, strip, and rolled bar
ASTM B888  Standard specification for copper alloy strip for use in the manufacture of electrical connectors or spring contacts
ASTM B740  Standard specification for copper–nickel–tin spinodal alloy strip

**Standard References for Socket Performance Qualification**

**Dielectric Withstanding Voltage**

ASTM D149  Standard test method for dielectric breakdown voltage and dielectric strength of solid electrical insulating materials at commercial power frequencies
EIA 364-20A  Withstanding voltage test procedure for electrical connectors
IEC 60512-2  Electromechanical components for electronic equipment; Part 1: basic testing procedures and measuring methods; Part 2: General examination, electrical continuity and contact resistance tests, insulation tests and voltage stress tests
MIL-STD-1344, Method 3001.1 Test methods for electrical connectors: dielectric withstanding voltage

Insulation Resistance
ASTM D257 Standard test method for dc resistance or conductance of insulating materials
EIA 364-21B Insulation resistance test procedure for electrical connectors
MIL-STD-1344, Method 3003 Test methods for electrical connectors: insulation resistance

Contact Force
EIA 364-04 Normal force test procedure for electrical connectors

Mating/Unmating Force
EIA 364-13A Mating and unmating forces test procedures for electrical connectors
MIL-STD-1344, Method 2013 Test methods for electrical connectors: mating and unmating forces

Contact Retention
EIA 364-29B Contact retention test procedure for electrical connectors
EIA 364-35B Insert retention test procedure for electrical connectors
MIL-STD-1344, Method 2007 Test methods for electrical connectors: contact retention

Engagement/Separation
EIA 364-37B Contact engagement and separation force test procedure for electrical connectors
IEC 60512-13-1 Mechanical operating tests: engaging and separating forces
IEC 60512-1-3 General examination: electrical engagement length
MIL-STD-1344, Method 2014 Test methods for electrical connectors: contact engagement and separation force

Contact Resistance
EIA 364-06 Normal force test procedure for electrical connectors
IEC 60512-2 General examination, electrical continuity, and contact resistance tests, insulation tests and voltage stress tests
MIL-STD-1344, Method 3004.1 Test methods for electrical connectors: contact resistance
MIL-STD-1344, Method 3002.1 Test methods for electrical connectors: low-signal-level contact resistance
ASTM B539-96 Standard test methods for measuring contact resistance of electrical connections (static contacts)
Current-Carrying Capacity
EIA 364-70A  Temperature rise versus current test procedures for electrical connectors and sockets
IEC 60512-3  Basic testing procedures and measuring methods: current-carrying capacity test

Capacitance
EIA 364-30  Capacitance test procedures for electrical connectors

Inductance
EIA 364-33  Inductance of electrical connectors

Standard References for Socket Reliability Qualification

Environmental Test Methods
MIL-STD-810  Environmental engineering considerations and laboratory tests
EIA 540-B0AE  Detailed specification for production land grid array (LGA) socket for use in electronic equipment
EIA 540-A000  Sectional specification for sockets for chip carriers for use in electronic equipment
EIA 540-H000  Sectional specification for burn-in sockets used with ball grid array devices for use in electronic equipment
EIA 364-C  Electrical connector test procedures, including environmental classifications
AEC Q100-Rev C  Stress test qualification for packaged integrated circuits
MIL-STD-883  Test methods and procedures for microelectronics

Reliability Modeling and Prediction
MIL-HDBK-217F  Reliability prediction of electronic equipment
MIL-STD-756  Reliability modeling and prediction

Durability
EIA 364-09B  Durability test procedure for electrical connectors
MIL-STD-1344, Method 2016  Test methods for electrical connectors: durability

Vibration
EIA 364-28C  Vibration test procedure for electrical connectors and sockets
IEC 60512-6-5  Dynamic stress test: Section 5, Test 6a: random vibration

Mechanical Shock
EIA 364-27B  Mechanical shock test procedure for electrical connectors
**Temperature Life**  
EIA 364-17  
MIL-STD-1344, Method 1005.1  
- Temperature life with or without electrical load test procedure for electrical connectors
- Test methods for electrical connectors: temperature life

**Thermal Cycling/Shock**  
EIA 364-32B  
MIL-STD-1344, Method 1003.1  
- Thermal shock test procedure for electrical connectors
- Test methods for electrical connectors: temperature cycling

**Humidity**  
EIA 364-31  
MIL-STD-1344, Method 1002.2  
- Humidity test procedure for electrical connectors
- Test methods for electrical connectors: humidity

**Altitude**  
EIA 364-03B  
- Altitude immersion test procedure for electrical connectors

**Solder Wicking**  
EIA RS-486  
- Solder wicking test procedure for sockets, plug-in electronic components

**Mixed Flowing Gases**  
EIA 364-65A  
IEC 60512-11-7 (or IEC 60512-11-14)  
- Mixed flowing gases
- Climatic tests: Section 7, Test 11g, flowing mixed gas corrosion test

**Salt Spray**  
EIA 364-26A  
MIL-STD-1344, Method 1001.1  
- Salt spray test procedure for electrical connectors
- Test method for electrical connectors: salt spray

**Sand and Dust**  
IEC 60512-11-8  
- Basic testing procedures and measuring methods: Part 11, climatic tests; Section 8, Test 11, sand and dust

**Gastight**  
EIA 364-36A  
- Test procedure for determination of gastight characteristics for electrical connectors, sockets and/or contact systems

**Other Miscellaneous Standards**  
**Reporting**  
ASTM B868  
- Standard practice for contact performance classification of electrical connection systems
STANDARDS AND SPECIFICATIONS

12.2 Obtaining Documents

Copies of federal documents (designated as QQ-) and military documents (designated MIL-) are available without charge. The contact address is:

DODSSP Standardization Document Order Desk
700 Robbins Avenue, Building 4D
Philadelphia, PA 19111-5094
Tel: 215-696-2667
Fax: 215-697-1462
Web site: http://astimage.daps.dla.mil/online/

Other sources for standards and specifications are listed as follows:

American National Standards Institute (ANSI)
11 West 42nd Street
New York, NY 10036
Tel: 212-642-4900
Fax: 212-398-0023
Web site: http://www.ansi.org/

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
Tel: 610-832-9585
Fax: 610-832-9555
E-mail: gluciw@astm.org
Web site: http://www.astm.org/

Electronic Industries Alliance (EIA)
2500 Wilson Boulevard
Arlington, VA 22201-3834
Tel: 703-907-7500
Fax: 703-907-7501
E-mail: jkelly@eia.org
Web site: http://www.eia.org/
Global Engineering Documents
Customer Support A105
15 Inverness Way
Englewood, CO 80112
Tel: 800-624-3974
Fax: 303-792-2192
E-mail: globalcustomerservice@ihs.com
Web site: http://global.ihs.com/

Institute for Interconnecting and Packaging Electronic Circuits (IPC)
2215 Sanders Road, Suite 250
Northbrook, IL 60062-6135
Tel: 708-509-9700
Fax: 708-509-9798
E-mail: orderipc@ipc.org
Web site: http://www.ipc.org/

International Electrotechnical Commission (IEC)
3 Rue de Varembe
P.O. Box 131
CH-1211 Geneva 20
Switzerland
Tel: +41 22 919 02 11
Fax: +41 22 919 03 00
E-mail: info@iec.ch
Web site: http://www.iec.ch/

Society of Automotive Engineers (SAE)
400 Commonwealth Drive
Warrendale, PA 15096-0001
Tel: 724-776-4841
Fax: 724-776-0790
E-mail: standards@sae.org
Web site: http://www.sae.org/
APPENDIX A
Terms and Definitions

Accelerated stress test (AST)  A test that is conducted at higher stress levels than that the product experiences in the field in order to reduce the test time.

Ball grid array (BGA)  A package that has solder balls arranged in a grid pattern on the bottom of the package.

Band  A frequency spectrum between two defined frequency limits.

Bandwidth  The frequency band within which the performance of a device with respect to some characteristics, such as signal attenuation, falls (within specified limits of the characteristics). It also refers to the maximum frequency that a device is capable of passing in which the responsivity is not reduced more than 3 dB from the maximum response.

Burn-in  A screening method used to precipitate potential infant mortality failures by exposing parts to accelerated stress levels.

Capacitance  A characteristic representing the interaction of the electric field around the active conductor with nearby conductors (mutual capacitance) or with ground (self-capacitance).

Chip on board (COB)  A process in which unpackaged integrated circuits are attached physically and electrically to a circuit board and are then encapsulated with a “glob” of protective material such as epoxy.

Chip-scale package (CSP)  A category of semiconductor chip structures with nominal size no more than $1.2 \times$ the area of the original die size.

Column grid array (CGA)  A package that has high-temperature solder cylinders or columns arranged in a grid array on the bottom of the package.

Conductive elastomer  An elastomer that is made conductive by incorporating conductive particles or metallic wires inside the elastomer matrix.

Constriction resistance  A portion of contact resistance that is due to contact roughness.

Contact force  A force exerted by two mating surfaces against each other.

Contact resistance  An electrical resistance resulting from the microscale contact interface roughness and accumulated interfacial insulating films.
Appendix A  Terms and Definitions

**Contact retention**  The minimum load in either direction that a contact must withstand while remaining fixed in its normal position within an insert.

**Contact wipe**  An action that occurs when two contacts are mated with a sliding action, to ensure a metallic contact by penetrating the surface oxide layer and removing particulates and debris on the contact surfaces.

**Corrosion**  The destructive attack on a metal by a corrosive medium through chemical and electrochemical reaction.

**Creep**  Material deformation under constant force. It may occur at stress levels well below the yield strength of the socket contact.

**Crosstalk**  A phenomenon resulting from coupling the electromagnetic fields surrounding an active conductor with its adjacent conductors.

**Current rating**  The maximum current that a conductor will carry based on temperature rise. Also called current-carrying capacity.

**Dielectric breakdown**  A phenomenon in which a voltage above a certain limit will cause the loss of insulating properties of a dielectric medium, leading to a large leakage current between contacts.

**Dielectric constant**  A measure of the ability of a material to store the electrostatic field energy.

**Dielectric withstanding voltage (DWV)**  The maximum voltage at which an insulator can withstand and maintain its insulating property under a specific condition for a specific period of time.

**Dissipation factor**  A measure of dielectric loss of an insulator. For an ideal dielectric, the current flows 90° out of phase with the voltage. However, for a nonideal dielectric, the current leads the voltage by an angle less than 90°. Suppose that the phase difference is $d$, the power loss is proportional to $\tan(d)$, which is called the dissipation factor, loss tangent, or quality factor. Dielectric loss is manifested by heat dissipation.

**Dual-in-line package (DIP)**  A package that has two rows of leads extending at right angles from the base, intended for through-hole mounting.

**Electrochemical migration**  The transport of an ionic species generated by electrochemical reactions from one electrical conductor to another separated by a dielectric medium under the influence of an applied potential. Also called electromigration, metal migration, conductive filament formation, or dendrite formation.

**Extraction force**  A force required to remove a lead from a contact.

**Failure mechanism**  The detailed process at the molecular level that offers a physical explanation of the failure mode observed in a system.

**Failure mode**  A discernible feature of a failure in a system, such as an open, short, or intermittent change in a particular parameter of interest.

**Fatigue**  A wear-out failure mechanism that includes the initiation and propagation of a crack. Fatigue is related to the accumulation of incremental damage of materials under cyclic mechanical loads.
**Flip-chip attach (FCA)**  A method of attaching a silicon device to a carrier. The interconnection pads or bumps on the active side of a silicon device are brought into direct contact with the bumps or pads on the carrier and reflowed to effect the interconnection. The gap between the silicon device and the substrate is filled with an encapsulant material for reliability and protection from the environment. Also called direct chip attach (DCA).

**Fretting corrosion**  The movement between contact surfaces, due to vibration or CTE mismatch, that breaks the brittle oxide film on the surface of a base metal (typically, tin or tin alloys) and exposes the fresh metal to oxidation and corrosion. The accumulation of oxides at the contacting interface due to repetitive sliding movements causes contact resistance to increase, leading to contact opens.

**Friction polymerization**  Related to thin insulating film growth, typically on the palladium-plated surfaces, in the presence of organic vapors and micromotion.

**Fungus growth**  Under conditions of high humidity, warm atmosphere, and presence of inorganic salts, fungus tends to develop on the surface of materials.

**Fuzz Button**  An interconnection technique for attaching components such as multichip modules to circuit boards utilizing metal wire buttons. Fuzz Buttons are inserted between the pads on the base of the package and their corresponding pads on the board. When the package is forced against the board, the Fuzz Buttons compress to form good electrical connections. One of the main advantages of the Fuzz Button approach is that it allows broken devices to be quickly removed and replaced.

**Galvanic corrosion**  Results when two dissimilar metals are coupled in the presence of a conducting electrolyte, due to the difference in their electrochemical potentials.

**Gas tightness**  A design characteristic of contact systems where the contact interface is impervious to corrosive gases or fumes.

**Gold flash**  An extremely thin layer of gold with a thickness measured on the molecular level, which is either electroplated or chemically plated onto a surface.

**IC component socket**  An electromechanical system that allows for a separable mechanical and electrical connection between IC components and a printed circuit board.

**Impedance**  Resistance to the flow of current caused by resistive, capacitive, or inductive devices (or undesired elements) in a circuit.

**Inductance**  A characteristic representing the interaction of the magnetic field around the active conductor with nearby conductors (mutual inductance) or with ground (self-inductance).

**Insertion force**  A force required to insert a package lead into a socket contact.

**Insulation resistance**  The resistance to leakage current of an insulating medium between two conductors.

**Intermetallic formation**  At high temperature the diffusion of metal atoms accelerates across the contact interface, causing the formation of intermetallics.
Leadless chip carrier (LCC) A family of packages with metallized castellations on the bottom and sides.

Multichip module (MCM) A functional island package to accomplish a number of functions by packaging several devices, both active and passive, onto one substrate.

Pad An area of metallization on a substrate used for probing or to connect to a via, plated through-hole, or an external interconnect.

Pin grid array package (PGA) A family of high-density through-hole packages with arrays of male pins extending from the bottom of the packages.

Plastic leaded chip carrier (PLCC) A package that has leads on all four sides, each lead bent like the letter J.

Plated through-hole (PTH) A drilled and plated hole in a printed circuit board to accomplish electrical interconnection to the circuit lines of different layers of the board to construct an interconnection between a component and the board.

Pore corrosion Although some alloys are plated with a layer of noble metal platings, the porosity of platings exposes the underplates and base metal to the environment, leading to corrosion. At elevated temperatures base metal atoms may diffuse to the contact surface and react with oxygen and pollutant gases, and the corrosion products may migrate out of the pores and spread over the noble metal platings.

Printed circuit board (PCB) A type of circuit board that has conducting tracks superimposed, or printed, on one or both sides, and may also contain internal signal layers and power and ground planes. An alternative name, printed wire board (PWB), is more commonly used in the United States.

Propagation delay A measure of the time for a wave to travel a specific length of a conductor.

Quad flat pack (QFP) A package that has surface-mountable leads on all four sides, which are bent down and out like gull wings.

Qualification The validation of a product’s capability to function in its intended application.

Reflow A method or technique of constructing an interconnection between components and the printed circuit board under a temperature profile, subsequent to placement of the parts in the corresponding locations.

Reliability The ability of a product or system to perform as intended (i.e., without failure and within specified performance limits) for a specified time, in its life-cycle application environment.

Signal attenuation A reduction in amplitude of a signal. The degree of attenuation is often measured in terms of decibels (dB).

Small-outline J-leaded package (SOJ) A leadframe-based package with a molded plastic body and leads extending out from two sides of the package and wrapped underneath the body, forming the shape of the letter J.

Small-outline package (SOP) A surface-mounted package that has two parallel rows of gull-wing leads.
**Solder wicking**  The movement of molten solder up a lead, along a conductor–dielectric interface, or through a via hole due to capillary action.

**Solderability**  A measure of the ability of a pad or component lead to be wetted by molten solder.

**Stress relaxation**  A time-dependent decrease in stress (force) under constant strain. It is correlated with plastic deformation under prolonged stressing.

**Surface-mounted technology (SMT)**  A technique for populating hybrids, multichip modules, and circuit boards, in which packaged components are mounted directly onto the surface of the substrate. A layer of solder paste is screen-printed onto the pads and the components are attached by pushing their leads into the paste. When all of the components have been attached, the solder paste is melted using either reflow soldering or vapor-phase soldering.

**Tape automated bonding (TAB)**  The process of mounting the die directly to the surface of a substrate, and interconnecting the two using a fine lead frame.

**Temperature rating**  A recommended temperature range within which the socket will operate successfully.

**Thick-film process**  A process used in the manufacture of hybrids and, to a lesser extent, multichip modules, in which signal and dielectric (insulating) layers are screen-printed onto the substrate.

**Type 1 assembly**  An exclusive SMT PCB assembly with components mounted on one or both sides of substrate.

**Type 2 assembly**  A mixed technology for PCB assembly with SMT components mounted on one or both sides of the substrate and through-hole components mounted to the primary side.

**Type 3 assembly**  A mixed technology for PCB assembly with passive SMT components and, occasionally, SOICs mounted on the secondary side of the substrate and through-hole components to the primary side.

**Via**  A hole filled or lined with a conducting material that is used to link two or more conducting layers in a substrate.

**Wave soldering**  A process of joining metallic surfaces through the introduction of molten solder to metallized areas.

**Whisker growth**  When subjected to compressive stresses, some metals, such as tin or silver, have a tendency to grow thin filament types of whiskers.
APPENDIX B
Socket Manufacturers

Advanced Interconnections
5 Energy Way
P.O. Box 1019
West Warwick, RI 02893
Web site: http://www.advintcorp.com
Production sockets: SIP sockets, DIP sockets, PGA sockets, sockets for surface mounted devices

AMP, Incorporated
Harrisburg, PA 17105
Web site: http://www.amp.com
Production sockets: DIP sockets, SIP sockets, PLCC sockets, PQFP/CQFP sockets, PGA sockets

Andon Electronics Corporation
4 Court Drive
Lincoln, RI 02865-9923
Web site: http://www.andonelect.com/
Production sockets: SIP sockets, DIP sockets, SOP sockets, SOJ sockets, PLCC sockets, PGA sockets, BGA sockets

Aries Electronics, Inc.
Trenton Avenue
P.O. Box 130
Frenchtown, NJ 08825-0130
Web site: http://www.arieselec.com
Test/burn-in sockets: DIP sockets, ZIP sockets, PGA sockets, PLCC sockets, SOIC sockets, BGA sockets, LGA sockets
Production sockets: DIP sockets, SIP sockets, ZIP sockets, PGA sockets, SOJ sockets, PLCC sockets

Azimuth Electronics, Inc.
2650 South EL Camino Real
San Clemente, CA 92672
Test/burn-in sockets: QFP sockets, PLCC sockets

Berg Electronics, Inc.
825 Old Trail Road
Etters, PA 17319
Web site: http://www.bergelect.com/
Production sockets: SIP sockets, DIP sockets, PLCC sockets, SOJ sockets,
PGA sockets

Century Interconnect Products
1895 Stratford Avenue, Unit F
Stratford, CT 06497
Web site: http://www.centuryinterconnect.com/
Production sockets: SOJ sockets, PLCC sockets

CGN Technology Innovators
E-mail: custserv@cgntech.com
Web site: http://www.cgntech.com/
Production sockets: PLCC sockets

Chupond America, Inc.
6168 Greenhill Road
New Hope, PA 18938-9630
Web site: http://www.chupond.com/
Production sockets: DIP sockets, SOJ sockets, PLCC sockets, PGA sockets

CINCH Connector Division
865 Parkview Boulevard
Lombard, IL 60148-9515
Web site: http://www.cinch.com
Production sockets: wire-button LGA sockets

Circuit Assembly
18 Thomas Street
Irvine, CA 92618
Web site: http://www.ca-online.com/
Production sockets: DIP sockets, PLCC sockets

Elastomeric Technology, Inc.
Hatboro, PA
Products: Elastomer sockets

Elpakco Corporation
2 Carl Thompson Road
Westford, MA 01886
Web site: http://www.elpacko.com/
Production sockets: ZIP sockets, SIP sockets, DIP sockets, PLCC sockets, PGA sockets, QFP sockets

Emulation Solutions
3024 Scott Boulevard
Santa Clara, CA
Web site: http://www.adapters.com/
Products: adapters

Emulation Technology
2344 Walsh Avenue, Building F
Santa Clara, CA 95051-1301
Web site: http://www.emulation.com/
Burn-in sockets: DIP sockets, flatpack sockets, LCC sockets, SOP sockets, SOJ sockets, PLCC sockets, QFP sockets, BGA sockets
Production sockets: DIP sockets, PGA sockets, LCC sockets, PLCC sockets, QFP sockets

Enplas-Tesco, Inc. (Pelham office)
73 Sherburne Road
Pelhem, NH 03076
Web site: http://www.enplas.com/
Test/burn-in sockets: PGA sockets, SOP sockets, TSOP sockets, PLCC sockets, SOJ sockets, QFP sockets, TAB sockets, BGA sockets.

Electronic Precision Technology
EPT USA Inc.
149A California Street
Newton, MA 02458
Web site: http://www.ept.de/home_e.htm
Production sockets: DIP sockets, PGA sockets

E-tec
P.O. Box 4078
Mt. View, CA 94040
Web site: http://www.e-tec.ch/
Production sockets: SIP sockets, DIP sockets, PGA sockets, SOJ sockets, LCC sockets, PLCC sockets, BGA sockets

Everett Charles Technologies
700 East Harrison Avenue
Pomona, CA 91767
Web site: http://www.ectinfo.com/
Test sockets: BGA sockets

Excel Cell Electronic (USA) Corp.
1 Gate Hall Drive, Plaza Level
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Parsippany, NJ 07054
Web site: http://www.ece-usa.com/
Production sockets: SIP sockets, DIP sockets, PGA sockets

FormFactor, Inc.
5666 La Ribera Street
Livermore, CA 94550
Web site: http://www.FormFactor.com/
Production sockets: LGA sockets

Foxconn
Web site: http://www.foxconn.com/
Production sockets: DIP sockets, PGA sockets, SOJ sockets, PLCC sockets

High Connection Density
1267 Borregas Avenue
Sunnyvale, CA 94089-1308
Web site: http://www.hcdcorp.com/
Burn-in sockets: LGA sockets
Production sockets: LGA sockets

IBM Technology Products Division
1701 North Street
Endicott, NY 13760
Production sockets: BGA sockets

IBM Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
Production sockets: BGA sockets

Intercon Systems
2800 Commerce Drive
Harrisburg, PA 17110-9310
Web site: http://www.interconsystems.com/
Production sockets: LGA sockets

Ironwood Electronics
P.O. Box 21151
St. Paul, MN 55121
Web site: http://www.ironwoodelectronics.com/
Production sockets: DIP sockets, PGA sockets, SOIC sockets, LCC sockets, PLCC sockets, QFP sockets, BGA sockets

JAE Electronics
142 Technology Drive, Suite 100
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Irvine, CA 92618-2430
Web site: http://www.jae.com/
Production sockets: PGA sockets

Johnstech International
1210 New Brighton Road
Minneapolis, MN 55413-1641
Web site: http://www.johnstech.com/
Test sockets: BGA sockets, CSP sockets

Kycon, Inc.
1810 Little Orchard Street
San Jose CA, 95125
Web site: http://www.kycon.com/
Production sockets: SOJ sockets, PLCC sockets

Logical Systems
Syracuse, NY 13217-6184
Web site: http://www.logicalsys.com/
Test sockets: DIP sockets, SOIC sockets

Loranger International Corporation
817 Fourth Avenue
Warren, PA 16365
Web site: http://www.loranger.com/
Test/burn-in sockets: SIP sockets, DIP sockets, ZIP sockets, PGA sockets, LCC sockets, PLCC sockets, SOJ sockets, SOIC sockets, QFP sockets, MCR sockets, MCM sockets, BGA sockets, CSP sockets, LGA sockets

Meritec
1359 West Jackson Street
P.O. Box 8003
Painesville, OH 44077
Test sockets: SOP sockets

Methode Electronics, Inc.
Connector Products
1700 Hicks Road
Rolling Meadows, IL 60008
Web site: http://www.methode.com/
Production sockets: PGA sockets, PLCC sockets

Mill-Max Corporation
190 Pine Hollow Road
P.O. Box 300
Oyster Bay, NY 11771-0300
Web site: http://www.mill-max.com/
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Production sockets: SIP sockets, DIP sockets, PGA sockets, PLCC sockets, BGA sockets

MMM
MMM Center, Building 304-1-01
St. Paul, MN 55144-1000
Web site: http://www.mmm.com/
Test/burn-in sockets: DIP sockets, PGA sockets, SOIC sockets, LCC sockets, PLCC sockets, BGA sockets, LGA sockets
Production sockets: DIP sockets, LCC sockets, QFP sockets

Molex, Inc.
2222 Wellington Court
Lisle, IL 60532-1682
Web site: http://www.molex.com/
Production sockets: PGA sockets, LCC sockets, PLCC sockets

Oupiiin America, Inc.
26821 Ruether Avenue, Unit G
Santa Clarita, CA 91351
Web site: http://www.oupiiin.com/
Production sockets: DIP sockets, PGA sockets, SOJ sockets, PLCC sockets

OZ Technologies
3387 Investment Boulevard
Hayward, CA 94545
Web site: http://www.oztek.com/
Test sockets: SOIC sockets, QFP sockets, BGA/TBGA/microBGA sockets

Paricon Technology
421 Currant Road
Fall River, MA 02720
Web site: http://www.paricon-tech.com/
Burn-in sockets: BGA sockets, LGA sockets
Production sockets: BGA sockets, LGA sockets

Plastronics Socket Company
2601 Texas Drive
Irving, TX 75062
Burn-in sockets: SOP sockets, SOJ sockets, PLCC sockets, LCC sockets, QFP sockets, BGA sockets, CSP sockets

Power Dynamics
59 Lakeside Avenue
West Orange, NJ 07052
Web site: http://powerdynamics.com/
Production sockets: DIP sockets, PGA sockets, SOJ sockets, PLCC sockets
PrimeYield Systems, Inc.
1375 Walters Boulevard
St. Paul, MN 55110
Web site: http://www.primeyield.com/
Test sockets: PGA sockets, PLCC sockets, QFP sockets, BGA sockets, micro
BGA sockets, LGA sockets

Robinson-Nugent, Inc.
800 East Eighth Street
P.O. Box 1208
New Albany, IN 47151-1208
Web site: http://www.robinsonnugent.com/
Production sockets: SIP sockets, DIP sockets, PGA sockets, SOP sockets,
SOJ sockets

Samtec
P.O. Box 1147
New Albany, IN 47151-1147
Web site: http://www.samtec.com/
Production sockets: DIP sockets, PGA sockets, PLCC sockets

Synergetix
310 South 51st Street
Kansas City, KS 66106
Web site: http://www.synerget.com
Test sockets: PGA sockets, BGA sockets, LGA sockets

Tecknit
129 Dermody Street
Cranford, NJ 07016
Web site: http://tecknit.com/
Test sockets: PGA sockets, QFP sockets, BGA sockets, LGA sockets

Texas Instruments
111 Forbes Boulevard, MS 14-2
Mansfield, MA 02048
Tel: 508-236-5216
Fax: 508-236-5339
E-mail: bwilkins@ti.com
Burn-in sockets: SOP sockets, SOJ sockets, QFP sockets, BGA sockets, CSP
sockets, LGA sockets
Production sockets: LGA sockets, micro-BGA sockets

Teledyne Technologies, Inc.
Teledyne Interconnect Devices
3565 Corporate Court
San Diego, CA 92123  
Production sockets: LGA sockets

Thomas and Betts  
8155 T&B Boulevard  
Memphis, TN 38125  
Web site: http://www.tnb.com/  
Production sockets: SIP sockets, DIP sockets, PGA sockets, PLCC socket, LGA sockets

TopTech Connection Co., Ltd.  
No. 2, Lane 145 Da-an Road  
Shu Lin Town  
Taipei, Taiwan  
Web site: http://www.top-tech.com.tw/  
Production sockets: DIP sockets, PLCC sockets

URex Precision, Inc.  
Building 53, 195-81, Section 4  
Chung Hsing Road  
Chutung, Hsinchu, Taiwan 310, R.O.C.  
Burn-in sockets: CSP sockets

Wells-CTI  
52940 Olive Road  
South Bend, IN 46628  
Test/burn-in sockets: DIP sockets, PGA sockets, SOJ sockets, SOP sockets, QFP sockets, LCC sockets, BGA sockets, CSP sockets

Yamaichi Electronics, USA  
2235 Zanker Road  
San Jose, CA 95131  
Web site: http://www.yeu.com  
Test/burn-in sockets: PGA sockets, SOP sockets, QFP sockets, BGA sockets  
Production sockets: DIP sockets, SOJ sockets, SOP sockets, PLCC sockets, QFP sockets

Y-S Electronic Co., Ltd.  
No. 101, Section 1, Long-An Street, Lu-Chu  
Taoyuan, Taiwan  
Tel: 886-3-3609819  
Fax: 886-3-3609817  
E-mail: yselec@ms17.hinet.net  
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