IC Component Sockets: Applications and Challenges

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Abstract

An IC component socket is an electromechanical system that provides a separable connection between an electronic component and a Printed Circuit Board. IC component sockets provide many advantages in IC design, selection, assembly, test, upgrade, and maintenance, and they have found extensive application in the microelectronics industry. However, some challenges exist for their applications. Sockets introduce extra contact interfaces, degradation of which raises reliability concerns. Sockets also add extra electrical signal path and occupy additional spaces. The trends towards higher I/O and finer pitch of electronic devices put more stringent requirements on the design and application of sockets. This paper presents an overview of the application and benefits of IC component sockets as well as the challenges facing their application and future development.

Key words:

IC Component Socket, Contact Interface, Burn-in, and Reliability.

Acronyms

ASIC Application specific integrated circuit
BGA Ball Grid Array
BOM Bill of materials
CFC Chlorofluorocarbons
DIP Dual-in-line package
EIA Electronic Industry Association
IC Integrated circuit
I/O Input/output
LGA Land Grid Array
OEM Original equipment manufacturer
PCB Printed Circuit Board
PGA Pin Grid Array
PLCC Plastic leaded chip carrier
PTH Plated-through-hole
QFP Quad flat package
RF Radio frequency
SOJ Small outline J-ledged package
SOP Small outline package

1. Introduction and Background

An IC component socket is an electromechanical system that provides a separable electrical and mechanical connection be-
between an electronic component and a Printed Circuit Board. Compared with permanent interconnection like solder joint, it provides many advantages in terms of component test, burn-in, field upgrade, and repair, IC design, and assembly flexibility, and cost savings.

The basic structure of an IC component socket includes plastic housing and metal contacts. Socket housing is usually made from thermoplastic polymers embedded with glass fibers, flame retardants, and other additives. The primary functions of socket housing are to electrically insulate the contact members, and mechanically support, and maintain them in the original positions. It is also designed to facilitate automation, heat dissipation, and assembly orientation. For socket contacts, the primary function is to provide a stable electrical connection between components and circuit boards. They are generally copper-based alloys, like beryllium, copper, brass, and phosphor bronze. Conductive elastomer contacts are currently gaining popularity due to their high compliance and capability for high-I/O applications. Metal wires, such as gold, steel, or brass, or metal particles, such as silver, or nickel, are embedded in the elastomer matrix to make it conductive.

An IC component socket can be classified according to a variety of design attributes and characteristics, as seen in Table 1. These can be the function that a socket is intended to perform, or the assembly process through which it is mounted on a board. The socket is also classified according to the component that is to be connected, or the contact design. A socket can be DIP socket, PGA socket, SOP socket, QFP socket, BGA socket, to mention a few. Each packaging style has its according socket designs that are available on the market. Accompanying the evolution of packaging technologies is the diversification of socket designs. New designs and technologies are constantly appearing; for example, for BGA sockets, there are over twenty different designs in the market. Selection of a suitable socket design for a specific application has been a challenging task. Sockets can also be designed according to special requirements of customers; they are easily adapted to different configurations, pin counts, footprint patterns, and dimensions of packages.

The world market for IC component sockets almost reached one billion US dollars in 1997, amounting to 4.2 percent of worldwide connector sales. The United States is the world’s largest market for IC component sockets, with more than fifty manufacturers are located inside USA. Among the world top-ten connector manufacturers, AMP (acquired by Tyco Electronics in 1999), Berg, Molex, 3M, JAE, and Thomas & Betts are producing IC component sockets.

In the following, application and benefits of using IC component sockets are presented. Challenges facing their applications are discussed as well.

### 2. Application of IC Component Sockets

Benefits of using IC component sockets are many: component test and burn-in, component upgrade and exchange, flexibility in IC design, assembly, and supply chain management, avoidance of directly soldering components, component replacement and repair, and cost savings. In the following, these benefits are discussed, respectively.

#### 2.1. Component Test and Burn-in

During various stages of manufacturing process, a great many defects can be introduced in IC components, resulting in their malfunctioning and variations in performance and reliability. Even at the beginning of design life, defective components are prone to failures and cause a higher initial failure rate. The early life failure is also called infant mortality. To ensure the reliability of components before delivery or assembly, burn-in has been widely adopted by subjecting components to accelerated stresses to precipitate potential defects and eliminate early life failures. Function tests can be performed during the burn-in (stress test) process or after (static test). An IC component socket provides a connection interface between devices being tested and testing systems, and this connection is separable; so after testing, components can be plugged out, and functioning components can be delivered or assembled.
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Besides burn-in, during phases of IC design, development, manufacturing, and assembly, IC components need to be tested for a variety of purposes: debug, emulation, and quality control. In such cases, test sockets are used as a connection media to exploit the functionality and performance of electronic components. A test socket is also used to sort out components with better performances. With the increasing frequency of electronic devices, designing a test socket with enough bandwidth becomes critical.

Sockets for test or burn-in applications are a major part of socket market, with their market share a little larger than that of production sockets (sockets for final assembly). According to Fleck Research, in 1997 the worldwide market for test and burn-in sockets is 484 million US dollars, while for production sockets, it is 473 million US dollars1.

2.2. Component Upgrade and Exchange

With advance of microelectronics technology, performances and functionality of electronic devices are being constantly enhanced. For example, in the last few years, the computer industry has seen an increase in clock frequency of microprocessors from 266 MHz to over 1000 MHz. However, the never-ending enhancement of performances has put customers in a dilemma. To keep pace with the latest technology, a customer has to buy an up-to-date product today but that will be out-of-date tomorrow.

Today’s competitive business environment demands customer satisfaction. To construct confidence of customers in acquisition of tomorrow’s technology without extra expenditure, sockets have long been one choice. An IC component socket allows for easy product improvement or update so that new technologies can be easily installed into a fielded system without replacing the whole system. In computer industry, eight socket versions have been available to be compatible with a variety of microprocessors; among these, the best known is Socket 7, the configuration used for the Pentium microprocessors. Although, with the Pentium II microprocessor, which is based on Intel’s new P6 microarchitecture, Intel changed to a new connection configuration called Slot 1 and Slot 2, in 1999 Intel began to offer “socket” version of the microprocessors in order to reduce cost and to simplify motherboard design2.

Another benefit of using sockets is the exchangeability of compatible components from different manufacturers. Sockets add the flexibility for customers to upgrade their systems, for the purposes of lower price and higher performance, using components from different manufacturers.

2.3. Flexibility in IC Design, Assembly, and Supply Chain Management

Use of IC component sockets provides flexibility in IC design and assembly. It provides an easy way to reprogram integrated circuits, simply exchanging intended packages. It also simplifies the process for board design and package assembly, as different packaging styles, no matter SM or PTH, can be installed onto a single board using the same soldering process. Under some circumstances, packages at hand may not match the mounting style of PCB, while matched packages may not be available. A situation may arise as well wherein it is necessary to utilize a through-hole component but that would be better designed as a surface-mount type, or vice-versa. If the component is mounted directly to the board, the design of the assembly may be less than the optimum. Technology advances may make it necessary to add a surface-mount component to a through-hole board or vice versa. Sockets provide a way to mount different packaging styles onto one type of PCB, making it easier to design and manufacturing; for example, a socket may transform a surface-mount package into a through-hole type, so an SM package can be mounted onto a PTH-type board.

In some situations, configurations of available packages may not be compatible with requirements of boards, not only in assembly style, but also in footprint pattern and pin spacing. Sockets provide a way to reconfigure and redistribute IC terminals to accommodate assembly differences between the package and the board.

The exchangeability between different packaging styles using sockets adds flexibility in supply chain management. Moreover, during the setup of equipment, new IC packages are often unavailable in full quantity. Use of IC component sockets allows assembly to proceed without interruption using on-hand components; new components can be simply plugged in when the delivery arrives.

IC component sockets help reduce in-process inventory by making it possible to install devices during final assembly. Less handling and exposure to environment could lead to a prolonged service life of components. Sockets also help manufacturers standardize their assembly procedures.

2.4. A Way to Avoid Soldering Components

Soldering is the most conventional way to connect an electronic component with the Printed Circuit Board. However, soldering is not without problems. The lead and CFCs (for removing flux) are very hazardous to the environment. The Montreal Protocol has mandated the elimination of CFC usage. The high assembly temperature, usually from 220°C to 260°C, raises another concern. During assembly, the fast exposure to high temperatures (within several minutes) can result in a rapid evaporation of saturated moisture inside a package, causing package delamination, cracking, or popcorning. As solder joints mechanically hold package body and circuit board, which are relatively more rigid, the mismatch of coefficient of thermal expansion between them could cause solder-joint fatigue under thermal cycling conditions. Numerous analyses and reviews have been published regarding thermal-cycle-induced fatigue failures of solder joints3-9.

The continuous enhancement in device performance and functionality requires a large number of I/O terminals. The state-of-the-art packaging technology makes it possible to mount almost 2000 I/O terminals on a single package. SIA has predicted a 12 percent increase in I/O number of high performance ASIC packages; therefore, by 2005, the I/O number of high-performance
ASIC packages will reach above 3000. To account for the increase in I/O counts, package terminals have been designed to extend from the bottom of packages instead of the periphery in the form of solder balls (Ball Grid Array packages). However, this configuration together with a high I/O count and a large package size make assembly a difficult process to achieve. No optimized process has been available for soldering components with over 2000 I/Os. For one thing, it is a formidable task to achieve accurate placement; any misalignment could lead to imperfect solder joints. Secondly, nonplanar I/O terminals due to package warpage and non-uniformity of temperature profiles across the large package body may also contribute to the assembly failure. If failures occur, it is difficult, or even impossible, to rework the faulty-assembled packages, and rework at elevated temperatures takes a risk of damaging the more expensive PCB. Furthermore, as mentioned before, the reliability of solder joints is another concern, challenging the use of soldering process.

Use of sockets provides an ease of assembly without soldering and rework difficulties of large packages. Electronic components can be mounted after assembly, thus, the thermal impact on components can be avoided. The influence of non-planarity of packages can be minimized by increasing the compliance of socket contacts.

However, due to softness, oxidation and plasticity of solder balls, BGA packages are seldom socketed onto board in the final assembly. Land-Grid-Array packages (LGA) have been introduced to substitute for BGA packages. LGAs are similar to BGAs, except that instead of solder balls, I/O terminals are made of arrays of tiny gold-plated flat pads on the bottom of packages. The LGA packages are to be socketed onto circuit boards.

2.5. Component Replacement and Repair

Use of sockets allows 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 burn-in of assembled equipment before shipment. Socketing provides an easy way to replace components with early life failures. 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.

2.6. Cost Savings

Although sockets add a cost to the bill of materials (BOM), the benefits of using sockets are apparent when their cost is compared with the cost of package repair and rework. If a soldered component is replaced more than once, then sockets provide a cost-effective interconnection alternative. Cost is also saved when considering the reduction of system downtime in terms of easy maintenance and fast repair. In the case of overseas manufacturing, use of sockets helps reduce tariffs on partial assemblies.

3. Challenges Facing IC Component Sockets

There are some challenges facing the application of IC component sockets. A socket introduces extra contact interfaces and thus extra failure opportunities. A socket may add extra electrical length and occupy extra space. The continuous reduction of package I/O pitches has made many traditional socket designs obsolete; designing a socket, which keeps pace with the evolution of the microelectronics technology, poses a great challenge for socket designers.

3.1. Reliability of Contact Interfaces

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

Socket failures can be in the form of contact open, contact short, or intermittent failures. The socket contacts are electrically insulated from each other; they may be shorted when a conducting path develops between them. Contact open refers to the discontinuity of current flow through the contact interface due to the escalation of contact resistance. The intermittent failures are also called no-failure-found (NFF) or cannot-duplicated (CND) failures. They are temporary failures; for example, a failure may appear when the product is in operation, but no failing elements can be found when the product is taken off the line to trace the failure root causes. Sockets are very prone to intermittent failures.

A variety of failure mechanisms may be responsible for socket failures, which can either be contact failures, or housing failures. Table 2 provides a summary of the failure mechanisms that may be experienced by IC component sockets. These failure mechanisms can be divided into two categories: overstress and wearout. Overstress failures are catastrophic sudden failures due to a single occurrence of a stress event that exceeds the intrinsic strength of a material. Wearout failures occur when the accumulation of incremental damage exceeds the material endurance limit.

A socket may experience a group of failure mechanisms, depending on application environment, contact design, contact materials, contact platings, housing design, housing materials, and their manufacture process and quality. For example, for the solder plating, the dominant failure mechanism may be fretting corrosion; while for the gold flash plating, pore corrosion may dominate the degradation process due to its high porosity.

To address these reliability concerns, qualification testing is usually performed by manufacturers. It generally includes a series of sequential tests in combination with design requirements that will qualify a socket to a specific specification. The testing procedures usually follow EIA or military standards. The re-
requirements and testing procedures are also issued by OEMs or component manufacturers; for example, Intel issued two documents on design specifications and performance and reliability assessment of sockets that support microprocessors\textsuperscript{11, 12}. The environmental durations are usually short or moderate (i.e. 100 or 240 hours), and the tests usually do not establish the long-term performance of a socket\textsuperscript{13}. Sockets are assessed in terms of “pass” or “fail” based on a specific criterion.

Table 2. Potential failure mechanisms of IC component sockets.

<table>
<thead>
<tr>
<th>Contact</th>
<th>Wearout</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Buckling</td>
<td>5.1 Oxidation</td>
</tr>
<tr>
<td>2. Yielding</td>
<td>5.2 Corrosion</td>
</tr>
<tr>
<td>3. Fracture</td>
<td>5.3 Electrochemical migration</td>
</tr>
<tr>
<td>4. Electrical discontinuity</td>
<td>5.4 Intermetallic formation</td>
</tr>
<tr>
<td>5. Device walking out</td>
<td>5.5 Creep</td>
</tr>
<tr>
<td></td>
<td>5.6 Stress relaxation</td>
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<tr>
<td></td>
<td>5.7 Contact wear</td>
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<tr>
<td></td>
<td>5.8 Friction polymerization</td>
</tr>
<tr>
<td></td>
<td>5.9 Whisker growth</td>
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<tr>
<td></td>
<td>5.10 Fungus growth</td>
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<tr>
<td></td>
<td>5.11 Fatigue</td>
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<tr>
<td></td>
<td>5.12 Material property</td>
</tr>
<tr>
<td></td>
<td>degradation</td>
</tr>
<tr>
<td>Housing</td>
<td>a. Outgassing</td>
</tr>
<tr>
<td>1. Dielectric breakdown</td>
<td>b. Swelling</td>
</tr>
<tr>
<td>2. Fracture</td>
<td>c. Moisture absorption</td>
</tr>
<tr>
<td>3. Cracking</td>
<td>d. Creep</td>
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<tr>
<td></td>
<td>e. Current</td>
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<tr>
<td></td>
<td>f. Material</td>
</tr>
<tr>
<td></td>
<td>property</td>
</tr>
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<td></td>
<td>degradations</td>
</tr>
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However, the traditional qualification is only valid for assessing existing technologies with known material properties. As new socket designs and technologies are constantly appearing, the manufacturer’s qualification for reliability may not necessarily yield their reliability. A systematic and stringent methodology is needed to assess their long-term reliability. This assessment process should take into account the function-performance-life requirements, the environmental and operational life cycle conditions, socket design, and materials and geometries, and the potential failure modes and mechanisms. The socket manufacture and assembly shall be included in the assessment plan, as they may introduce extra failure opportunities. Moreover, a system-level assessment, incorporating circuit board and component, shall be reached; an assessment purely on sockets may result in missing some failure modes and mechanisms. CALCE Electronic Products and Systems Center at the University of Maryland has been a pioneer in researches on connector and contact reliability. Its current work includes drafting a process for reliability assessment of IC component sockets and reliability evaluation of metal-particle-filled elastomer sockets.

3.2. Extra Electrical Length

The evolution of microelectronics towards higher frequency and speed pushes a more stringent requirement on socket design, as sockets introduce an extra electrical path, which may cause excessive propagation delay and cross talk. For RF and microwave devices, the operating frequency is often from 1 to 10 GHZ. The bandwidth of a socket shall be several times the operating frequency of the device being tested, due to the harmonic content of the waveform’s rise and fall times\textsuperscript{4}. It is essential for sockets to be equipped with short contacts and sometimes special grounding and decoupling schemes to acquire a high bandwidth and assure adequate signal fidelity. Accordingly, the traditional cantilever spring contact, with an electrical length of typically around 5.0 mm, cannot meet the stringent requirements of high frequency applications. New technologies and designs, such as conductive elastomer contact design and microstrip contact design\textsuperscript{15}, are needed to scale down the electrical length.

3.3. Occupation of Extra Spaces

A socket may occupy more real estate on PCB and add an extra height. For test and burn-in applications, this may not be a primary concern. For production sockets, specific requirements on sockets may be imposed concerning their dimensions and profiles. The occupation of extra spaces may limit sockets for some applications, when size is of prior consideration.

For different types of sockets, the situation is varied. For example, some DIP and PGA sockets may add a specific height, but no extra real estate is occupied. For components with peripheral leads, the sockets are usually 20 percent larger, with profiles kept within 5 mm, demonstrating almost the same height as socketed packages.

3.4. Compatibility with Fine-pitch Applications

The need to shrink package size drives down the pitch of device terminals. Recent years have witnessed a continuous reduction of I/O pitches, from 1.27 mm eventually down to below 0.5 mm, even to 0.25 mm. The shrinkage of package pitches, together with small terminals, like solder balls, put IC component sockets to the test, making many time-worn designs obsolete. For the stamped contact design, the BGA sockets are mounted to board in a through-hole method. This can create significant bottleneck for escape routing, making it unusable for the 0.5 mm pitch application\textsuperscript{16}. The pinch-style contact design of BGA sockets, which works well for a pitch of 0.75 mm, 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 that you make the pitch contacts out of\textsuperscript{17}.” One way to go down to finer pitches is to make contact materials thinner. However, this poses a great difficulty for manufacturing and assembling very small contacts into a socket. In place of the pinch-style contacts, TI is designing a spring-style contact that touches the bottom of solder balls, eliminating the dimensional constraints of side approaching\textsuperscript{17}.

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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\textsuperscript{17}. The flex-circuit interposer design has been a solution for pitches of 0.75 and 0.8 mm\textsuperscript{18}, and they are potential to a finer pitch. A further move towards finer pitches will pose a more tough challenge towards socket industry, not only in socket design, but also in contact reliability, co-planarity, and cost.

4. Summary and Future Directions

IC component sockets provide designers and manufacturers much flexibility to optimize their electronic systems. The need for component test, burn-in, upgrade, or repair puts IC component sockets in an important position in microelectronics industry. New designs are being constantly developed by socket manufacturers to provide interconnect solutions for low profile, fine pitch and high I/O applications and to meet more stringent requirements on performance and reliability. Among the trends observed are reduction of signal path, built-in grounding and decoupling schemes, fully shielded sockets and interconnects, and use of conductive elastomer design. It is expected that socket designs will continue to evolve to keep pace with semiconductor and device development and to meet requirements from IC designers and component and equipment manufacturers, for which they need to partner with socket manufacturers in the product lifecycle to ensure a cost-effective and reliable solution.

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