

**SOLDER CHARGE GRID ARRAY: ADVANCEMENTS IN THE
TECHNOLOGY OF SURFACE MOUNT AREA ARRAY SOLDER JOINT
ATTACHMENT**

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ABSTRACT

Surface mount area arrays (SMAA) have been in existence for decades and are increasingly becoming more important as printed circuit board (PCB) assemblies become further complex with package miniaturization and density. Although the PCB space savings afforded with SMAA solder joint technology is advantageous and necessary it is also extremely important that the solder joints formed when using SMAA technology are reliable and robust. A recent advancement in SMAA technology is the solder charge grid array (SCGA). During the development of this new SMAA technology much attention was given to existing SMAA structures such as the ball grid array (BGA) and column grid array (CGA) with the intent of improving on some of the advantages afforded by each of these technologies. A focus was placed on improvements in the areas of processing, inspection and reliability while maintaining the strengths of existing SMAA features such as density, simplicity and cost. As a result, SCGA technology requires no special processing or equipment during PCB assembly and has been designed to be flexible enough to be used as a drop in replacement for existing BGA or CGA components. SCGA also improves on the co-planarity, inspection, compliancy, and reliability challenges of current SMAA solder joint attachment technologies. This paper will focus on two primary areas of the SCGA: the design and research involved in the development of the SCGA, and the reliability testing completed to insure the SCGA meets industry specifications for SMAA technology and to predict the performance of the SCGA through harsh environments.

Key words: Solder Charge Technology, Surface Mount Area Array, SCGA, BGA, CGA

INTRODUCTION

As package miniaturization and the density of smt interconnects and other components continues to advance, the technology of SMAA solder attachment methods must also continue to evolve and improve in order to meet the challenges of the increased density and reliability requirements of smt component packages.

While having been successful in meeting the density requirements of many smt components, traditional SMAA solder attachment methods used for high density smt interconnects and other smt components such as the BGA and CGA have been challenged with reliability, automated processing, and inspection difficulties.

The latest development in SMAA solder attachment technology, solder charge grid array (SCGA), was designed and developed to improve on the challenges and limitations of current SMAA solder attachment methods while maintaining their advantages, for example, density, simplicity, and cost.

Research and Design

The SCGA development was focused on improving three key areas of concern with current SMAA solder attachment methods. Firstly, focus was emphasized on the advantage of automated pick and placement machinery being able to identify and cleanly place the component on a PCB assembly. Secondly, SCGA design strategies were reviewed to make automated and manual x-ray image interpretation more distinguishable, reliable, and less dependent on an x-ray operator's experience and skill. Finally attention was placed on improving on the solder joint reliability of current SMAA solder attachment technologies.

Automated Pick and Placement

By design, the shape of the SCGA allows for easy vision recognition by today's common automated pick and place equipment, thus eliminating the requirement for special training or software upgrades to

program for automated vision inspection. This is particularly important in the design of any SMAA technology when taking into account personnel turnover at contract manufacturers and the requirement to train all new staff. The SCGA is composed of two main components, the first being the terminal that the solder charge is mounted to, and the second being the solder charge itself. The geometry of both the terminal and the solder charge allow for automated pick and place vision systems to inspect both the solder charge and terminal base as one solid rectangular image allowing for quick detection of a missing or damaged solder charge or terminal. The terminal and solder charge shape can be seen in more detail in Figure 1.

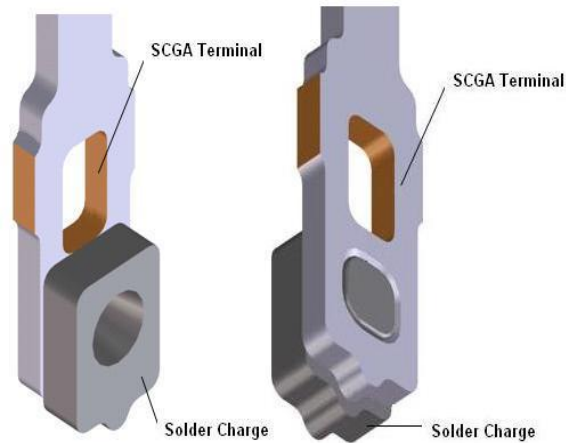


Figure 1: SCGA Terminal and Solder Charge

Co-Planarity

As PCB assemblies continue to increase in component density and require further decreases in terminal pitch specifications it's becoming more common for a PCB assembler to use a .10mm-.127mm thick screen printer stencil to avoid solder bridging or other screen printing related defects. These thinner screen printer stencil requirements continue to drive the co-planarity requirements of a component's terminals tighter and tighter. Whereas in the past there may have been co-planarity requirements of .15mm-.2mm now it is more common to see co-planarity requirements of .10mm-.12mm with smt roadmaps indicating a drive to .08mm.

The design of the SCGA controls and improves upon co-planarity challenges of current SMAA solder attachments in two unique ways. The first improvement in co-planarity comes from the attachment of the solder charge to the terminal itself. The solder charge is stamped from a ribbon onto the terminal resulting in a very accurate, repeatable, and predictable location on the terminal. The second feature of the SCGA which further helps compensate for co-planarity requirements is the design of the solder charge and terminal themselves. The tip of the solder charge is slightly lower than the base of the terminal tip as seen in figure 2. Also, the solder charge tip is malleable which allows for some compression during automated placement. This compression helps compensate for any PCB warpage and further improves the co-planarity of the component itself.



Figure 2: Solder Charge location on Terminal

Inspection

Because the very nature of SMAA solder attachment methods require many of the contacts to be under the component package, visual inspection is limited to the outside rows requiring x-ray inspection to verify proper solder wetting and solder joint formation of the remaining hidden contacts. The design of the SCGA makes x-ray inspection easier and more reliable than other SMAA solder attachment methods through the use of simple geometry. The solder charge which is stamped onto the terminal is rectangular in design and the PCB pad is round or oval depending on the OEM's requirements. This difference in geometry makes it much more simple to detect a solder failure because if the solder charge has not formed a preferred solder joint with the terminal and PCB pad the x-ray image will result in a lumpy or rectangular shape whereas an x-ray image of a preferred solder joint will indicate a round or oval shape depending on the PCB pad design. This improvement of the SMAA design of the SCGA reduces, if not eliminates, the risk of either false failures at x-ray or true failures not being detected such as a head in pillow defect associated with the BGA. See Figures 3 and 4 for x-ray images of preferred and non-acceptable SCGA solder joint formations.

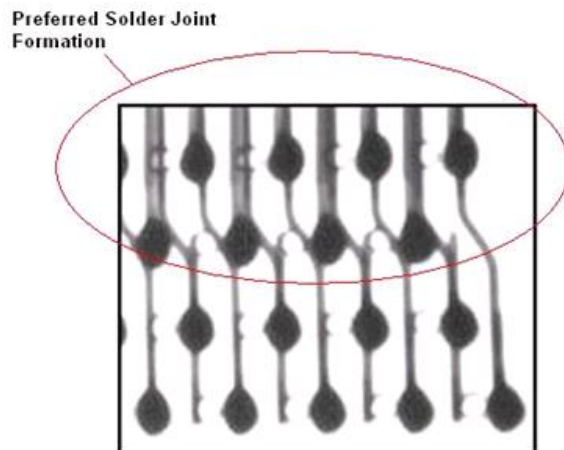


Figure 3: 2D x-ray images of preferred SCGA solder joints

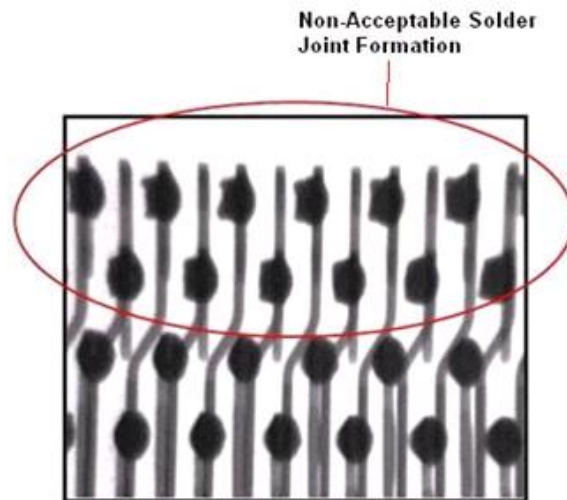


Figure 4: 2D x-ray images of non-acceptable SCGA solder joints

Solder Joint Reliability

Several factors contribute to the solder joint reliability of SMAA solder attachment methods including the end solder joint formation and terminal design. The terminal design has great impact on solder joint reliability by influencing the strength of the solder joint and incorporating compliancy to account for stress that may be introduced to the solder joint. The SCGA terminal and solder charge have specific design features to address both of these contributors to the solder joint reliability.

First, the SCGA terminal has two design features to improve upon the solder joint strength of current SMAA solder attachment methods. The terminal base is not flat but has a tip designed to penetrate and seat into the printed solder paste on the PCB pads and to keep the bulk of the terminal base up off the solder pad surface increasing the solderable area of the terminal. The terminal also has a hole, or eye, in it that not only secures the solder charge during the mating of the solder charge to the terminal but also allows for the solder mass of the solder charge and the solder printed onto the PCB pad to flow through, fill the hole (eye), and engulf the terminal. These two design features of the SCGA terminal, the tip on the terminal base and the hole (eye) in the terminal, allow for an exceptional amount of solderable surface area of the terminal including both sides of the terminal, the base of the terminal, and the inner surface of the terminal in the hole (eye) location. See Figure 5 for a model and Figures 6 and 7 for cross sectional images of these terminal features.

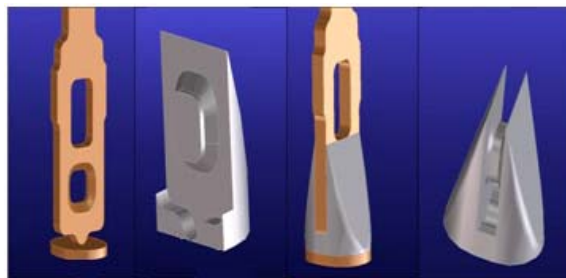


Figure 5: Model of SCGA solder joint formation

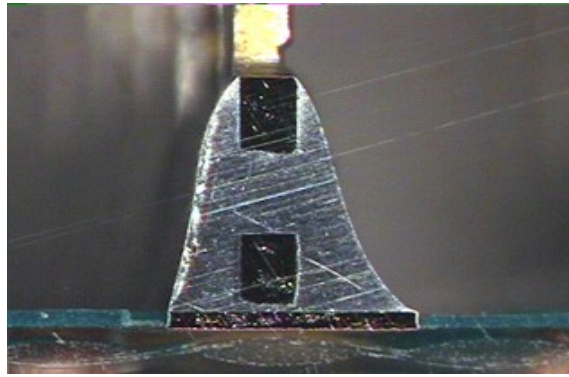


Figure 6: Cross Sectional Images (x-axis) of SCGA solder joint formation

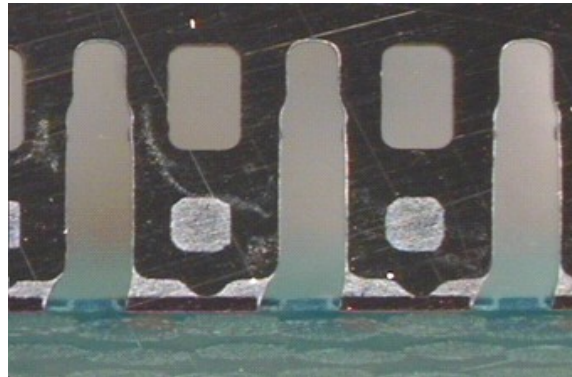


Figure 7: Cross Sectional Images (y-axis) of SCGA solder joint formation

The length of the SCGA terminal design provides increased compliancy and reduces stresses that may be introduced to the solder joint. Whereas many SMAA terminals are short and rigid, the SCGA terminal acts as a beam and deflects with induced stresses, readily absorbing the forces that result in fractures in standard SMAA solder joints.

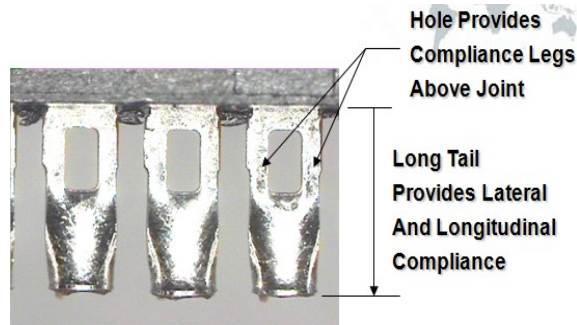


Figure 8: SCGA Terminal Compliancy Feature

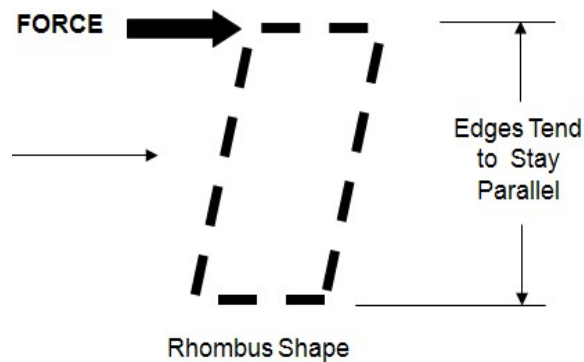


Figure 9: SCGA Terminal Compliancy Compensator

Inter-metallic compounds (IMC's) affect solder joint reliability because as they grow and increase in thickness the solder joint becomes brittle leading to solder joint cracks and eventual solder joint failure. IMC's are formed when solder is reflowed to form a solder joint to a substrate whether it is a PCB pad or a terminal surface such as occurs with ball attachment to a BGA terminal. SMAA solder joints have many opportunities for excessive IMC growth including original ball attachment onto a BGA terminal, during burn in or pre-baking to remove moisture prior to attachment to a PCB (an IMC already formed during attachment to a terminal can continue to grow¹, and/or by a reflow soldering profile with an extended time above liquidus or too slow of a cooling rate. The SCGA eliminates the first two opportunities for excessive IMC growth by stamping the solder charge onto the terminal and avoiding the need to reflow or solder it onto the terminal. The SCGA solder charge attachment process eliminates any IMC formation prior to attachment to a PCB pad. See Figure 10 for description of the solder charge attachment to the terminal.

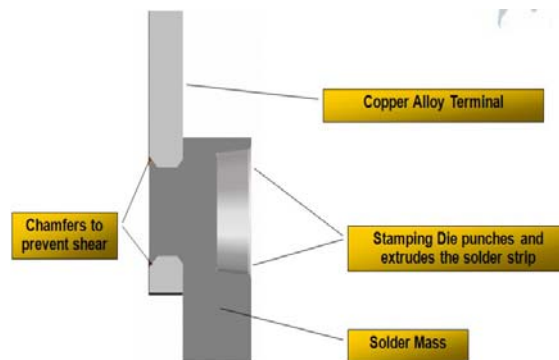


Figure 10: Solder charge attachment to terminal

Reliability Testing Results

The SCGA has completed and passed a series of qualification tests to validate and assure both mechanical and electrical integrity is maintained under various environmental conditions. These tests were conducted per IPC-9701 "Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments" and EIA-364-1000 "Environmental Test Methodology for Assessing the Performance of Electrical Connectors and Sockets used in Controlled Environment Applications". The SCGA was further tested per Telecordia MFG procedures as well as solder joint pull strength and shear force testing.

IPC-9701 testing required the SCGA to undergo temperature cycling from 0C to 100C for a total of 6,000 cycles. The test vehicles used for this test were laid out with 4 sets of connectors using the SCGA technology (one test vehicle with 4 receptacles and another test vehicle with 4 plugs). The test board layouts are shown in Figures 11 and 12.

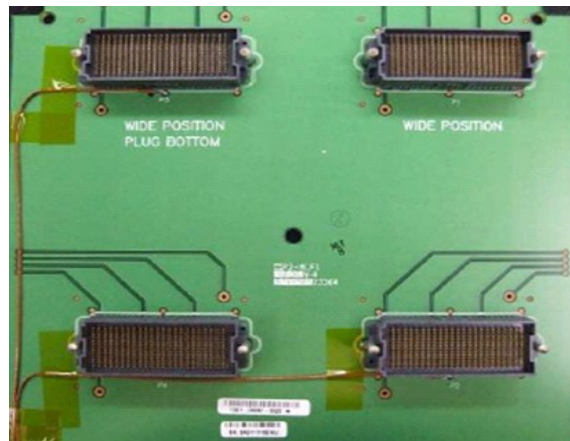


Figure 11: Test Vehicle Layout used for IPC-9701 Testing (Plug Side)

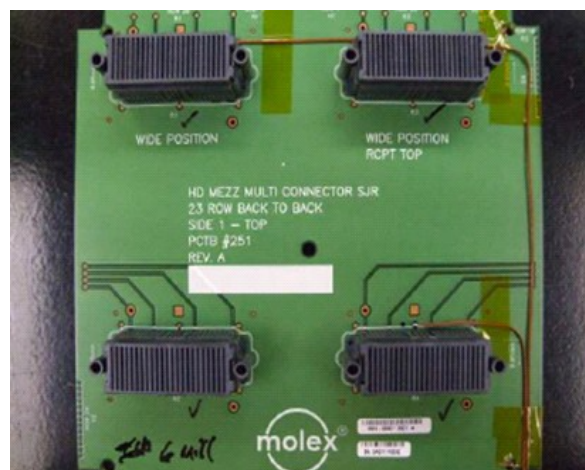


Figure 12: Test Vehicle Layout used for IPC-9701 Testing (Receptacle Side)

Each board had a daisy-chain circuit running through the interconnect so electrical continuity could be confirmed at different points in the test sequence. The boards were taken out of the chamber and tested every 500 cycles to identify the point in the test process where failures may have begun to be found. The temperature profile used for each of those cycles can be seen in Figure 13.

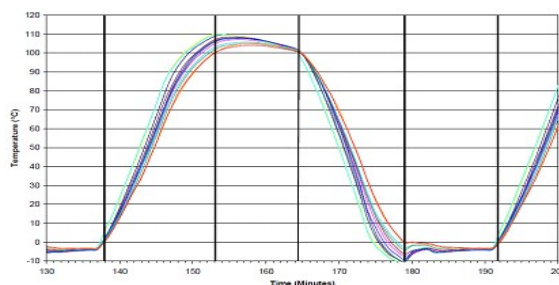


Figure 13: IPC-9701 Testing Temperature Cycle Profile

Upon completion of the test the resulting data concluded that none of the solder joints were cracked to the point of failure. By definition, failure was considered to be the identification of a “glitch” in the daisy chain, meaning a delta of 10mΩ in resistance lasting over 1 millisecond. Thus, a cracked solder joint would result in contact resistance increasing over a long interval of time and affect the signal transmission capability. Such cracks are caused from the stresses in temperature cycling and the ability of the solder joint to absorb those temperature variations through metallic properties in the PCB adhesion. The solder joint reliability results of SCGA in the IPC-9701 test sequence can be seen in Table 1.

Table 1: Results of IPC-9701 testing for SMT SC

DESCRIPTION	TREATMENT	REQUIREMENT	NUMBER OF FAILURE EVENTS		
IN-SITU EVENT DETECTION	TC-1 0°C to 100°C 6000cycles	RECORD FAILURE EVENTS (Ten consecutive 10 Ω Change in Resistance lasting over 1 millisecond)	0 FAILURES		
Loop Resistance (Across 53 ckt Daisy Chain)	Initial	1.25 Ω Nominal, Reference-No Limit set.	AVG 1.25 Ω	MIN 1.171 Ω	MAX 1.406 Ω
	500 cycles	Delta Resistance Ω (Reference)	-0.019 Ω	-0.028 Ω	0.064 Ω
	3000 cycles	Delta Resistance Ω (Reference)	-0.008 Ω	-0.017 Ω	0.009 Ω
	6000 cycles	Delta Resistance Ω (Reference)	-0.017 Ω	-0.023 Ω	0.014 Ω

As part of the standard qualification procedure used to validate the robustness and reliability of a new SMAA solder attachment method several sequences provide insight into the solder joint reliability through testing that is application oriented: Durability, Thermal Shock, Temperature Cycling with Humidity, Mechanical Shock and Random Vibration.

These sequences as applicable to the solder joint condition depend on Low Level Contact Resistance (LLCR in accordance with EIA-364-23) as the gage of performance since damaged/over-stressed solder joints can result in high increases in LLCR. Figure 14 shows the test setup for LLCR measurement.

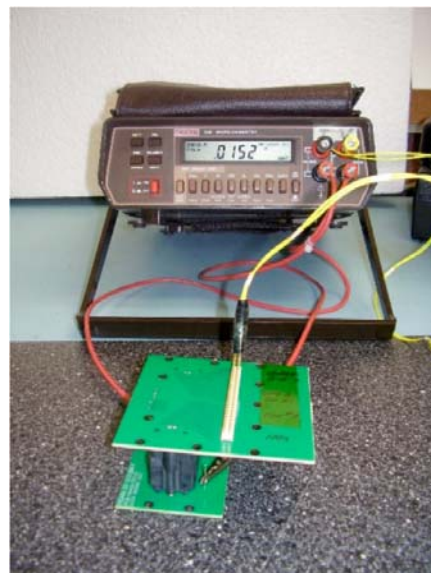


Figure 14: LLCR test setup configuration

The durability test in accordance with EIA-364-09 stresses the solder joints through repeated mating and unmating of the connectors in a typical, real-life set up where the mating halves are allowed to self center as they are repeatedly plugged and unplugged. The LLCR is periodically measured and recorded as well as an indication of stability. This test is part of a sequence whereby the stresses imposed by said durability testing on the contact interfaces as well as the solder joints is exacerbated by exposure to Thermal Shock and Cyclic Humidity.

One hundred Thermal Shock cycles (+85°C to -55°C, 30 minutes at each extreme/cycle) are performed in accordance with EIA-364-32 monitoring of the LLCR at the completion of said exposure. These thermal shocks are more severe and faster in transition time than the standard Solder Joint Reliability (SJR) testing providing similar stress at an accelerated level. The comparison of the initial LLCR vs. the final LLCR is the gage of solder joint performance.

The Humidity test (also referred to as Temperature Cycling with Humidity) is performed for ten days in accordance with EIA-364-31. This test further stresses the solder joints by adding humidity to further aid in the detection of degrading solder joints. The LLCR is also measured following this exposure using the delta as a gage of solder joint performance. Table 2 below shows the test results of the temperature cycling with humidity testing.

Table 2: Temperature Cycling with Humidity Test Results

TEST	STRESS	REQUIREMENT	AVERAGE (mΩ)	MAXIMUM (mΩ)
Initial LLCR	None	Measure and record	13.8	27.1
Post Durability	100 Durability cycles	Delta from initial	0.3	4.4
Post Thermal Shock	100 Thermal Shocks	Delta from initial	1.4	7.3
Post Humidity	240 Hr Exposure	Delta from initial	1.4	8.0

Additionally a sequence of testing solely concerned with the mechanical robustness of the contacts/package bodies and solder joints begins with Mechanical Shock in accordance with EIA-364-27 (100 G's, 6 mS, 3 blows/axis/direction) and proceeds through a Random Vibration exposure in accordance with EIA-364-28, TC VB (7.56 grams). While a group of samples is exposed using LLCR as the gage of performance for the contact interface, a second group of samples is run monitoring for discontinuities of electrical signal through the connector assemblies. This second group is the key to identifying cracked solder joints since this condition would cause very high resistance glitches to trigger the discontinuity/event detector while the samples are being shocked/vibrated. Figure 15 shows the fixture used for mechanical shock/vibration testing.

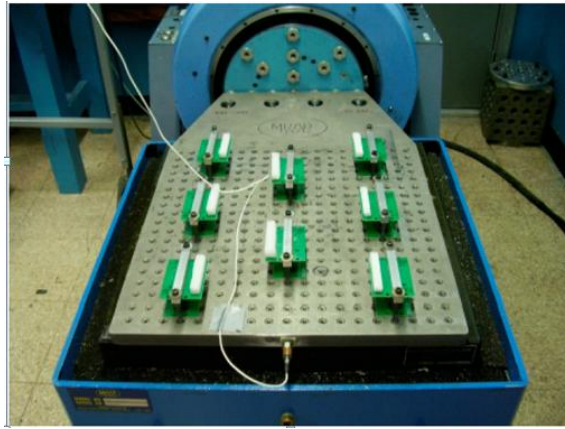


Figure 15: Mechanical Shock/Vibration Test Fixture

The test results of the mechanical shock and vibration testing indicate no damage to the solder joints. Tables 3 and 4 below contain the test results.

Table 3: Test result data for mechanical shock and vibration testing

TEST	STRESS	REQUIREMENT	AVERAGE (mΩ)	MAXIMUM (mΩ)
Initial LLCR	None	Measure and record	13.0	26.2
Post M. Shock	18 Shocks Total	Delta from initial	0.8	6.3
Post Random Vibration	2 Hours/axis, 6 Hours Total	Delta from initial	1.2	7.0

Table 4: Test result data for mechanical shock and vibration testing

TEST	STRESS	REQUIREMENT	RESULTS
M. Shock	18 Shocks Total	No discontinuities > 1.0 μS	Passed
Random Vibration	2 Hours/axis, 6 Hours Total	No discontinuities > 1.0 μS	Passed

In addition to IPC and EIA testing the solder joint pull strength and shear force were tested as well. Solder joint pull force testing was done using both Sn/Pb and Pb Free SCGA technology. Pull force testing resulted in the Sn/Pb solder joint strength being measured at 2,658 g/solder joint and Pb free solder joint strength being measured as 2,887 g/solder joint. These results showed the SCGA solder joint pull force strength to be more than 2.5X that of a comparable BGA solder joint which measure a pull force of 1008 g/solder joint.

Side loads also play a major role in the strength and reliability of solder joints so lateral and longitudinal forces were calculated versus deflection in the contact. A side load test was performed on mated connectors that were soldered to a PCB using the SCGA technology with 299 contact points. Figure 16 shows the reading of lateral travel (x axis) versus pound force of a side load (y axis) applied to a free

PCB when the other PCB is fixed. Resistance of the daisy chained system was monitored during loading.

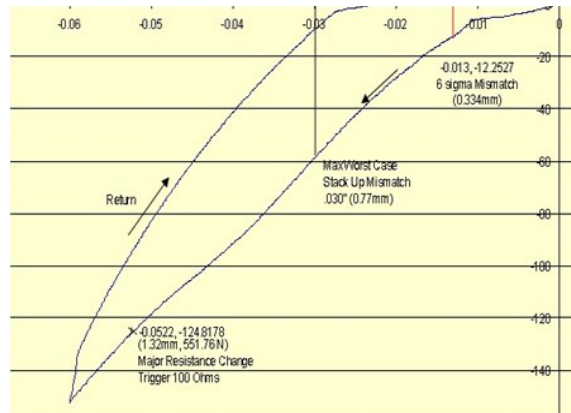


Figure 16: Lateral resultant force (lbf) versus forced travel (inch)

There are two conditions for mismatched positional values that must be considered for a side load: mechanical tolerance stack for 2 mated components that are forced out of position by the PCB mounting hardware and mechanical tolerance stack of multiple parts per board. These positional mismatches generate side loads which must be withstood by the SCGA. In this case, the statistical 6 Sigma tolerance stack for a multiple part per board set of connectors was found to be 0.013". The resulting side load force of 12.25 lbs (or 0.041 lbs per solder joint) was measured at this amount of forced travel. The worst case stack mismatch of 2 sets of mating components on the same board can be up to 0.030", resulting in a side load of 58.3 lbs (or 0.195 lbs per solder joint). The test continued until a deflection of 0.052" with a side load of 124.8 lbs (or 0.417 lbs per solder joint) created significant change in contact resistance. The load was released shortly after this event and electrical resistance returned to its original value.

Conclusion

As SMAA devices and applications continue to evolve, solder attachment methods must also evolve to meet the needs of these more advanced and dense electronic packages and applications. Proving out the effectiveness and reliability of a new SMAA technology requires numerous different test sequences to replicate extreme environments that may be faced in the wide variety of applications that electronic components are designed for. Using these standardized test sequences offers a designer the ability to compare the performance of a new SMAA technology versus different technologies that already exist today.

To effectively prove out the effectiveness of a new SMAA, a designer must consider pick and place compatibility, high-density pin coplanarity, ease of oven processing, inspection effectiveness and solder joint reliability through industry standard testing. With those factors in mind, the SCGA was designed to meet current SMAA benefits and exceed some of the shortfalls of current designs through thorough analysis of those important factors mentioned in the previous sentence. As is seen in the results and data shown in the previous sections of this report, the SCGA has been designed as a next generation SMAA solder attachment method and test data, along with current major OEM applications, has shown that the SCGA does indeed meet or exceed all current expectations and requirements of a SMAA solder attachment method.

A follow-on investigation to be considered is the fine balance between the signal integrity performance of a new SMAA technology and the mechanical robustness of a solder joint. In many designs an

electrical designer may have different priorities than a mechanical designer but both must work together to find harmony in appeasing each other for a beneficial overall system cohesiveness. In looking at a new SMAA technology like the SCGA, it would be interesting to do an analysis of the SI performance and any electrical benefits or drawbacks it may have when compared to the mechanical advantages it may bring.

Bibliography

[1] Thomas W. Edwards, "Solder joint similarities between BGA/Chipscale and other surface mount devices", IPC/SMTA Ball Grid Array National Symposium in Bedford, Massachusetts on 23-24 June 1997.