Next-Generation Pin-in-Ball and Non-Solder Ball Grid Arrays Demonstrate Advancements in Surface-mount Area Array Solder Joint Attachment with the Capacity to Satisfy IPC-A-610 and IPC J-STD-001 Class 3 Criteria

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ABSTRACT
Interconnect miniaturization and reliability are becoming increasingly important, especially in complex, smaller, lighter, denser, and more portable applications in industries such as mil/aero and medical. Traditional surface mount and through-hole interconnects are reaching their limits on density and the number of signals that can effectively be used, and many product design teams are increasingly required to implement high I/O array component styles. 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 with the capacity to satisfy IPC-A-610 and IPC J-STD-001 Class 3 acceptance criteria is increasing as these types of interconnects are necessary for technological advancements. Many current pin-in-ball interconnects offer straight tails and minimal tail penetration into the ball. By contrast, the Next Generation Pin-in-Ball Grid Array connectors, and similar non-solder ball versions, offer *contoured* tails, deeper tail penetration and, therefore, an increased solderable surface area. These next generation interconnects were developed to offer dense components capable of meeting today's performance demands, such as 112Gbps PAM4 (56 Gbps NRZ), while providing robust and reliable solder joints. This paper will focus on the research and development of the Next Gen Pin-in-Ball Grid Array connectors, and the non-solder ball versions, with emphasis on reliability testing per IPC-9701 and EIA-364-100 and the prediction of performance in harsh environments.

Key words: surface mount area array (SMAA), solder joint integrity, thermal cycling, signal integrity, pin-in-ball

INTRODUCTION
As packages become progressively smaller and performance/signal requirements continue to evolve, the need for dense, high-speed, highly-reliable interconnects becomes increasingly necessary to meet the demands of advancing technologies. Traditional surface mount and through hole interconnects are reaching their limits on density and the number of signals that can effectively be used [1] and many product design teams are increasingly required to implement high I/O array component styles. Industry publications [2] report good solder joint reliability for select BGA-style and pin-in-ball connectors. This paper details the design characteristics and testing that has been performed to verify robust solder joint and signal integrity of the Next Gen Pin-in-Ball Grid Array and non-solder ball version.

RESEARCH AND DESIGN
The Next Gen Pin-in-Ball Grid Array development 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)
4. For the non-solder ball versions:
    a. Even further miniaturization and increased density
    b. Improved signal integrity
    c. Increased first pass yields
    d. Low temp solder (LTS) compatibility
    e. Tin whisker mitigation

The tail design of the Next Gen Pin-in-Ball Grid Array components incorporates a fully plated, rounded and coined bottom with contoured sides for increased robustness and an attached collapsible solder ball. These components are typically soldered to round land patterns. Manufacturers may also offer non-solder ball versions, which utilize the same tail style but are soldered with increased solder paste volume in lieu of an attached solder ball.

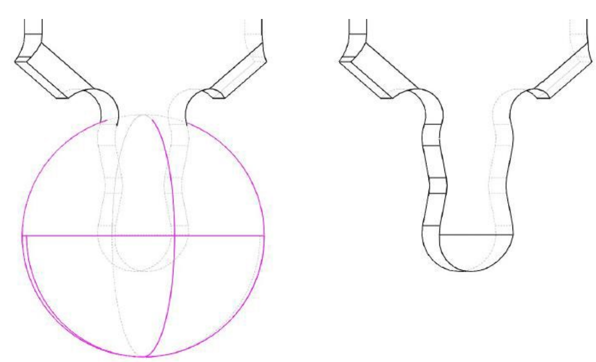

Figure 1. Next Gen Pin-in-Ball Grid Array Tail Design

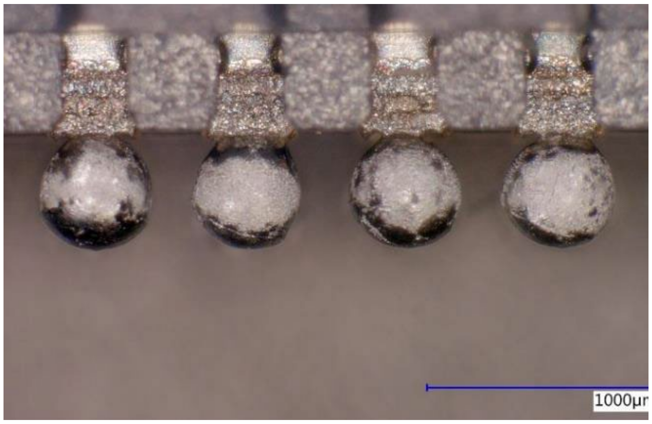

Figure 2. Next Gen Pin-in-Ball Grid Array

Figure 3. Non-Solder Ball Version

COPLANARITY

As package miniaturization continues, it is becoming 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 Gen 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 and it has the benefit of being able to be used in combination with other SMT lead styles within the same connector (i.e., signal/power combo).

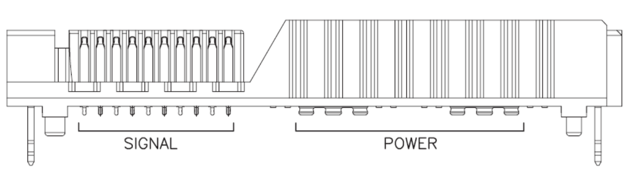

Figure 4. Non-Solder Ball Version – Signal/Power Combo

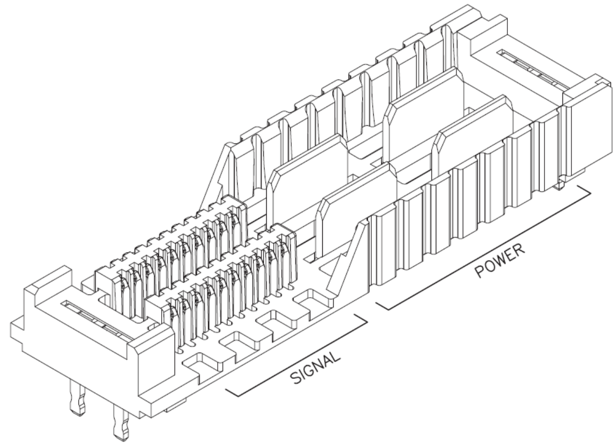

Figure 5. Non-Solder Ball Version – Signal/Power Combo

INSPECTION

Visual inspection of SMAA connectors is generally limited to the outside rows and therefore X-ray inspection is required to verify proper solder joint formation of the inner rows. The Next Gen Pin-in-Ball Grid Array uses simple geometry to promote ease of inspection with visual, manual X-ray or automatic X-ray. 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.

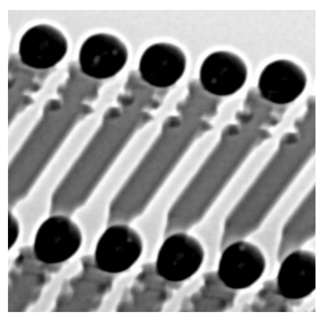

Figure 6a. X-Ray – Solder Ball Version

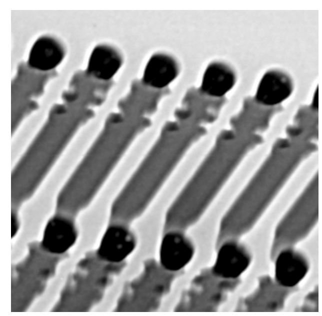

Figure 6b. X-Ray – Non-Solder Ball Version

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

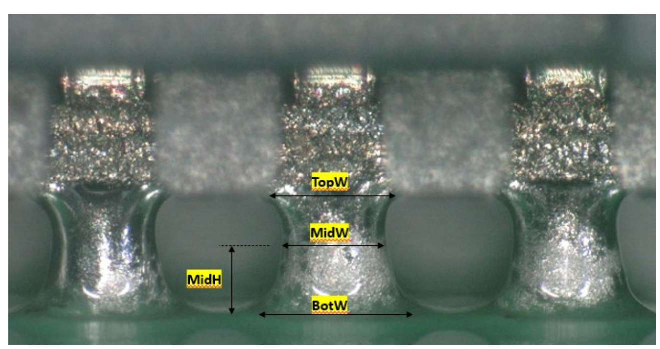

Figure 7. Ideal AXI Slice Levels (Non-Solder Ball Version Shown)

SOLDER JOINT RELIABILITY

The terminals used in the solder ball and non-solder ball versions of the Next Gen Pin-in-Ball Grid Array connector have four design features to improve solder joint strength and reliability:

1. The terminal base is coined and rounded to increase the solderable surface area of the terminal.
2. Its contoured sides also increase the solderable area as well as 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 Gen Pin-in-Ball Grid Array terminal design provides an increased tail length for deep solder ball penetration.

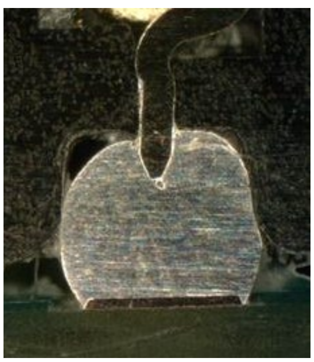

Figure 8. Current Generation Pin-in-Ball Grid Array

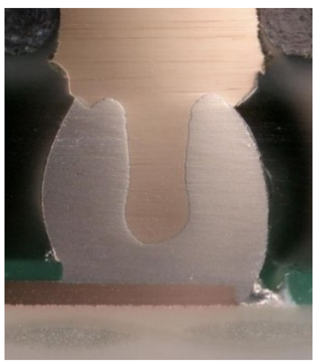

Figure 9. Next Gen Pin-in-Ball Grid Array

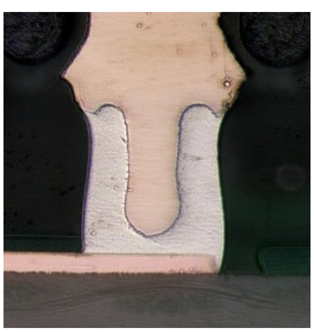

Figure 10. Non-Solder Ball Version

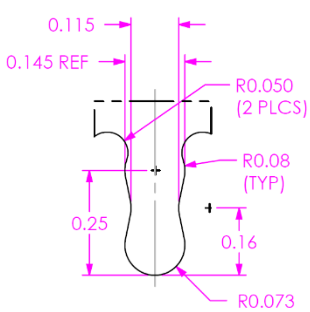

Figure 11. Contoured Tail Design

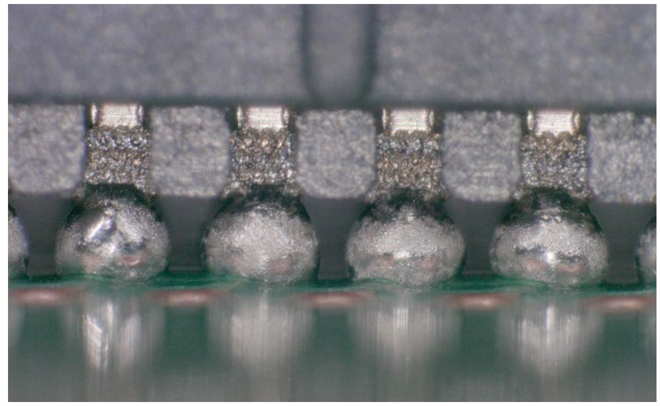

Figure 12. Solder Joint Formation – with SAC305 Collapsible Solder Balls (Soldered with SAC305 Solder Paste)

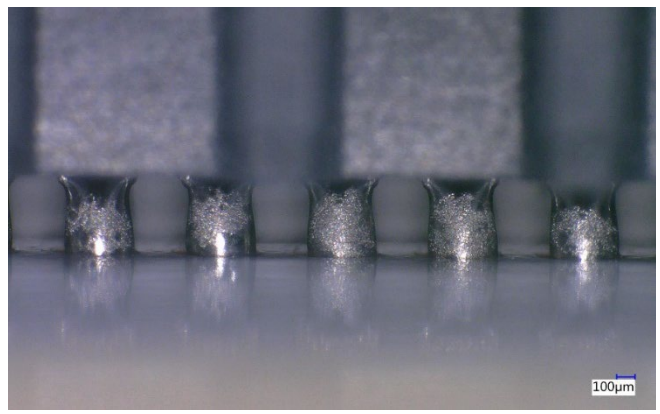

Figure 13. Solder Joint Formation – without Collapsible Solder Balls (Soldered with SAC305 Solder Paste)

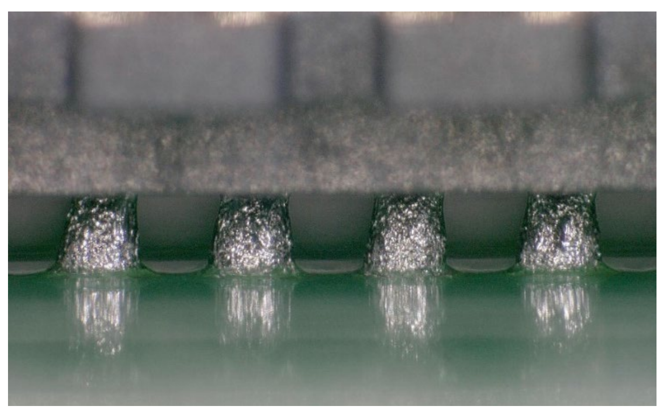

Figure 14. Solder Joint Formation – without Collapsible Solder Balls (Soldered with Bismuth-Based Low Temp Solder Paste)

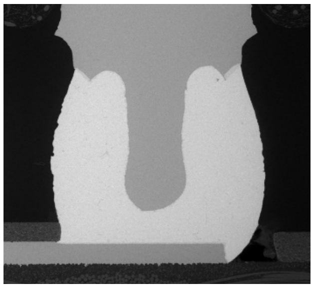

Figure 15. Solder Ball Version - Typical Intermetallic Formation of SAC305 with a C17200 (BeCu) Tail with Matte Tin after Processing

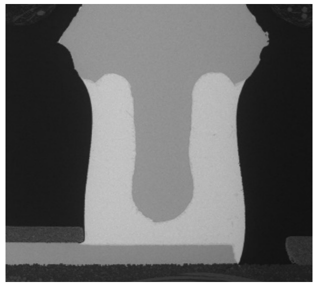

Figure 16. Non-Solder Ball Version - Typical Intermetallic Formation of SAC305 with a C17200 (BeCu) Tail with Matte Tin after Processing

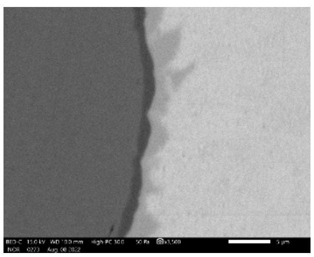

Figure 17. Solder Ball Version - Typical Intermetallic Formation of SAC305 with a C17200 (BeCu) Tail with Matte Tin after Processing

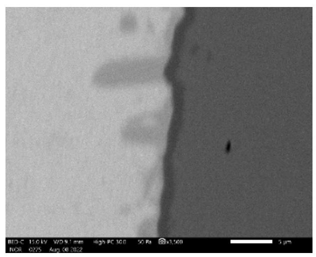

Figure 18. Non-Solder Ball Version - Typical Intermetallic Formation of SAC305 with a C17200 (BeCu) Tail with Matte Tin after Processing

SOLDER JOINT STRENGTH SIMULATION

Finite Element Analysis (FEA) simulations show comparable strength between the solder ball and non-solder ball versions. With comparable strength, yet less solder volume, the tapered shape of the non-solder ball version shows to be more efficient in distributing stress and absorbing deflection/flex in the solder joint.

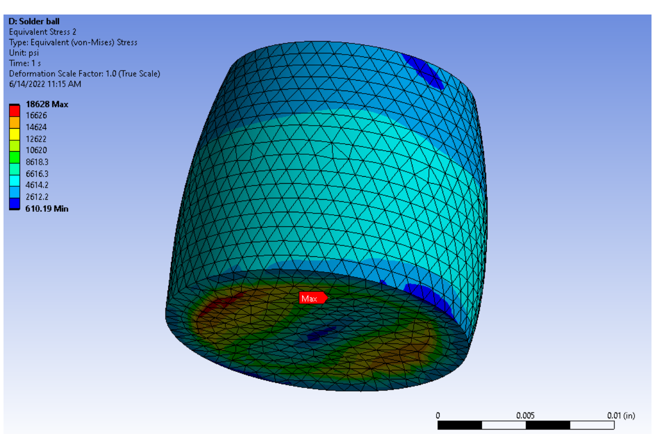

Figure 19. FEA Simulation – Solder Ball Version

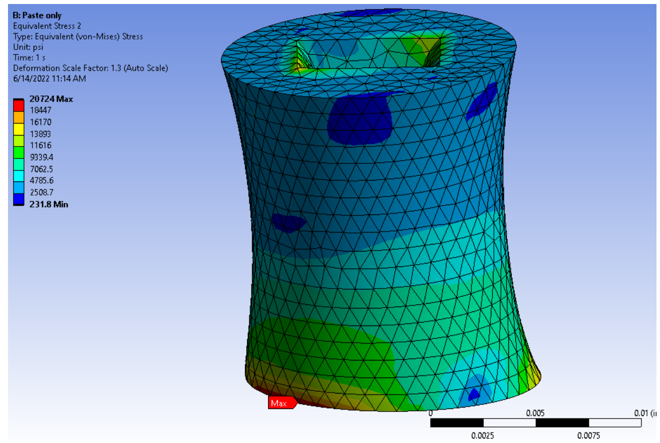

Figure 20. FEA Simulation – Non-Solder Ball Version

RELIABILITY TESTING RESULTS

The Next Gen Pin-in-Ball Grid Array connectors have completed and passed a series of qualification tests to validate that 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 test vehicle was .125" thick with eight copper layers and constructed using FR-4 material with an Organic Solderability Preservative (OSP) surface finish.

Figure 21. Test Vehicle Layout used for IPC-9701 Testing (Plug Side)

Figure 22. Test Vehicle Layout used for IPC-9701 Testing (Receptacle Side)

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 #23. The testing results are shown in Table 1 and 2.

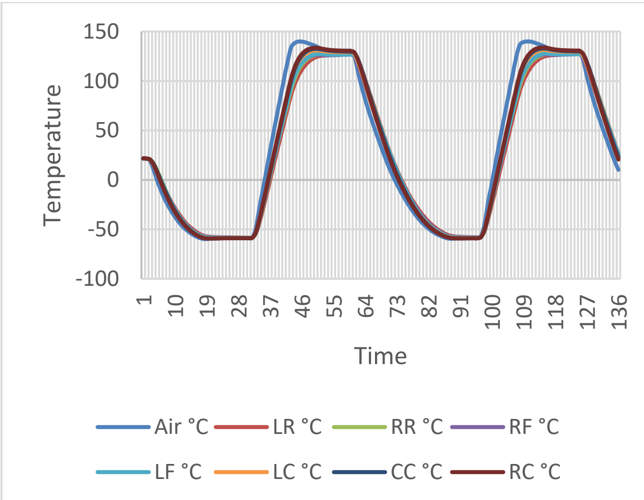

Figure 23. IPC-9701 Testing Temperature Cycle Profile

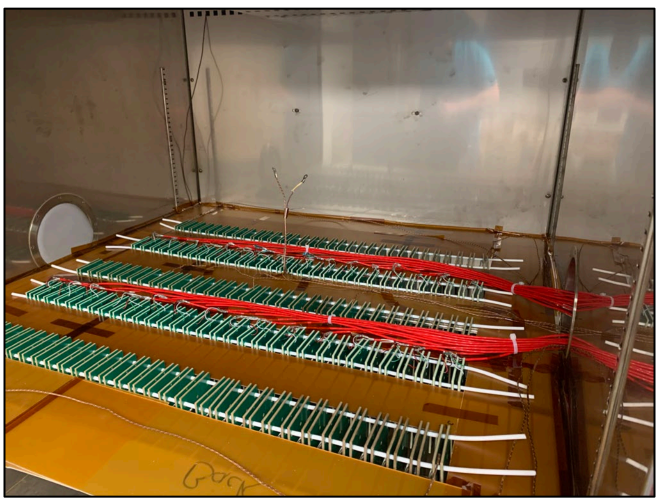

Figure 24. IPC-9701 Testing Chamber Setup

Table 1. Results of IPC-9701 Testing (0-1000 Cycles)
**Infant mortality failure analysis did not reveal an issue with solder joint.*

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

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

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

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

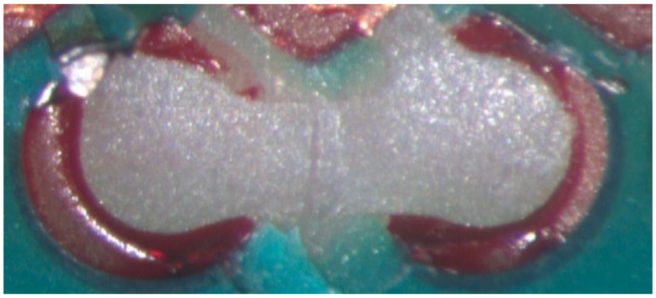

Figure 25. Dye and Pry Sample
(PCB Pad Torn from PCB Resin)

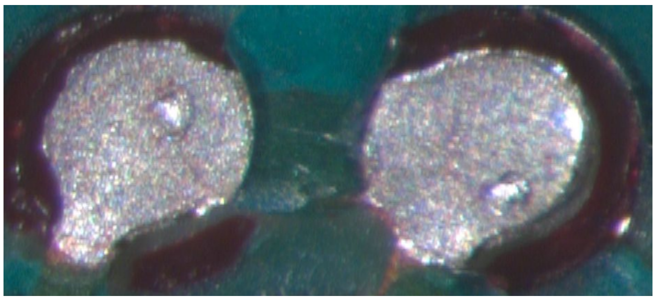

Figure 26. Dye and Pry Sample
(Solder Fractured from PCB Pad)

SIGNAL INTEGRITY PERFORMANCE

As data rates increase, termination designs must evolve to keep pace. The shorter signal path and smaller PCB footprint pad dimensions of Next Gen Pin-in-Ball Grid Array connectors result in improved electrical performance over other lead styles such as J-leads. Measurements with a Vector Network Analyzer (VNA) have been performed and Next Gen Pin-in-Ball Grid Array connectors have proven to be compatible with 112Gbps PAM-4 (56 Gbps NRZ) and faster applications.

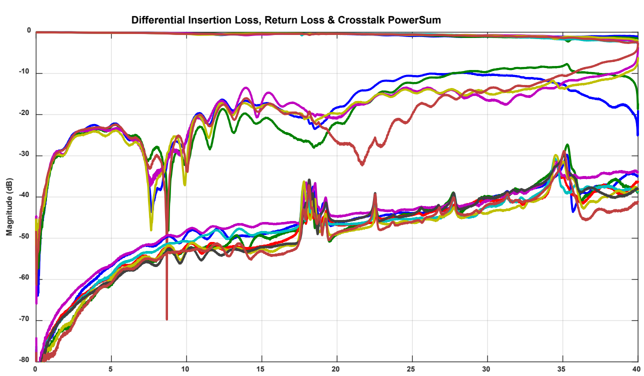

Figure 27. Next Gen Pin-in-Ball Grid Array – Measured Differential Insertion Loss, Return Loss, and Crosstalk Power Sum

Signal integrity simulations have also been performed and 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.

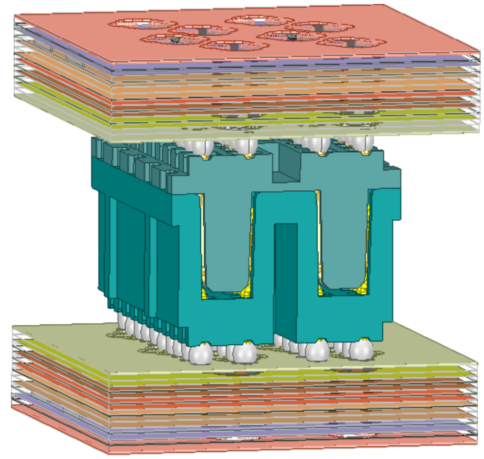

Figure 28. Solder Ball Attach Simulation Model

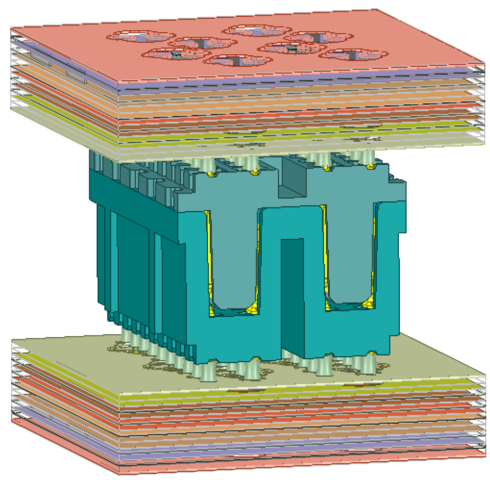

Figure 29. Non-Solder Ball Attach Simulation Model

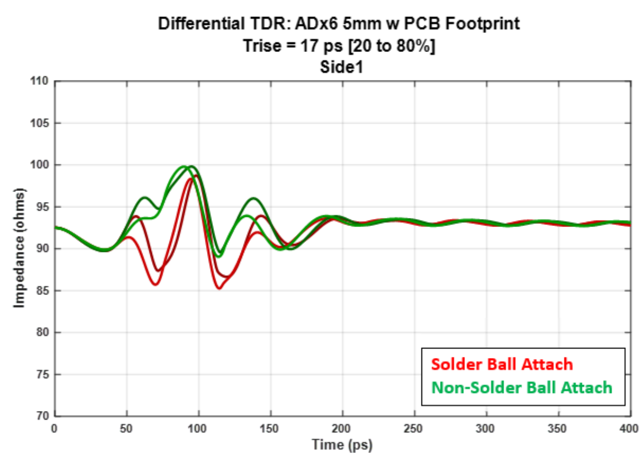

Figure 30. Differential TDR of Solder Ball vs Non-Solder Ball Attach

Proposed Inspection Criteria

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 four 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.

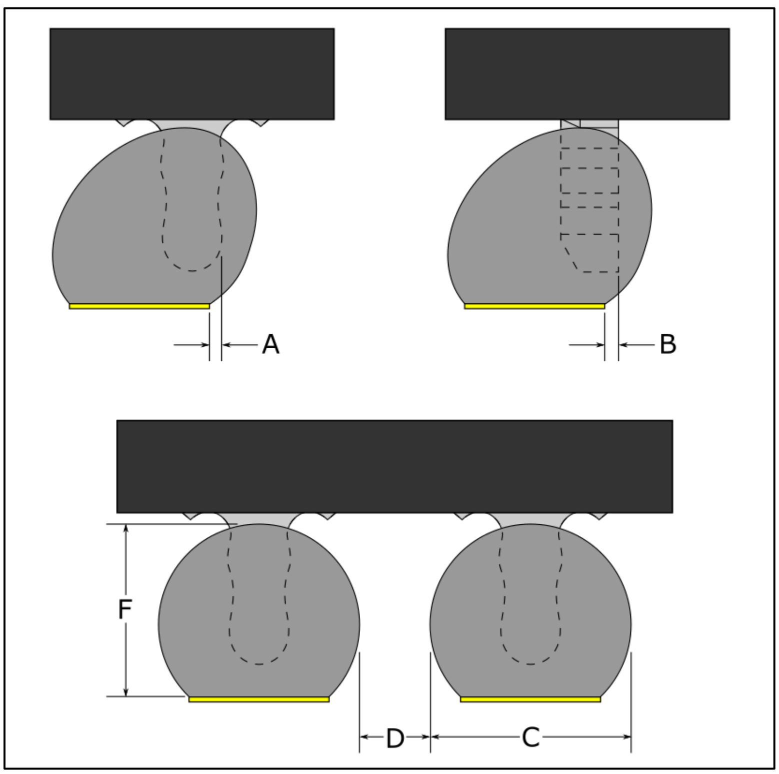

Figure 31. Next Gen Pin-in-Ball Grid Array

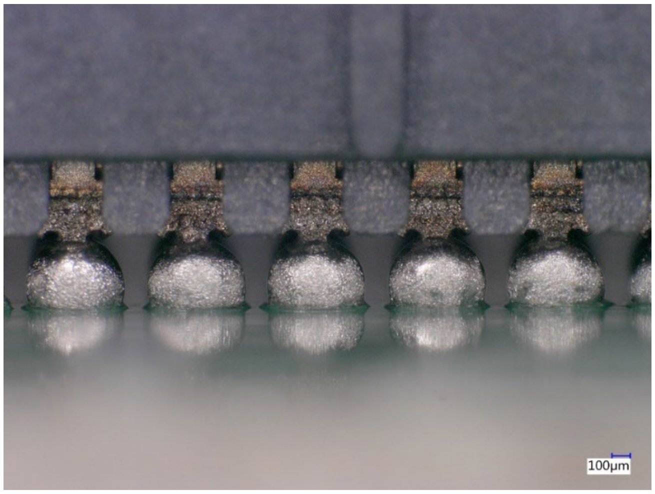

Figure 32. Acceptable Condition (Solder Ball Version)

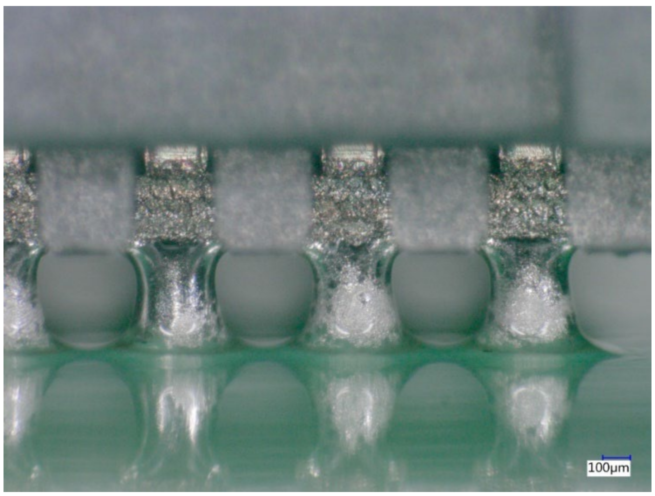

Figure 33. Acceptable Condition (Non-Solder Ball Version)

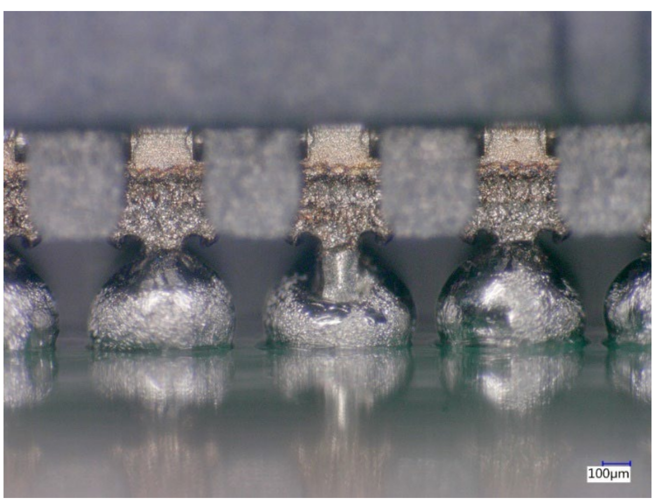

Figure 34. Defect (Minimum Fillet Height)

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 Figures 32, 33.

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 34.

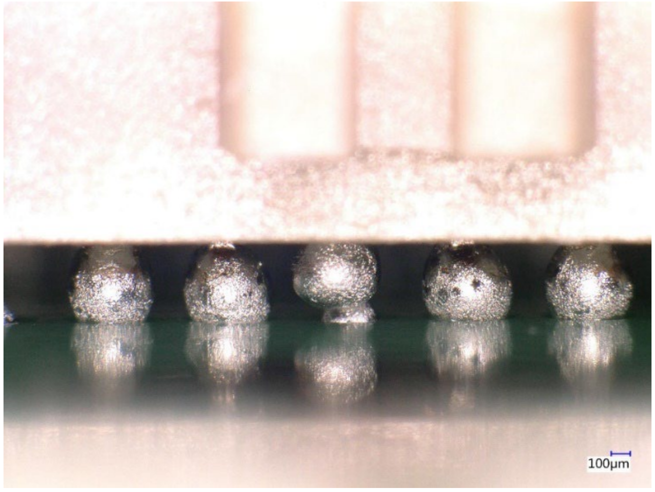

Figure 35. Defect (Head-in-Pillow)

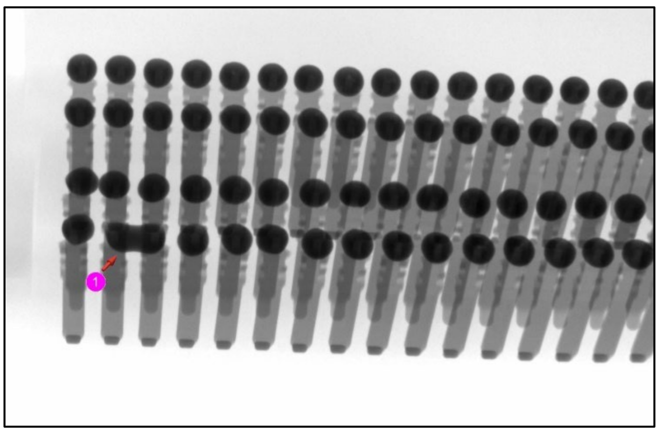
Figure 36. Defect (bridging)

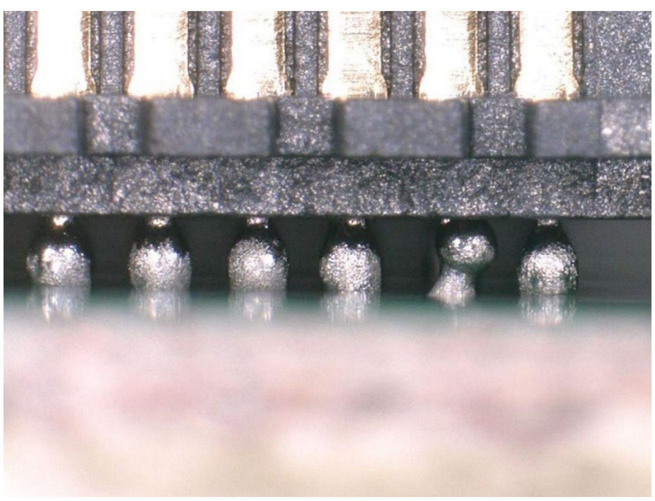
Figure 37. Defect ("Waist" in Solder Connection)

Defect – Class 1, 2, 3
- Ball is not wetted to solder (head-in-pillow), see Figure 35.
- Visual or X-Ray evidence of solder bridging, see Figure 36.
- A "waist" in the solder connection indicating that the solder ball and the attaching solder paste did not flow together, see Figure 37.
- Incomplete wetting to the land.
- Solder terminations have incomplete reflow of the solder paste.

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 limits regarding pitch, signal integrity, etc. As the results and data in the previous sections show, the Next Gen Pin-in-Ball Grid Array was designed for advanced and future applications. The test data and current major OEM applications show that this design meets or exceeds all current expectations and requirements for SMAA technologies.

References
[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, Document Number ETAD-F0347"