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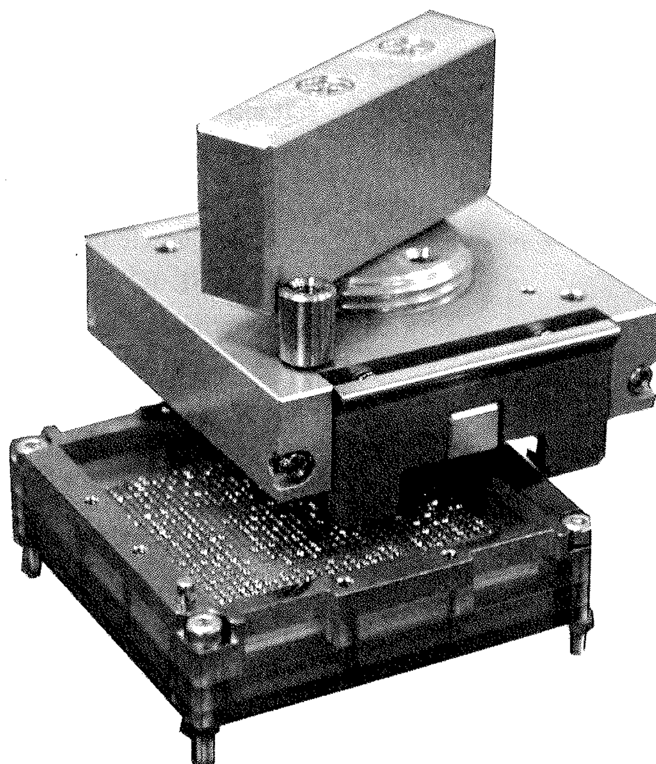
Technology and Performance of Solder-less IC Socket for BGA / CSP Packages



ELECTRONICS PARTS
CUSTOMIZED SOCKETS & CONNECTORS

S.E.R. CORPORATION

Technology and Performance of Solder-less IC Socket for BGA / CSP Packages

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Abstract

SER non-soldered type IC socket called as Solder-less (SL) IC socket, provides significant benefits surpassing traditional IC sockets to design and test engineers. It can be used for a variety of applications, including IC Tester, IC-handler, and PCB in both prototype and high volume productions. The SL IC socket is also suitable for other applications such as a system level design verification, debugging and testing of new system or board products under development. This article describes advantages of the technologies which enables us to develop and produce these innovative IC sockets, including the structure of the contact, operating characteristics, as well as our reliability testing results.

Introduction

SER Corporation has successfully developed and produced a product-family of high density solder-less (no soldering requirements to PCB) IC sockets for BGA and CSP packages.

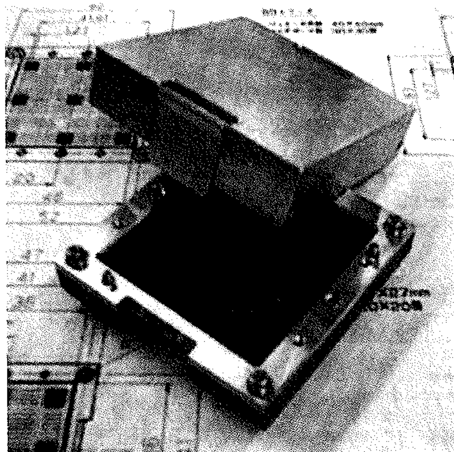


Photo-1 BGA/CSP SL IC socket

The most significant advantage of our SL-Type IC socket, is the high level functionality and operating performance achieved by using extremely small, thin and double-movable contact-probes on both ends of the contact body. The SL IC socket has been developed for application such as the evaluation, testing, and inspection of BGA, FBGA and CSP ICs, as well as volume production use. It has stable contact resistance (around 60mΩ), and high-frequency operating performance (exceeding 7GHz). It also provides a higher reliability (It achieved 200K endurance cycle testing). The SL IC Socket revises a concept of IC socket from the past.

This article introduces the design and the structure of our SL IC Socket. It also gives the performance and reliability testing results.

High Density Solder-less Contact

1. Basic structure and characteristics

The basic structure of the contact used in the high density SL IC Socket is shown in **Figure-1**. It consists of 4 basic components: the plungers (movable contact) with contacts at either end, a coil-spring, and a barrel. This is called the Spring Mini-probe from features of this structure. Approximately 99% of circuit current flow from one end of the plunger to the other end via two contact points which passes between the plunger and inner wall of the barrel. Maximum barrel radius size is available from 0.25mm and over (shown in **Figure-2**). For

standard applications such as high pin-count BGA and FBGA IC with 1.27 or 1.00mm contact pitch IC socket, 0.75mm version is available. 0.64mm version is also available for FPGA and CSP with 0.80mm or 0.75mm pitch and the 0.4mm version is for CSP with 0.65mm or 0.5mm pitch.

2. Contact shape

The tip shape of the plunger is selected according to the contact shape of BGA or CSP package. The basic top end shape are shown in **Figure-3**. Cross-cut shape is ideal to receive solder-ball contacts of the BGA and CSP without any mechanical damage. The Arrow and the R-cut type are used for Land Grid Array (LGA) and some selected CSP packages.

3. Surface finishing

Cupper alloy is normally selected as a material of the Spring Mini-probe for several advantages; easy to process, lower cost and better electrical characteristics. To satisfy higher reliability requirements, Phospherous Bronze or Beryllium Copper is used for some particular products. The surface of the plunger and the barrel are plated 0.25μm gold underplating nickel with 3μm thickness. The spring is gold flash.

Plating is required in order to obtain a lower contact resistance and better anti-corrosion characteristics.

4. Verification for contact pressure and resistance

Figure-4 shows a structure of SL IC Socket, which is assembled by attaching a number of Spring Mini-probes into a socket housing. **Figure-5** shows an operating model when contact pressure and resistance are measured under the practical operating conditions. These values were measured between a

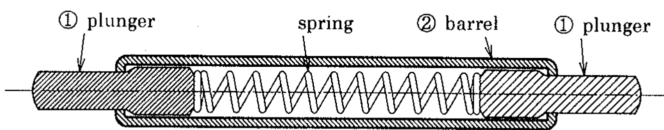


Figure-1 Structure of the Double Mini-probe

[Specification]
Traveling Distance: 0.55 mm(total)
spring pressure: 20±5 g total at 0.55 mm stroke
Maximum current: 0.3A
Operating temperature range: -20~+85℃
Durability: 20,000 cycles at 0.28 mm stroke
5,000 cycles at 0.55 mm stroke

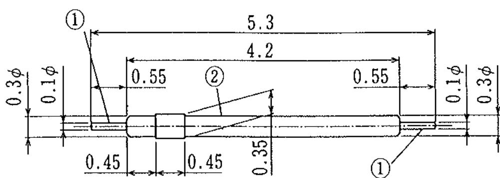


Figure-2 Double Mini-probe

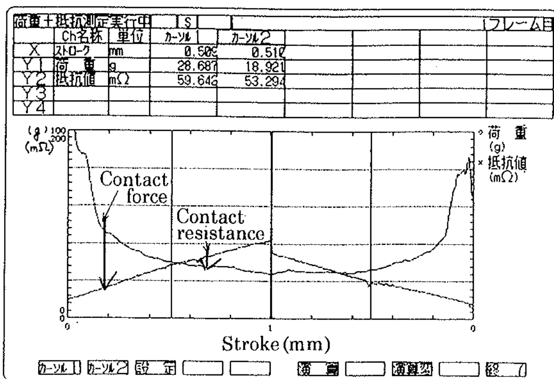


Figure-6 Contact force and resistance

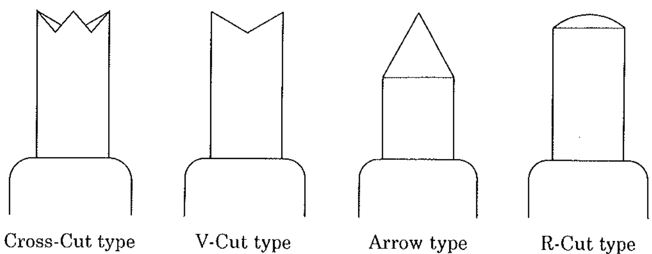


Figure-3 Tip shapes of plungers

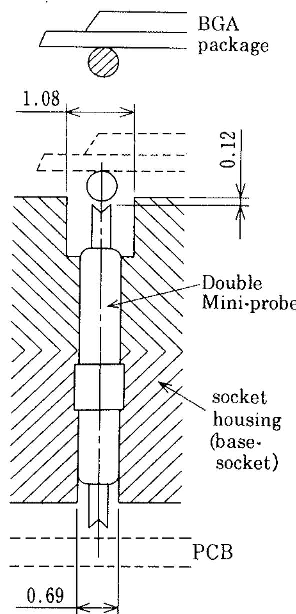


Figure-4
Assembled Double Mini-probe

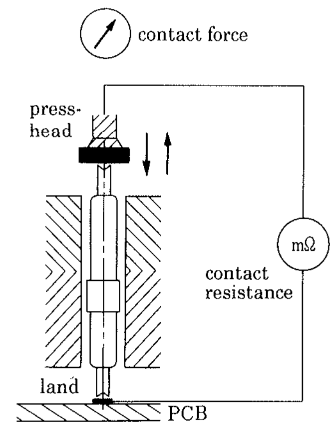


Figure-5
Test model and configuration

press-head and a footprint on PCB. **Figure-6** shows a data measured under a test condition where the plunger has kept standing without mechanical support and let the contact move slowly to up/down direction by using a press-head.

For typical applications, less than 100mΩ contact resistance and less than 40g contact pressure are desired. Our testing results shown on **Figure-6**, indicates that the socket meets this requirements at 0.2mm to 1.0mm stroke range. Our product is designed as the bottom side plunger (PCB side) has 0.35mm strokes, while the top side plunger (BGA or CSP ball side) has 0.45mm strokes. The two plungers located at both ends will have the total of 0.8mm traveling distance, with the total pressure load around 35g. This design automatically has operating margins,where as even if the top (ball side) plunger has no stroke, the bottom (PCB trace) plunger will have 0.15mm stroke margin. Even when the top side plunger is contacted to a ball of BGA without any traveling distance, acceptable lower contact resistance values will be obtained, since the PCB side plunger keeps more than 0.35mm strokes.

The value of contact pressure and resistance are determined by total stroke which is the sum of both ends. Hence, almost the same values are obtained on these parameters from each pin contact, even if the mounted positions of the Spring Mini-probes have some fractional errors in a contact array. Therefore, the SL IC Socket, several ten or thousand plus contacts have to operate simultaneously.

This features of large operating margins and a nature of averaged contact resistance and pressure values allow us to use this IC socket structure not only for BGA or CSP package but also for connectors and other surface mount packages, such as QFP and LCC without soldering requirements.

SL IC Socket design and performance

1. Contact array

For practical applications, a number of Spring Mini-probes are assembled as a SL IC Socket in a matrix array, as shown in **Figure-7**. Polyetherimide (PEI) is used as a housing material based on consideration for performance and process easiness.

In our performance testing, we grounded contacts adjacent two contacts under test. Two adjacent contacts shown in **Figure-7** are used as measurement of the test and the other pins surrounding them are connected to the ground.

The PCB for performance testing designed to have 50Ω characteristic impedance. IC socket, including contacts to be tested, were mounted to the primary PCB, which should supply a test signal, then the secondary PCB was mounted to the socket housing to measure performance values. Three types of circuit termination on the secondary PCB were prepared for this testing; open, short, and through.

2. Frequency characteristics testing

Figure-8 shows equivalent circuit model of tested contacts with a socket housing. **Table-1** shows values of each parameter in this equivalent circuit. These values are estimated for the simulation, but our testing results showed that these estimated values were almost same as real characteristics values of our Spring Mini-probe.

The equivalent circuit model which is compatible with spice characteristic was simulated by HP Micro Design System Software. Our testing was performed by using HP 8510 Network Analyzer with 450μm pitch GGB pico-probe. S parameter of 4 terminal circuit network and cross-talk level to adjacent contacts were measured.

Figure-9 shows our testing results when secondary PCB with an open condition was connected. In the Smith Chart shown in **Figure-9**, actual measure values are marked as △, and our simulation values are marked as □.

Parameters were measured at the frequency range from 0GHz (50MHz) to around 3GHz with 0.5GHz step. At 0GHz, it becomes to an infinity value on the real number axis. When the frequency was increased to 0.5GHz and 1.0GHz, the value moved down along with the circumference of the imaginary circle. It indicates that our socket has a very stable small inductance element. We also confirmed that the cross-talk level was suppressed by a approximately -

14dB level.

Figure-10 shows our testing results for secondary PCB having a short condition. Because it has a short condition, the value became to 0Ω on the left end of the real number axis, and move up along with the circumference. At 3GHz, the results were plotted a little inside of imaginary circumference around 3GHz by mutual capacitance. But it is within acceptable performance. The test results here have an acceptable cross-talk level that is less than-13dB.

Figure-11 shows testing results for PCB having a through condition. In this configuration, it is desired

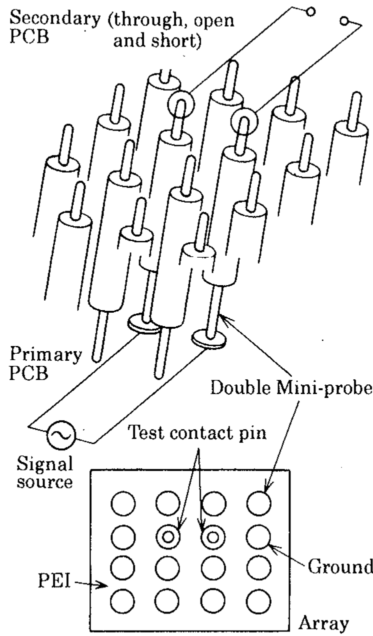


Figure-7 Contact array arrangement

[Element definition]
L_1, L_2: Self inductance of pin
M_{21}: Mutual inductance between neighboring pins
R_1, R_2: Shunt resistance of L_1, and L_2
C_{21a}, C_{21b}: Mutual capacitance

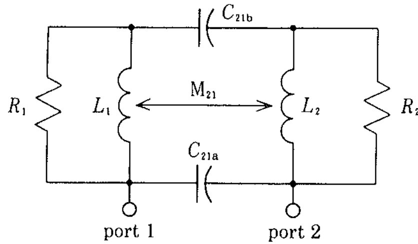


Figure-8 Equivalent circuit

Table-1 Equivalent element values

L_1 & L_2	M_{21}	R_1 & R_2	C_{21a}	C_{21b}
2.4nH	0.4nH	750Ω	0.03pF	0.06pF

Figure-9 Test result for an open condition

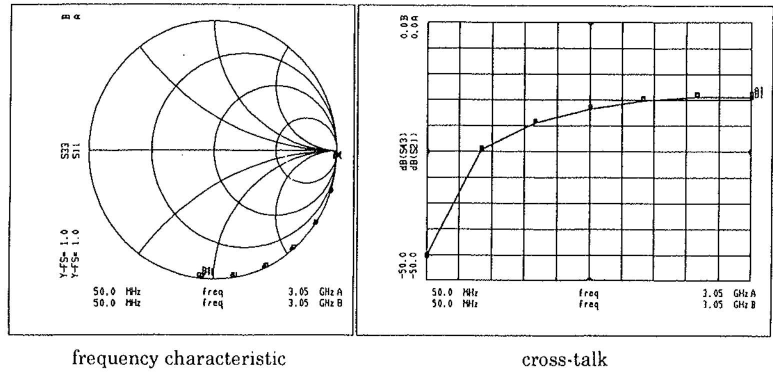


Figure-10 Test result for a short condition

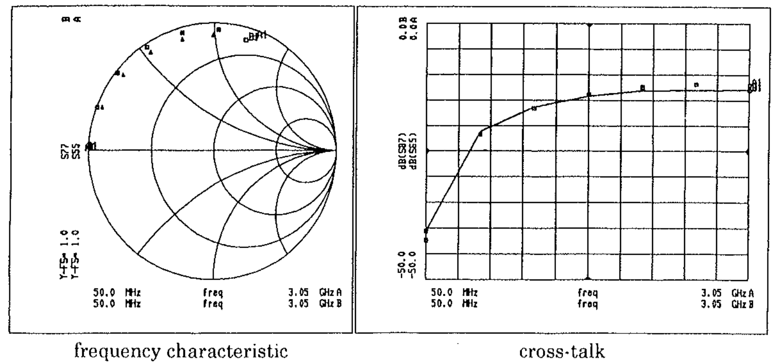
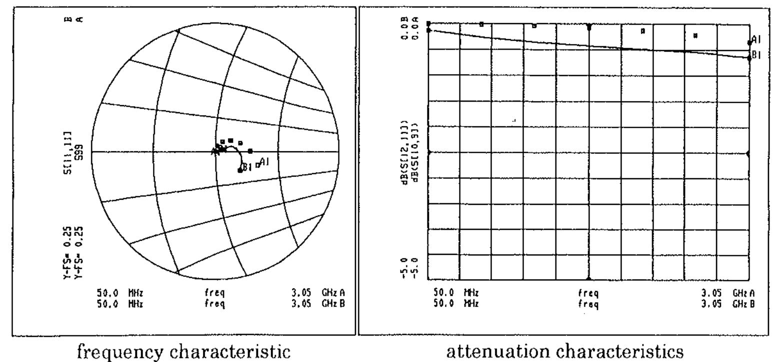


Figure-11 Test result for a through condition



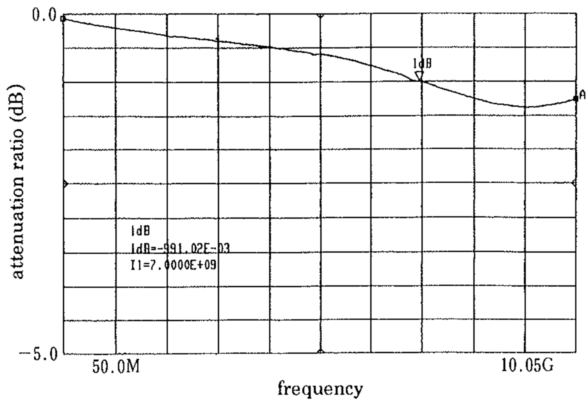


Figure-12 Extended frequency characteristics

that all measured values of impedance parameters (Z_{12}, Z_{21}) or admittance parameters (Y_{12}, Y_{21}) might be plotted at focus point on the real number axis. The testing results show us that this requirement was mostly satisfied. At our measurement, a signal attenuation characteristics of -0.6dB was obtained at 3GHz.

Figure-12 shows the complete attenuation characteristics when the testing frequency was extended to 10GHz. In this extended frequency testing, -1dB attenuation frequency was 7GHz. And 5.8GHz, when the test contact was moved to a corner where no ground pins were surrounding it.

Conclusion of our performance testing

Our testing results described as above, indicates us that we can implement SL IC Socket using our Spring Mini-probes which has best performance for the contact pressure and resistance, And also this structure achieves the high frequency performance with stable characteristics on a real number axis. From this implemented results, we ensure an innovative IC socket for realistic applications.

Basic configuration of SL IC Socket

1. Mounting and Holding to PCB with BGA or CSP ball

Figure-13 shows a basic concept how SL IC Socket probes are mounted to PCB, and how holds a BGA or a CSP socket. The SL IC Socket is held by 4 screws though 4 though-holes located at corners of the base socket to the PCB.

The BGA or CSP package is put into a socket cavity, and fixed by a screw cap or one-touch cap (**Figure-14**). With this configuration, PCB footprints are connected to contacts (balls) of BGA/CSP IC via a plunger, a barrel and another plunger at the other end.

2. Configuration, design and production of SL IC Socket

Today, there are a variety of BGA (LGA) and CSP packages available that offer different features, specifications and technologies. However, our SL IC socket is adaptable to all kinds of these IC packages, regardless of a size, a contact (ball) pitch, and an array configuration. **Figure-15** shows a schematic diagram of our product assembled to a BGA IC socket in a 1.27mm ball pitch.

This SL IC socket is designed for BGA IC of 35×35 mm size and 456 balls. As typical applications, this BGA package has been used for PC CHIP SET and ASIC. The schematic and dimensions of the base socket are shown in **Figure-16**.

By mounting Spring Mini-probes to the base socket of the SL IC socket, it can have a same contact array configuration as BGA 26×26 ball array layout. It can be changed into any configurations or layouts according to the requirement. The IC package can easily be mounted on the IC socket with a good alignment capability which is implemented by a self ball alignment effect of holes on the base socket where balls of IC are contacted. **Figure-17** shows a cap of the SL IC socket.

Figure-18 shows a schematic of footprints, locations of holes to fix the SL IC socket, and an

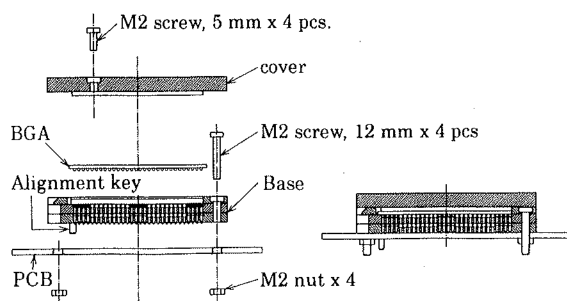


Figure-13 Assembled SL IC socket (Screw Cap type)

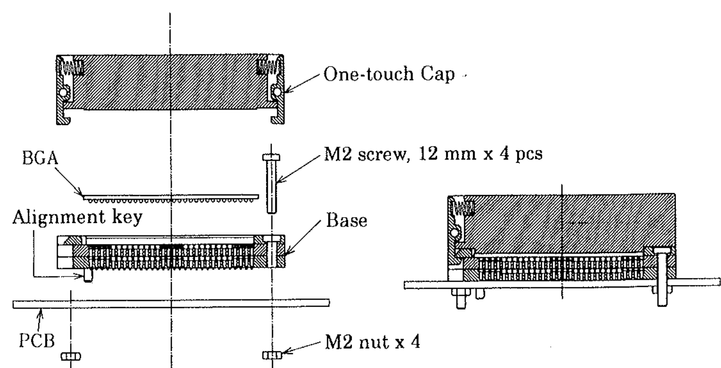


Figure-14 Assembled SL IC socket (One-touch Cap type)

alignment key position on customer's PCB. The footprint design is exactly compatible with the design of mounting BGA package. This feature allows system designers to use a single PCB for both of the evaluation model and production model even when ASIC or other custom IC are used for new designs.

Figure-19 shows schematic diagrams of base sockets of our product-family which can be used for most of any kinds of BGA packages in 1.27mm contact pitch. **Figure-20** shows customer's PCB design requirements for our SL IC socket family.

The design diagram of our CSP IC socket with 0.5mm pitch, 16×16 mm size and 326 contacts, is shown in **Figure-21**. This CSP IC socket has been designed for IC testers and inspection equipment. This product has a good mechanical feature corresponding to handler's mechanism. The socket uses a self ball alignment metric and a lifting structure. The IC package is received by a dish (base D) at a proper position with a good ball alignment. Then, by pushing down the IC package together with the dish from the cap or handler-head, it is connected to the PCB footprints. To implement

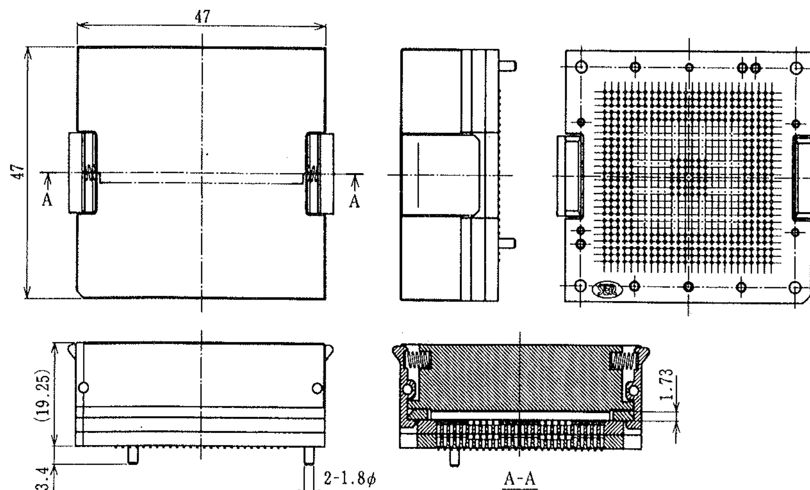


Figure-15 SL IC socket for BGA

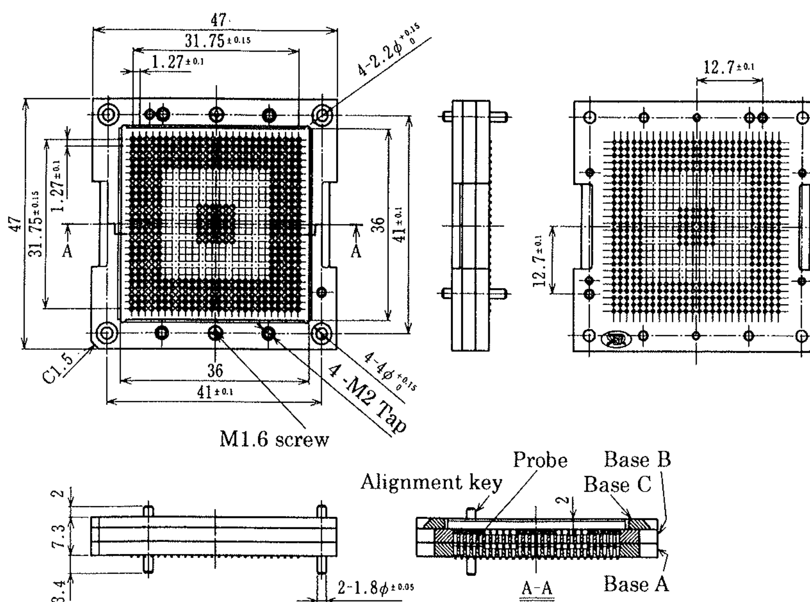


Figure-16 Base socket

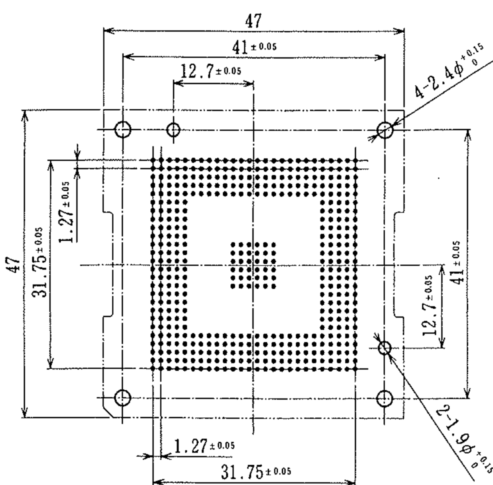


Figure-18 User PCB design

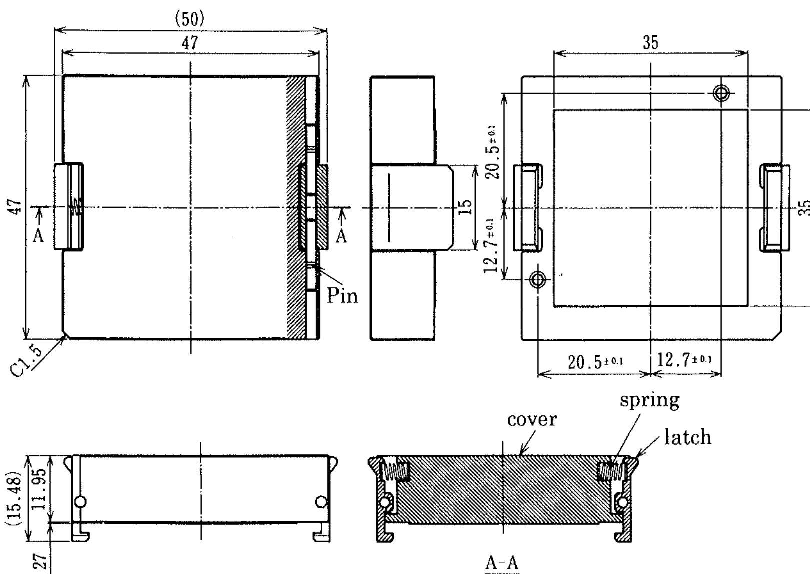


Figure-17 Cap

Figure-19
Base socket dimension
for 1.27mm pitch BGA series

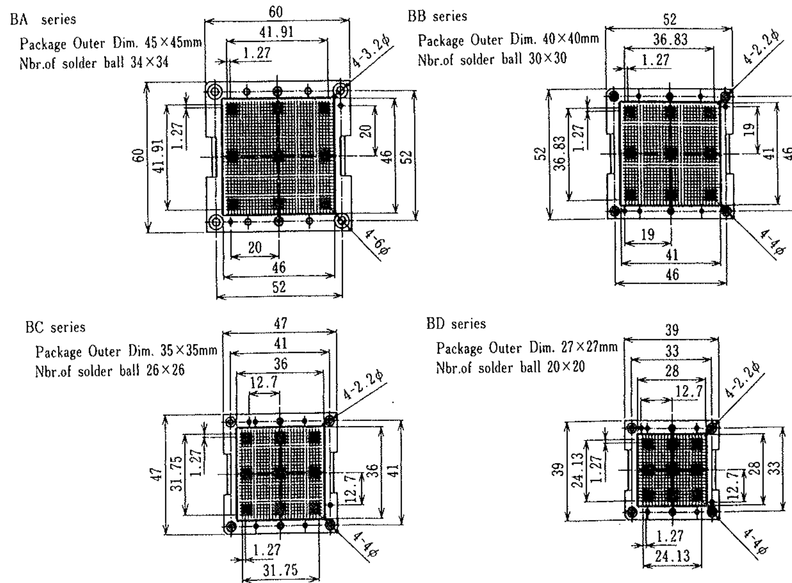
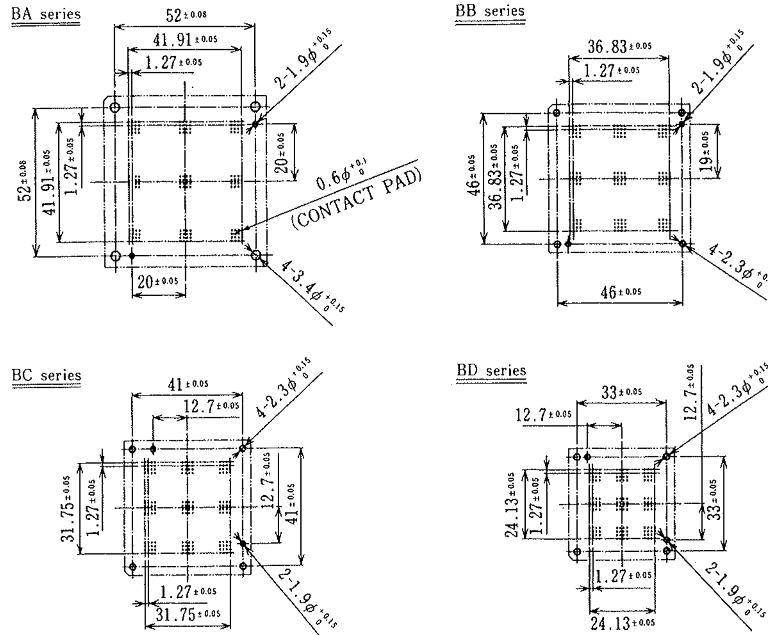


Figure-20
User PCB design
for 1.27mm pitch BGA series



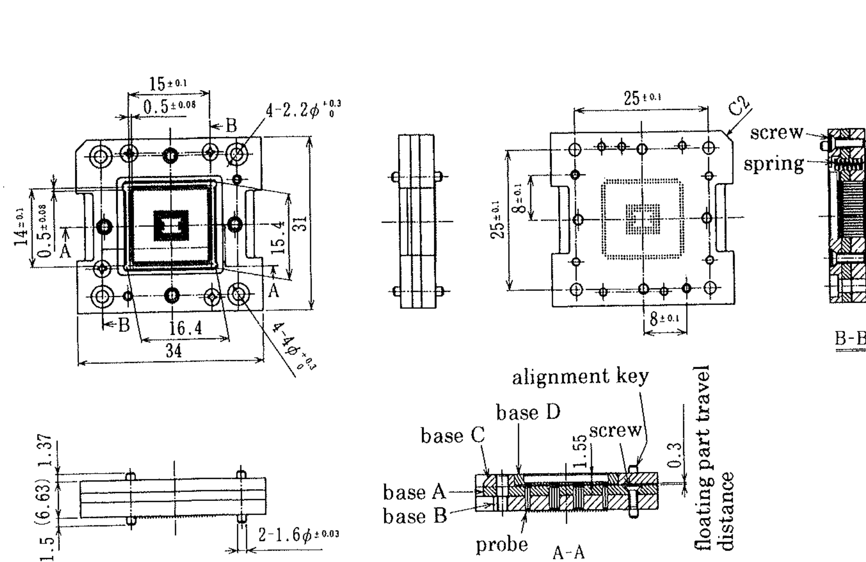
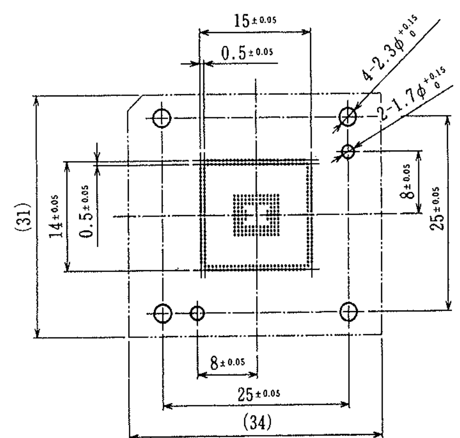


Figure-21 Schematic of 0.50mm pitch CSP SL IC socket



[Note]
1. Top view
2. Footprint width must be more than 0.35ϕ.

Figure-22
User PCB design
for 0.50mm pitch CSP IC socket

this mechanism, the base socket have a multi-layer structure including a dish. Since this structure can keep enough operating stroke margin for all contacts, it is usable for target applications without any degradation on operating performances. **Figure-22** shows footprint design requirements when this CSP socket is mounted on PCB. This footprint design for the CSP IC socket is compatible with a design of mounting CSP package.

For 1.0mm, 0.8mm or 0.75mm pitch IC package, the SL IC sockets have also been implemented with same contact pin arrangement as the IC as well as the same performances and configurations of 1.27mm or 0.5mm pitch products.

Reliability Testing Results

1. Endurance cycle Testing

Figure-23 and **-24** show our reliability test results

Figure-23
Endurance cycle test result for contact force

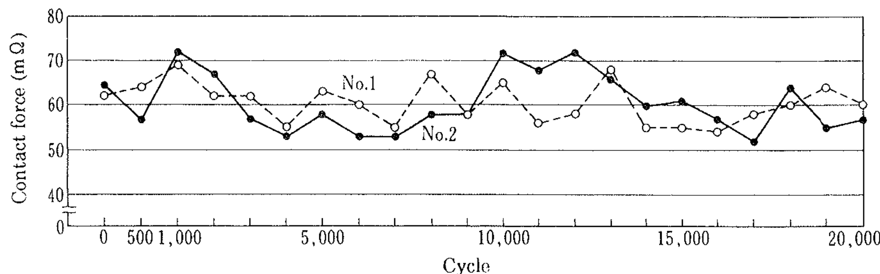
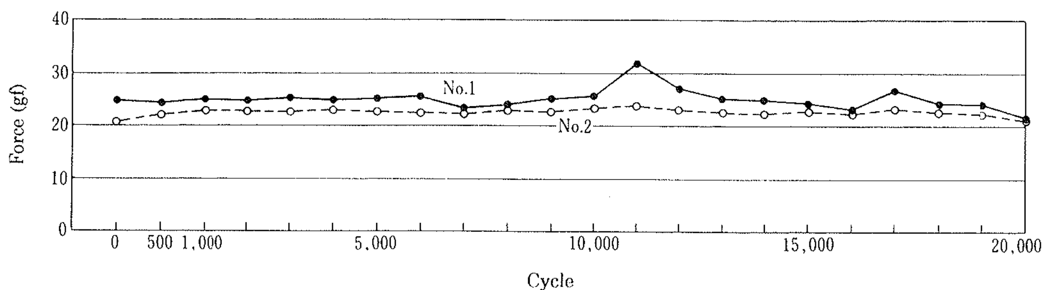


Figure-24
Endurance test result for contact pressure



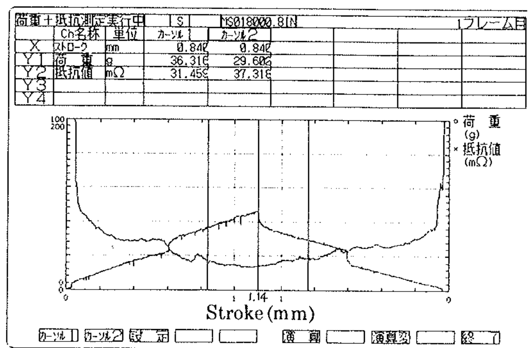


Figure-25
Initial characteristic before endurance cycle test

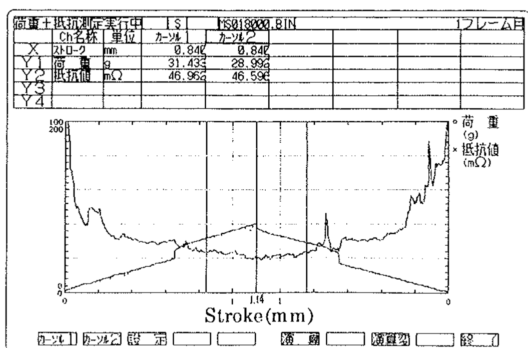
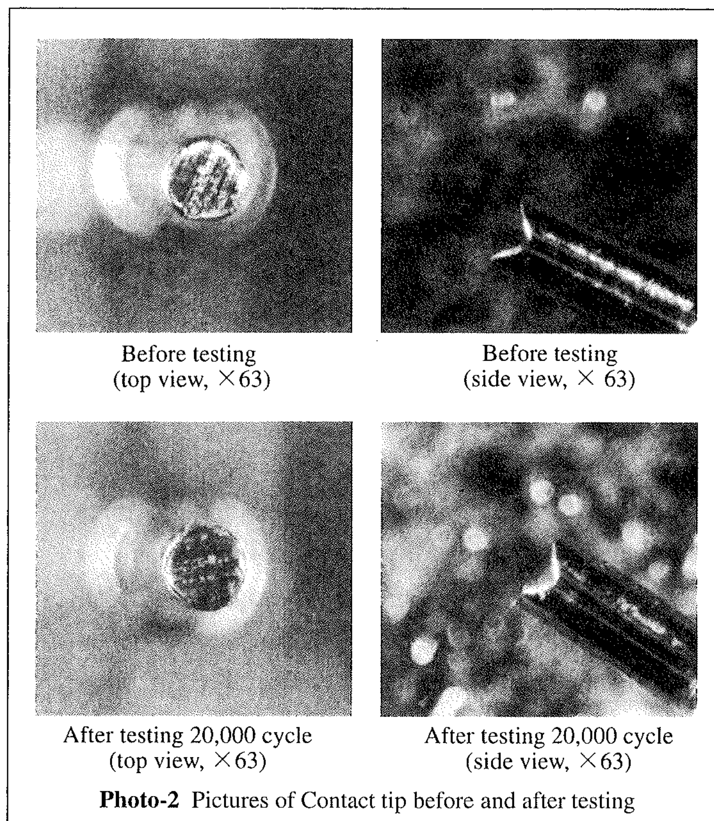


Figure-26
Characteristics after 20,000 cycle test



Before testing (top view, ×63)

Before testing (side view, × 63)

After testing 20,000 cycle (top view, ×63)

After testing 20,000 cycle (side view, ×63)

Photo-2 Pictures of Contact tip before and after testing

for both the contact pressure and resistance of the SL IC socket. A total of 20,000 endurance test cycles, a continuous load/unload operation, were performed. **Figure-25** shows an initial performance of the SL IC socket before testing, and **Figure-26** shows the performance after 20,000 cycles. **Photo-2** shows pictures of the contact tip, before and after endurance cycle testing. **Figure-27** indicates results of our Auger Electron Spectroscopy (AES) analysis for the surface on contact tip.

Our analysis results indicated some residual solders were existed on the surface of a plunger, gold underplating nickel.

Although no problems were found for the contact performance at our analysis, a higher contact resistance problem may appear if more or thicker residual, are found (approximately, 2 times of our analysis result). The higher resistance problem could occur when extremely strong mechanical shocks are given to the contact head over a few thousand or ten thousand times. This is a preventable problem, but a careful attention is required for some applications when using a handler.

2. Other reliability testing results

The vibration test result is shown on **Table-2**. (no problems were found by the instantaneous circuit shut-down). The mechanical shock test result is also shown on **Table-3** (no problems were found by the instantaneous circuit shut-down). High temperature storage test result is listed on **Table-4** (No problems were found).

Applications

Our SL IC socket, which eliminates soldering requirements to PCB, covers all functionality of traditional IC sockets and adds various new features to it, including a capability to repair the contacts or socket itself, a maintenance, removing and re-mounting. Our product is applicable not only for BGA, FBGA and CSP packages but also for other surface mount packages including SOP, QFP and LCC.

For applications to evaluate and test new IC products, or to use it as a test head socket of In-Circuit Emulator, customers do not need to prepare any special PCB, but can use a single PCB designed for a volume production at the development, proto-typing, reliability testing and performance analysis stage. BGA/CSP IC can be directly soldered to PCB without SL IC socket at the initial production or in volume production. When future upgrade is required for the LSI, customer can ship the system with boards mounting the SL IC socket.

Also, with these advantages, customer can dynamically reduce total costs and a time from the development stage to the volume production. It will result in customer's benefit to achieve "faster time to market". Our SL IC socket also allows users to perform a failure analysis and re-evaluation to field failure IC's. In this case, they can perform re-testing for the claimed IC by removing it from PCB, then mounting it with SL IC socket.

Our SL IC socket can be used for all kinds of IC products, including ASIC, ASSP, FPGA/PLD, MCU/CPU,Memory, and Linear IC.

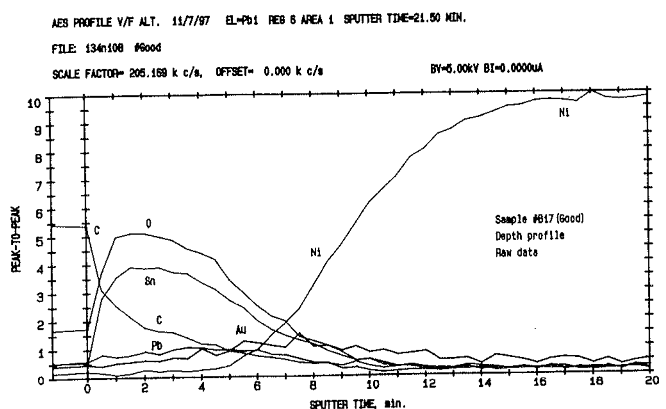


Figure-27 ASE analysis result for contact head

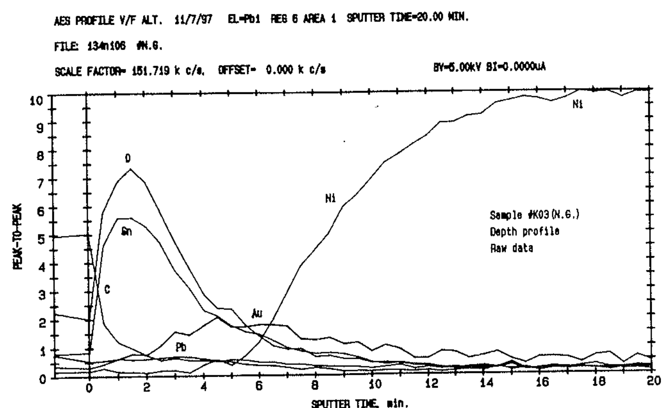


Figure-28 ASE analysis result (High contact resistance)

Table-2 Vibration test

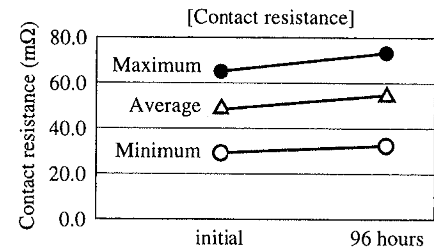
Test Conditions, Criteria	●MIL-STD-202, Method 204 ●Condition A (frequency: 10~500Hz, 2hours to X, Y, and Z directions) ●Travel distance of probe: 0.84mm ●No open circuits exceeding 1μs period must be found during testing. No degradation or derangement must be found by visual inspection.
Test Equipment	●Vibraion Emic Corporaion, Model: F-400 BN-E47 ●Open Circuit 10ch.-circuit Open Detector
Test Results	No failures were found

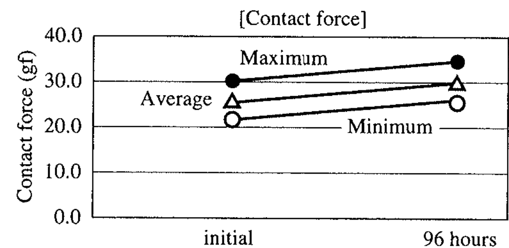
Table-3 Mechanical shock test

Test Conditions, Criteria	●MIL-STD-202, Method 213 ●Condition A (half sine wave, 50G, 11ms, 2 times to X, Y, and Z directions) ●Travel distance of probe: 0.84mm ●No open circuits exceeding 1μs period must be found during testing. No degradation or derangement must be found by visual inspection.
Test Equipment	●Mechanical shock AVEX, Model: SM-110-3P ●Open Circuit 10ch.-circuit Open Detector
Test Results	No failures were found

Table-4 High temperature storage test

Test Conditions, Criteria	●MIL-STD-202, Method 108 ●Condition A (Ta = 85℃±2℃, 96 hours) ●Travel distance of probe: 0.84mm ●Following parameters must meet to each specified value. Breakdown voltage: AC 500V for 1 minutes before testing and AC300V for 1 minutes after testing Insulation resistance: 500MΩ min. before testing and 300MΩ min. after testing Contact resistance: 200mΩ max. before testing and 300mΩ max. after testing Contact force: 30±10g before testing and 30±20g after testing
Test Chamber	Tabai-Espec, Model: STH 120
Test Results	Breakdown voltage: No failures were found Insulation resistance: No failures were found Contact resistance: No failures were found Contact force: No failures were found





Conclusion and future planning

Because our product innovated to the traditional concept of IC socket, more time may be required to evaluate the performance of SL IC socket with its advantages of none soldering requirements. But we believe that our SL IC socket will soon become one of the industry standard IC sockets or connectors in the future market, since it offers significant benefits and innovative environment to customers who develop new IC or systems. Especially, our SL IC socket is expected to become an industry standard product for BGA and CSP packages.

We have to develop new products that will have a higher frequency performance, better space utilization and a better mounting method. Our most important issue is to achieve a lower production cost. Our further efforts to develop better products are now in progress.