Improved Solder Joint Integrity for High-Density Interconnect Applications

White Paper

May 2023

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Abstract

Interconnect miniaturization and reliability are important, especially in complex, smaller, lighter, denser, and more portable applications in industries such as military/aerospace and medical. Pin-in-ball surface mount area arrays (SMAA) have been widely used in the industry for decades but have lacked IPC classification. The demand for board-to-board (B2B) SMAAs compatible with IPC-A-610 and IPC J-STD-001 Class 3 acceptance criteria is increasing as these types of interconnects are necessary to advance the state of the art.

Many current pin-in-ball interconnects offer straight tails with minimal tail penetration into the ball. Alternatively, the next-generation pin-in-ball grid array connectors (and similar non-solder ball versions) are being manufactured with contoured tails, deeper tail penetration into the ball and an increased solderable surface area. These next-generation interconnects support high-performance demands up to 112 Gbps PAM4 (56 Gbps NRZ) and beyond while providing robust and reliable solder joints. This paper focuses on the research and development of these next-generation pin-in-ball grid array connectors with emphasis on reliability testing as well as performance in harsh environments.

Authors

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Introduction

Interconnect miniaturization and reliability are important, especially in complex, smaller, lighter, denser, and more portable applications in industries such as military/aerospace and medical. Pin-in-ball surface mount area arrays (SMAA) have been widely used in the industry for decades but have lacked IPC classification. The demand for board-to-board (B2B) SMAAs compatible with IPC-A-610 and IPC J-STD-001 Class 3 acceptance criteria is increasing as these types of interconnects are necessary to advance the state of the art.

Traditional surface-mount and through-hole interconnects are reaching their limits in terms of density and the number of signals that can effectively be used [1], so many product design teams are implementing high I/O array styles of interconnects. Industry technical documents [2] report good solder joint reliability for select BGA-style and pin-in-ball connectors. This paper details the design characteristics and verification testing used to evaluate the signal integrity and robustness of the solder joint in next-generation pin-in-ball grid array connectors (and similar non-solder ball versions) that feature contoured tails, deeper tail penetration into the ball, and an increased solderable surface area. These next generation interconnects support high-performance demands up to 112 Gbps PAM4 (56 Gbps NRZ) and beyond while providing robust and reliable solder joints.

Research and Design

The next-generation pin-in-ball grid array development project focused on improving many aspects of SMAAs and SMAA solder attachment methods:

1. Miniaturization and increased density
2. Improved solder joint reliability
3. More feasible and reliable automated x-ray inspection (AXI)

And, specifically for the non-solder ball versions:

- Additional miniaturization and increased density
- Improved signal integrity
- Increased first-pass yields
- Low temp solder (LTS) compatibility
- Tin whisker mitigation

The tail of the next-generation pin-in-ball grid array components incorporate a fully plated, rounded, and coined bottom with contoured sides for increased robustness and an attached collapsible solder ball (see Figure 1, left). These components are typically soldered to round land patterns. Manufacturers may also offer non-solder ball versions, which use the same tail style but are soldered with increased solder paste volume in lieu of an attached solder ball (see Figure 1, right).

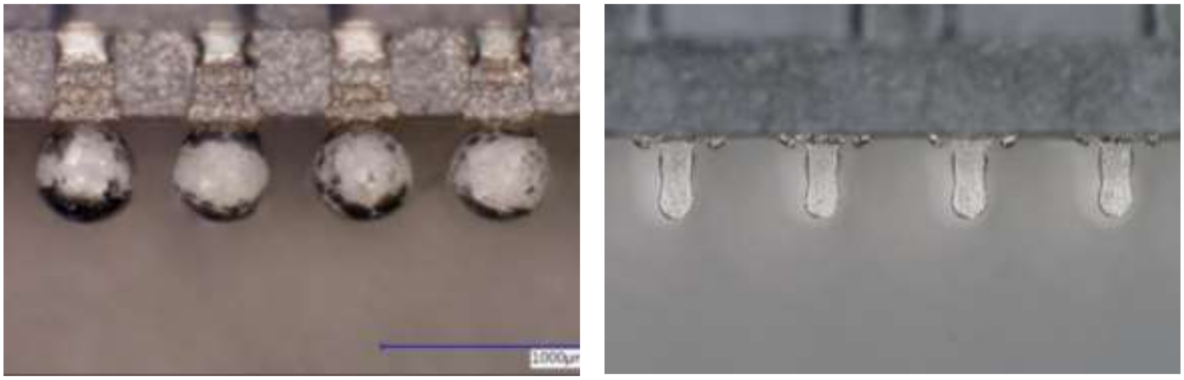


Figure 1: Next-generation pin-in-ball grid array tail design with a solder ball (left) and without (right).

Coplanarity

As package miniaturization continues, it is more common for PCB assemblers to use thinner stencils to prevent screen-printing related defects with their smaller, finer-pitch components. The trend of thinner stencils continues to drive the need for tighter coplanarity requirements. Like many other SMAAs, the next-generation pin-in-ball grid array uses collapsible solder balls which help overcome coplanarity variation. While the non-solder ball version does not have the coplanarity benefit of collapsible solder balls, its simple design results in tightly coplanar tails. It also can be used in combination with other SMT lead styles within the same connector, i.e., signal/power combination (see Figure 2).

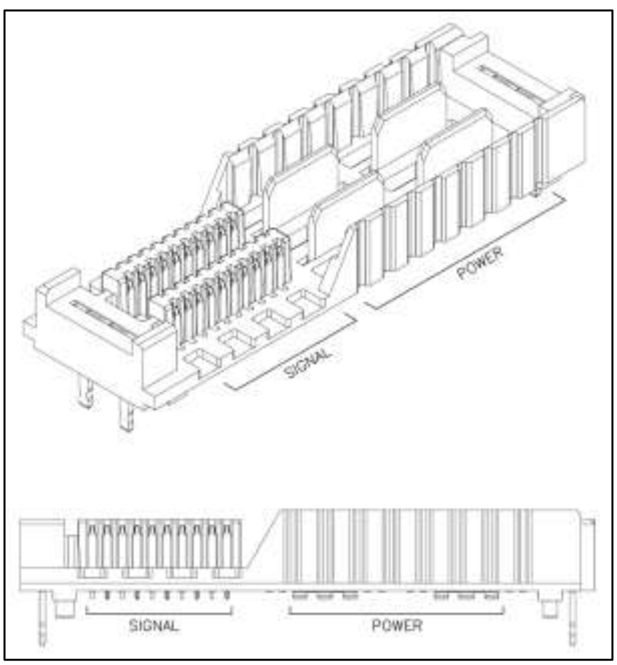


Figure 2: Non-Solder Ball Version – Signal/Power Combination

Inspection

Visual inspection of SMAA connectors is generally limited to the outside rows; therefore, X-ray inspection is required to verify proper solder joint formation of the inner rows (Figure 3). The next-generation pin-in-ball grid array uses simple geometry to promote ease of inspection with visual, manual X-ray, or automatic X-ray inspection. The contour feature provides a reference point for fillet height inspection, and the simple design reduces the risk of false failures while simultaneously increasing the detection of true failures.

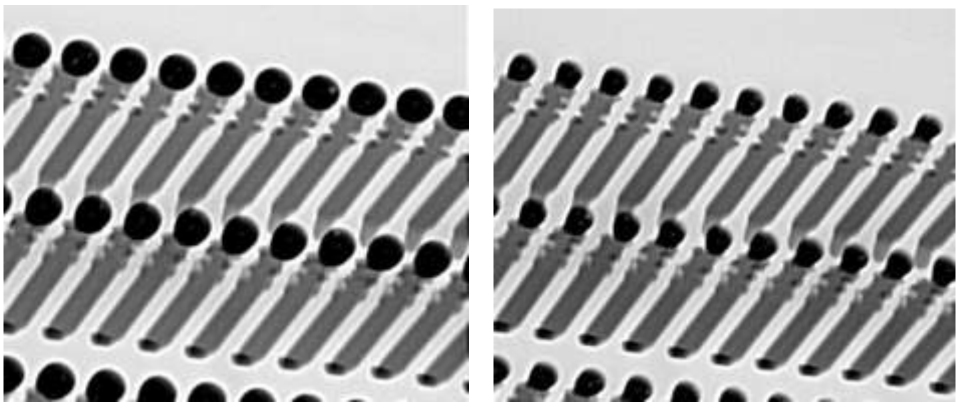


Figure 3: X-Ray image (solder ball version, left, non-solder-ball version, right) allows ease of inspection.

Both the solder ball and non-solder ball version can be accurately dispositioned using standard AXI algorithms and standard 3-slice methodology (see Figure 4).

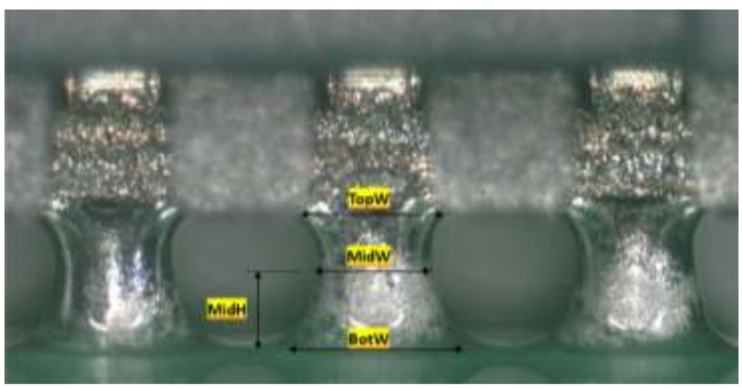


Figure 4: Ideal AXI Slice Levels (Non-Solder Ball Version Shown); TopW: package, MidW: midball, BotW: pad.

Solder Joint Reliability

The terminals used in both versions of the next-generation grid array connector have four design features to improve solder joint strength and reliability (see Figures 5-8):

1. The terminal base is coined and rounded to increase the solderable surface area of the terminal.

2. Contoured sides increase the solderable area and increase retention within the solder joint.
3. The terminal is fully plated with a highly solderable surface finish (e.g., matte tin) that eliminates carrier break-off areas and exposed basis metal inside of the solder joint.
4. Whereas many other pin-in-ball array connectors have minimal tail protrusion into the ball, the next-generation pin-in-ball grid array terminal design provides an increased tail length for deep solder ball penetration.

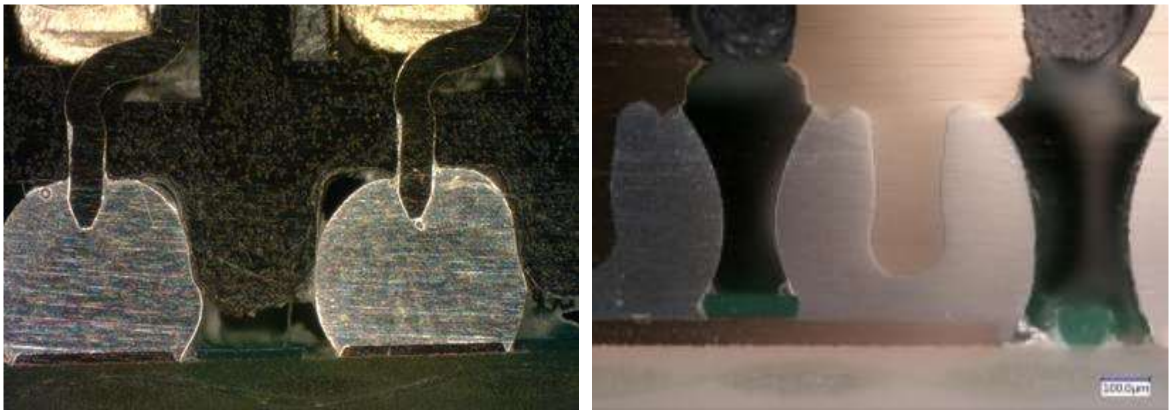


Figure 5: Current generation pin-in-ball grid array (left) vs next-generation pin-in-ball grid array (right).

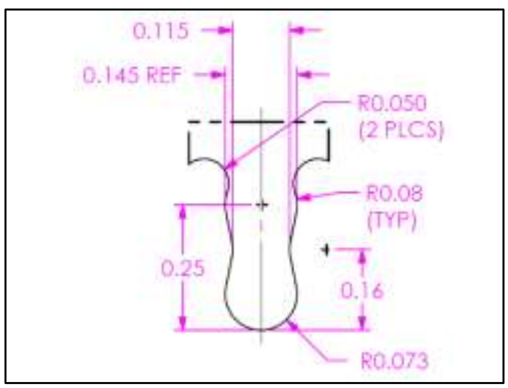


Figure 6: Contoured tail design increases solderable area and retention.

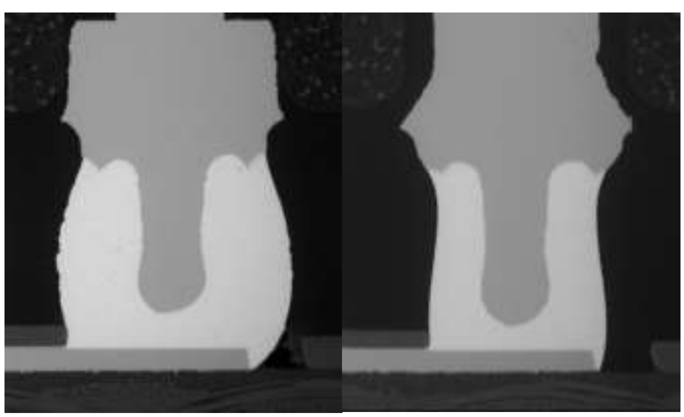


Figure 7: Typical intermetallic formation of SAC305 with a C17200 (BeCu) tail with matte tin after processing: solder ball version (left), non-solder ball version (right).

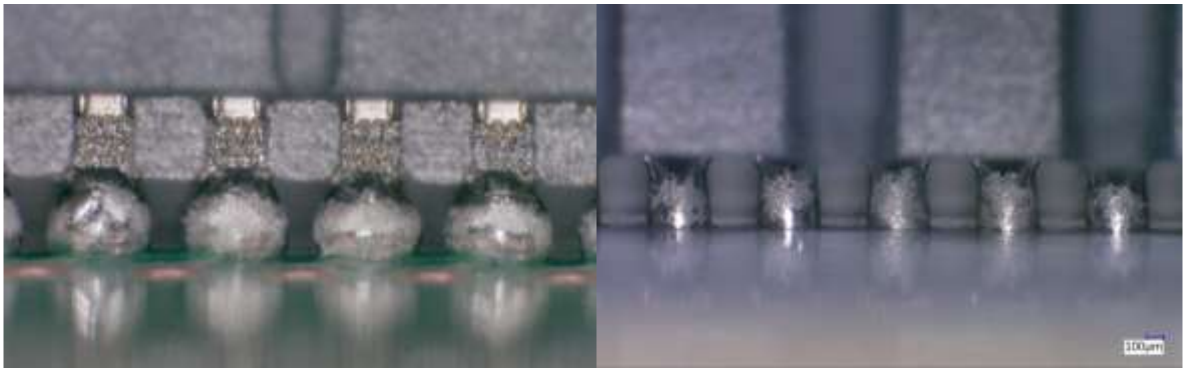
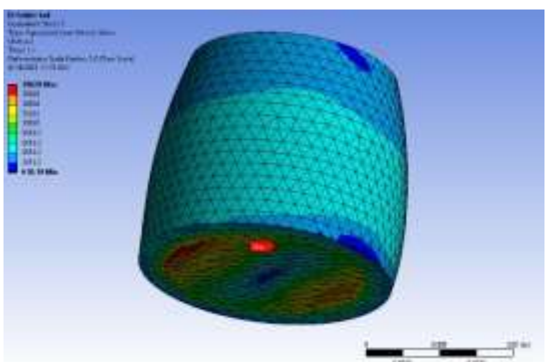


Figure 8: Solder Joint Formation – with (left) and without (right) collapsible solder balls (soldered with SAC305 solder paste).

Solder Joint Strength Simulation

Finite element analysis (FEA) simulations (Figure 9) show comparable strength between the solder ball and non-solder ball versions, despite the fact that the non-solder ball version is smaller. In fact, with comparable strength, yet less solder volume, the tapered shape of the non-solder ball version demonstrates greater efficiency in distributing stress and absorbing deflection/flex in the solder joint.



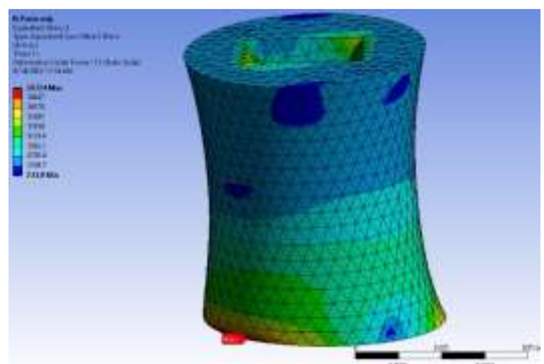


Figure 9: FEA simulation: solder ball version (left) and non-solder ball version (right). The colors represent the levels of stress, with red being the areas of maximum stress.

Reliability Testing Results

The next-generation grid array connectors passed a series of qualification tests to validate mechanical and electrical integrity 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” [3].

The test vehicle was 0.125” thick with 8 copper layers and constructed using FR-4 material with an organic solderability preservative (OSP) surface finish. Each board had a daisy-chain circuit running through the interconnect with constant event detection for continuity. The temperature profile used for each of those cycles is shown in Figure 10. The testing results are shown in Table 1 and 2.

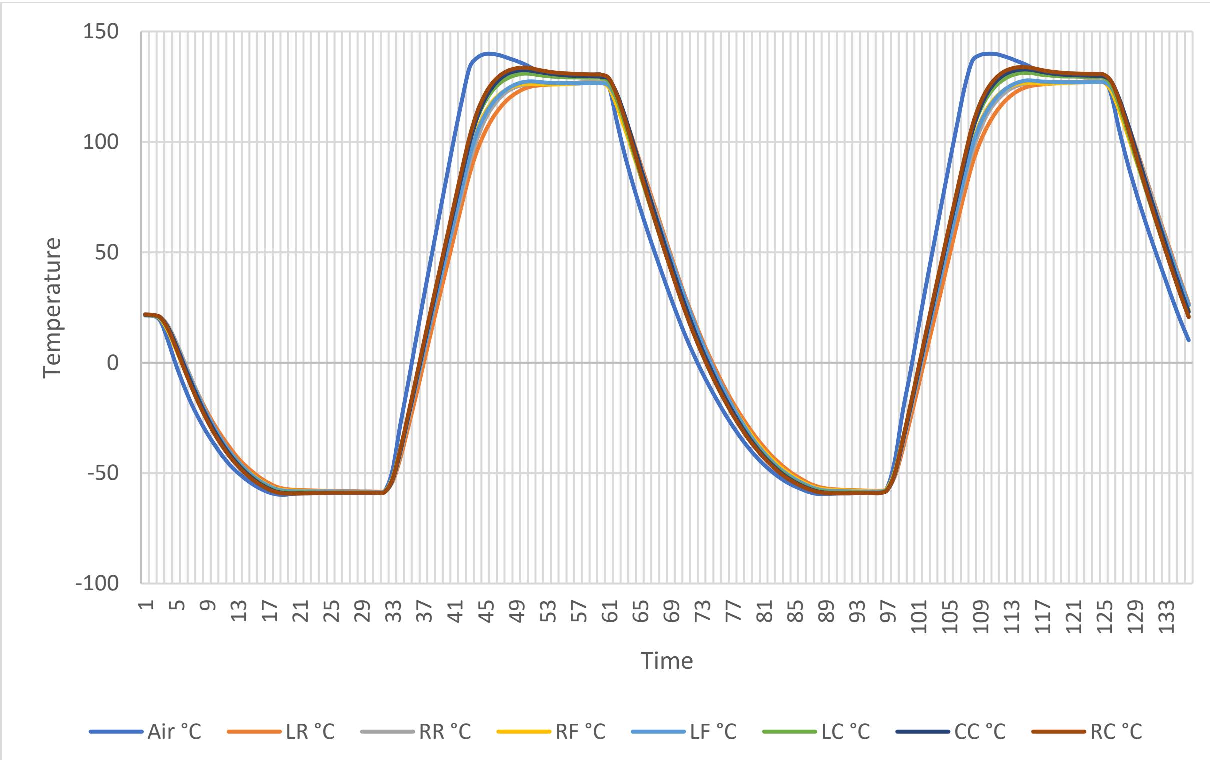


Figure 10: IPC-9701 Testing temperature cycle profile.

Table 1: Results of IPC-9701 Testing (0-1000 Cycles)

Group	DESCRIPTION	TREATMENT	REQUIREMENT	NUMBER OF FAILURE EVENTS	Failure Cycle #
Group 1 (Solder Ball) 64 Connectors	IN-SITU EVENT DETECTION	TC-4 -55°C to 125°C 1000 cycles 10 min dwell, 20°C/min max ramp	**RECORD FAILURE EVENTS** 1000Ω, 10 events (maximum), 1 micro-second duration (maximum)	3	60; 165; 237
Group 2 (Non-Solder Ball) 64 Connectors				4	2*; 246; 395; 540

**Infant mortality failure analysis did not reveal an issue with solder joint.*

Table 2: Results of IPC-9701 Testing (1000-1600 Cycles)

Group	DESCRIPTION	TREATMENT	REQUIREMENT	ADDITIONAL NUMBER OF FAILURE EVENTS	Failure Cycle #
Group 1 (Solder Ball) 64 Connectors	IN-SITU EVENT DETECTION	TC-4 -55°C to 125°C 1000-1600 cycles 10 min dwell, 20°C/min max ramp	**RECORD FAILURE EVENTS** 1000Ω, 10 events (maximum), 1 micro-second duration (maximum)	1	1523
Group 2 (Non-Solder Ball) 64 Connectors				3	1157; 1239; 1457

After thermal cycling, six samples were submitted to an independent lab [4] for dye and pry testing. Dye and pry testing revealed no major dye penetration.

Signal Integrity Performance

The shorter signal path and smaller PCB footprint pad dimensions of next-generation grid array connectors result in improved electrical performance over other lead styles, such as J-leads. Vector network analyzer measurements reveal that next-generation grid array connectors meet 112 Gbps PAM4 (56 Gbps NRZ) and faster application performance requirements (see Figure 11) at 28 GHz, such as better than -1 dB insertion loss, 10 dB return loss, and -40 dB far-end crosstalk power sum at 28 GHz.

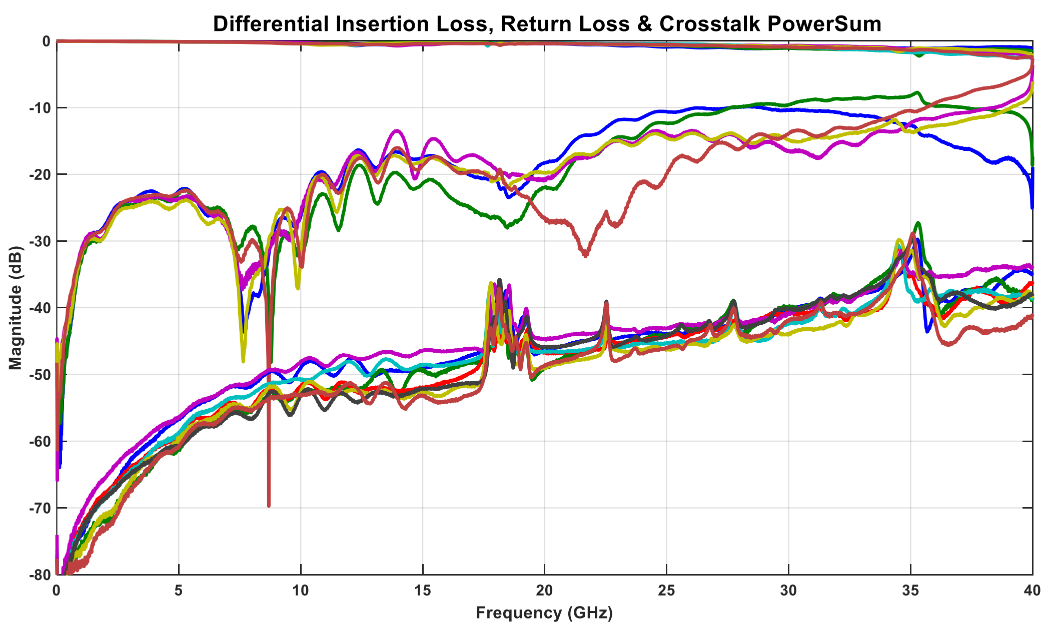


Figure 11: Next Gen Grid Array – Measured Differential Insertion Loss, Return Loss, and Crosstalk Power Sum meet 112 Gbps PAM 4 performance requirements. Measured on a Samtec AcceleRate® HP product.

Signal integrity simulations show comparable performance between the solder ball and non-solder ball version. The non-solder ball version has a slight electrical advantage due to the smaller solder volume, which reduces the capacitive coupling and raises the impedance of the attach region (see Figure 12).

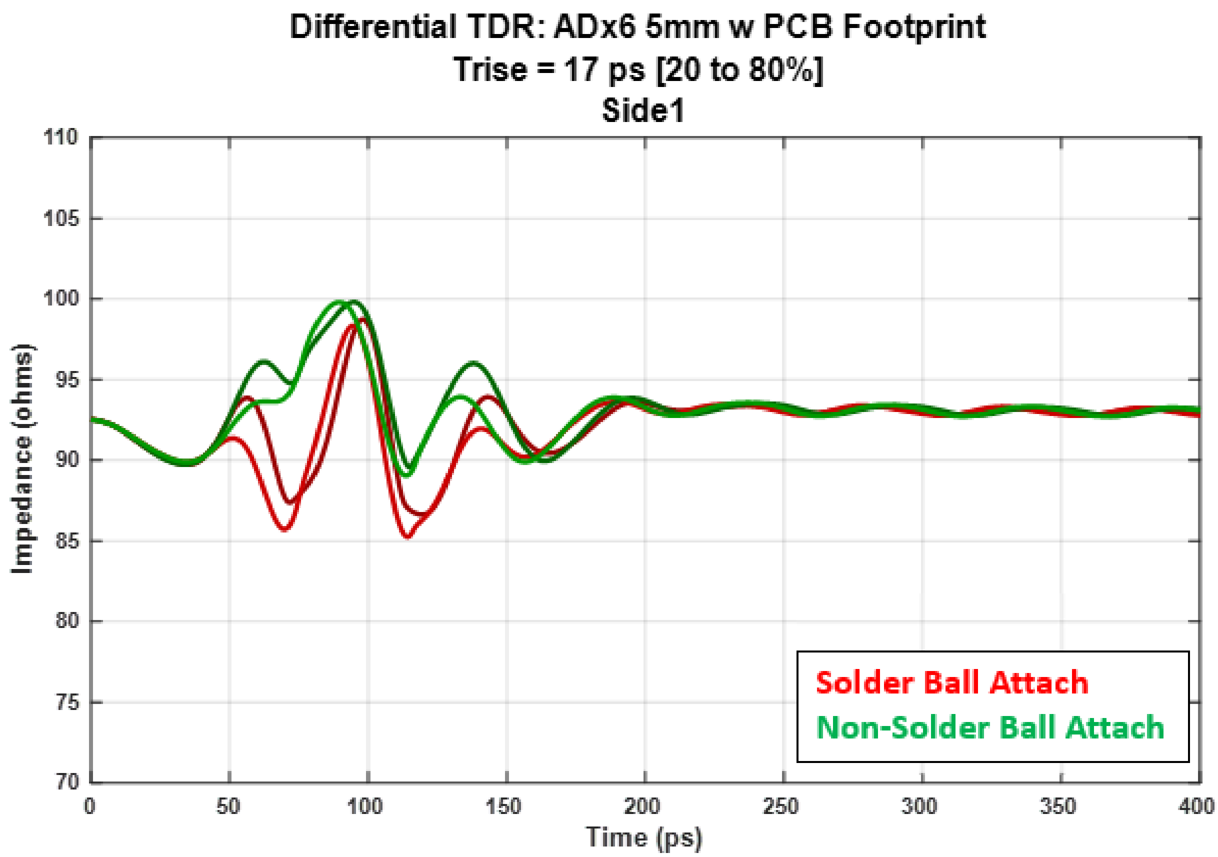


Figure 12: Differential TDR of Solder Ball vs Non-Solder Ball Attach

Proposed Inspection Criteria

The demand for B2B SMAAs compatible with IPC-A-610 and IPC J-STD-001 Class 3 acceptance criteria is increasing as these types of interconnects are necessary to advance the state of the art. Next-generation grid array interconnects are proven to meet the solder joint reliability and signal integrity performance required to support high-reliability high-speed applications. Table 3 summarizes a list of proposed inspection criteria to ensure a successful implementation, and the following figures demonstrate examples of acceptable and failed conditions.

Table 3: Proposed Acceptance Criteria

Feature	Dim.	Class 1	Class 2	Class 3
Lead Side Overhang	A	Not Permitted		
Lead Toe Overhang	B	Not Permitted		
Minimum End Joint Width	C	100% of land diameter		
Alignment and Spacing	D	Offset/spacing does not violate minimum electrical clearance		
Soldered Connection		Solder contacts and wets to 100% of the land		
Minimum Fillet Height	F	Solder reaches top of contour in tail on all 4 sides		
Voids		30% or less voiding of the ball in the x-ray image area		

Note 1. Design induced voids, e.g., microvia in land, are excluded from this criteria. In such cases acceptance criteria should be established between the manufacturer and user.
Note 2. Plating process induced voids, e.g., champagne voids, are excluded from this criteria. In such cases acceptance criteria should be established between the manufacturer and user.

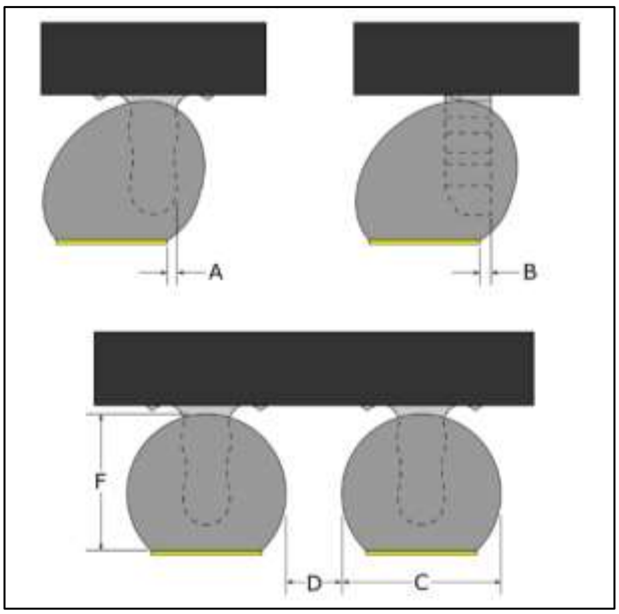


Figure 13: Showing dimensions (Dim) from Table 3 as applies to next-generation pin-in-ball grid array interconnects.

Acceptable – Class 1, 2, 3

- Terminations are uniform in shape and size.
- Terminations contact and wet to the land, forming a continuous elliptical round or columnar connection, see Figure 14.

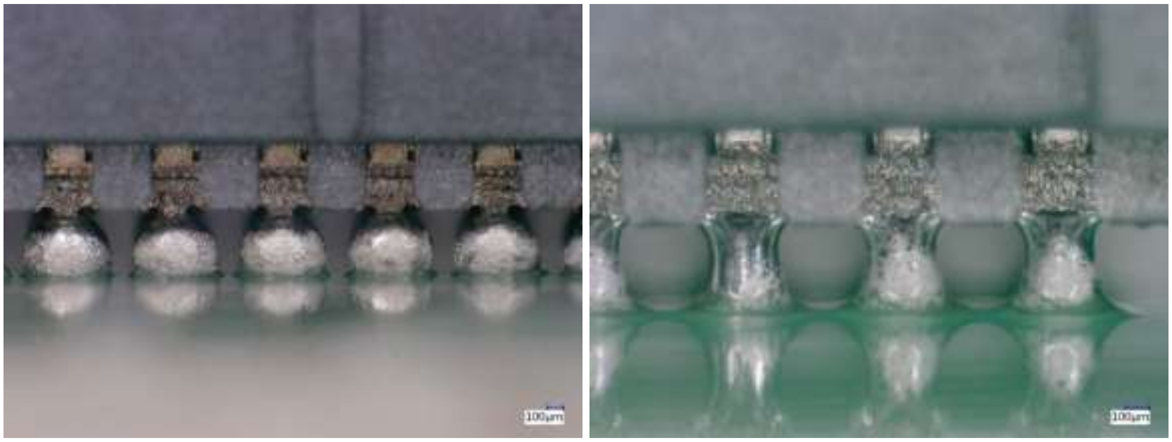


Figure 14: Acceptable Class 1, 2, 3 conditions.

Process Indicator – Class 2, 3

- Terminations are not uniform in size, shape, coloration, and color contrast.

Defect – Class 1, 2, 3

- Solder does not reach top of contour in tail on all four sides, see Figure 15.

Figure 15: Defect Class 1, 2, 3 conditions.

Defect – Class 1, 2, 3

- Ball is not wetted to solder (head-in-pillow), see Figure 16.
- Visual or X-Ray evidence of solder bridging, see Figure 17.
- A “waist” in the solder connection indicating that the solder ball and the attaching solder paste did not flow together, see Figure 18.
- Incomplete wetting to the land.
- Solder terminations have incomplete reflow of the solder paste.

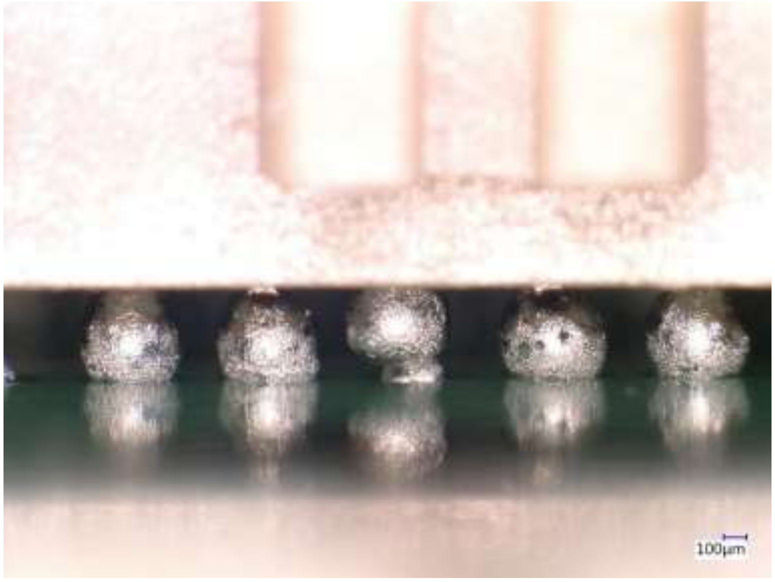


Figure 16: A defect Class 1, 2, 3 condition: Ball is not wetted to solder.

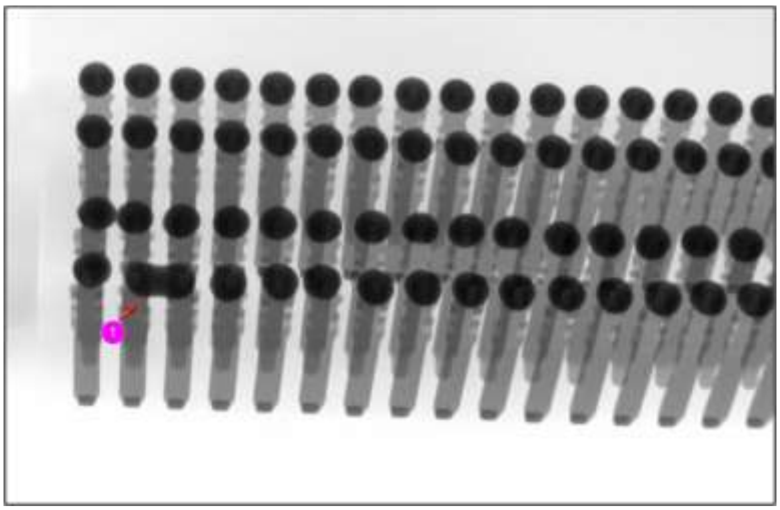


Figure 17: A defect Class 1, 2, 3 condition: Solder bridging.

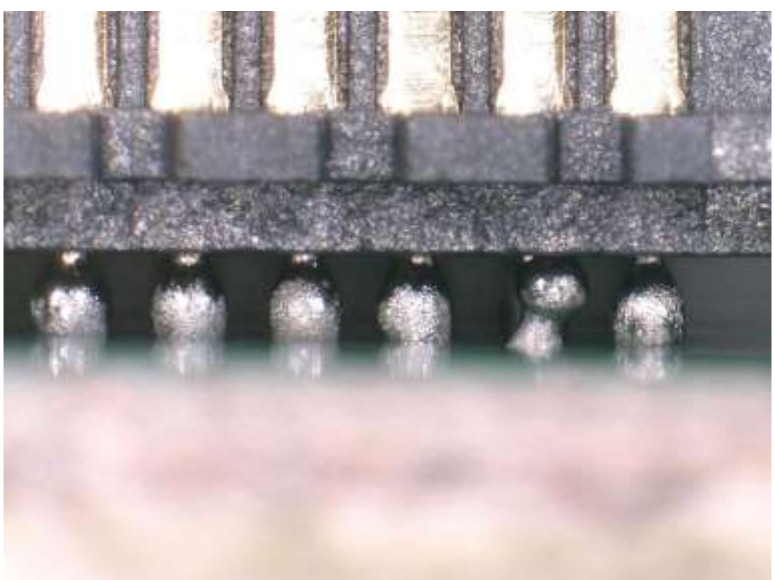


Figure 18: A defect Class 1, 2, 3 condition: The solder ball and the attaching solder paste did not flow together.

Conclusion

As packages continue to evolve in complexity and miniaturization, interconnects and solder attachment methods must also evolve to meet demands.

Today's SMAA technologies have reached or are near their limits regarding pitch, signal integrity, etc. As the results and data above demonstrate, the next-generation grid array interconnects can be used for advanced and future applications. Samtec currently offers AcceleRate® and AcceleRate®HP products [5] with this lead style and has several other products in the development pipeline. The test data collected in this research as well as deployment in major OEM applications support that this design meets or exceeds all current expectations and requirements for SMAA technologies.

Resources

1. D. Hillman, R. Wilcoxon, K. Cho, J. Sailer, J. Waskow, J. Crawford, T. Wade, "High I/O BGA Connector Solder Joint Integrity Investigation"
2. Hirose IT3 Connector System Design Notes, Document Number ETAD-F0347.
3. 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"
4. Insight Analytical Labs (Colorado Springs, CO)
5. Samtec AcceleRate extreme density and performance systems product information.