QUALIFICATION OF HIGH DENSITY CONNECTOR SOLUTIONS FOR MILITARY AND AVIONIC ENVIRONMENTS

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ABSTRACT

This paper discusses the qualification of high density connector solutions for rugged military and avionics environments. As electronic products become progressively smaller in size, there has been a corresponding increase in the demand for miniature, electronic components and the development of high density connectors. The consumer electronics industry has already implemented high density connectors while many avionics/military products still use traditional surface mount and plated through-hole connectors. These traditional connectors are increasingly too large and cannot meet the signal capacity requirements of modern avionics/military product designs within the limited available printed circuit board space. In this study, two major types of high density connectors, the fine-pitch leaded style and the area-array style, were installed on test boards using automated assembly with tin-lead and lead-free soldering processes. The assemblies were subjected to -55°C to +125°C thermal cycle testing in accordance with the IPC-9701 specification, Performance Tests Methods and Qualification Requirements for Surface Mount Solder Attachments. The first part of this paper discusses the results and observations from the new testing of fine-pitch style (Samtec LSHM) and area-array style (Samtec LPAM/LPAF) connectors. The second part of this paper compares the data for the Samtec LSHM to previously tested area-array connectors (Samtec SEAM/SEAF). Tradeoffs between these two types of connectors, including producibility, reliability, printed circuit board (PCB) space usage, rework, ease of assembly, and defect identification, are discussed.

Key words: high density connectors, thermal cycle testing, fine-pitch leaded, area-array

BACKGROUND

Thermal cycle testing of solder joints is necessary because printed circuit board (PCB) assemblies are made up of many different materials that have different coefficient of thermal expansion (CTE) values. These differences generate mechanical stresses that can crack the weakest link in the assembly. In the case of connectors, the weakest link is typically the solder joint between the connector and the host PCB, due to the CTE mismatch between the plastic housing and the host PCB material. Over the past 20 years, thermal cycle testing of connectors has become increasingly important, due to the replacement of through-hole soldered pins and compliant lead frames with relatively non-compliant solder balls, solder pillars, and fine-pitch "hockey stick" style lead frames. These changes have enabled higher density connectors but have presented challenges in ease of manufacturing assembly and reliability of the solder joint interconnect. Figure 1 shows the progression of connector technology over time. Solder joint reliability is an even larger concern in military and avionics environments. In these harsh environments, the thermal cycling extremes are much greater and occur more frequently than commercial products found in more controlled environments, such as an air conditioned office.

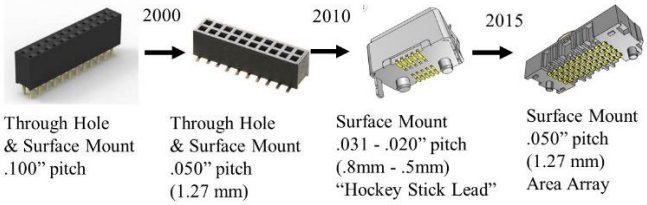


Figure 1: Progression of Connector Technology

While this paper focuses on solder joint thermal cycle reliability, there are other characteristics that are equally important for the successful application of advanced connector technologies. These parameters include signal speed performance, the robustness of the contact designs and finishes in vibration and shock, and the mitigation of tin whisker risk on matte tin tail finishes, which are not recommended for military and avionics environments.

INTRODUCTION

Two families of connectors were tested in this experiment. The first was the Samtec LSHM family in vertical and horizontal configurations with input/output (I/O) counts ranging from 40-100. The second was the Samtec LPAM/LPAF family in the vertical configuration with I/O counts ranging from 40-80. The connectors were assembled with tin-lead and lead-free solder and thermal cycle tested in accordance with the IPC-9701 specification. The connectors were subjected to a total of 2000 thermal cycles from -55°C to +125°C with electrical continuity monitored throughout the test. The transition ramp rate was 10°C-12°C /minute, and all boards were within ±5°C of each other during the

dwells at temperature extremes, which lasted for at least 10 minutes.

TEST VEHICLE

In the test vehicle that was designed for the connectors, one side of a mated pair was positioned on the main test board. The other side of the mated pair was positioned on a "cut-out coupon" designed to allow easy separation from the main test board. After the test vehicles were built, the connectors on the cut-out coupons were separated and plugged into the mating connectors on the main test board. A daisy chain circuit ran through every pin, contact, and solder joint of a mated pair. The test boards were fabricated with IPC-4101/126 material with an electroless nickel immersion gold (ENIG) finish. The test board had 10 layers, 5 signal layers, 5 ground layers, and an overall thickness of .082″. The solder mask for the lead-free assemblies was blue in color, while the solder mask for the tin-lead assemblies was green in color.

TEST PARTS

The connector styles subjected to thermal cycle testing were the Samtec LSHM ("hockey stick" leaded) and the Samtec LPAM/LPAF (area-array). Four sizes of LSHM were included: 40, 60, 80, and 100 I/O. Two sizes of LPAM/LPAF were included: 40 and 80 I/O. The specific connectors tested are listed in Table 1 and photos are shown in Figure 2.

Table 1. List of Connectors Tested

Samtec Connector Part Number	Mating Samtec Connector Part Number	I/O Count
LSHM-120-01-L-DH-A-S	LSHM-120-06.0-L-DV-A-S	40
LSHM-130-01-L-DH-A-S	LSHM-130-06.0-L-DV-A-S	60
LSHM-140-01-L-DH-A-S	LSHM-140-06.0-L-DV-A-S	80
LSHM-140-02.5-L-DV-A-S	LSHM-140-02.5-L-DV-A-S	80
LSHM-150-01-L-DH-A-S	LSHM-150-03.0-L-DV-A-S	100
LSHM-150-06.0-L-DV-A-S	LSHM-150-03.0-L-DV-A-S	100
LPAM-20-01.0-S-04-2	LPAF-20-03.5-S-04-2	80
LPAF-10-03.5-S-04-2	LPAM-10-01.0-S-04-2	40

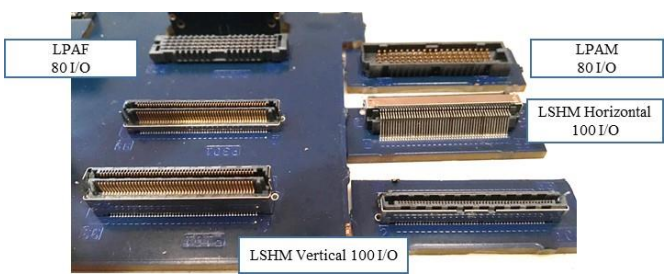


Figure 2: LPAF/LPAM 80 I/O and LSHM 100 I/O

ASSEMBLY

The test vehicles were assembled at the Collins Aerospace Coralville, IA production facility. For the tin-lead assemblies, the solder paste was Indium SMQ92J tin-lead eutectic solder. For the lead-free assemblies, the solder paste was Indium 8.9 SAC305 lead-free solder alloy. The stencil thickness was 0.004 inches. The stencil apertures were designed at 1:1 with the copper pad sizes on the test board for both the LSHM and LPAF/LPAM connectors. The board was thermally profiled using a multi-channel, occurrent logger evaluator (MOLE) thermal profiler. A Koh Young was programmed and used for solder paste volume verification. The components were placed using a Universal Advantis automated placement machine. The assemblies were reflowed in a Heller 1912EXL Reflow Oven. The oven profiles used are shown below in Figures 3 and 4. Assemblies were cleaned in the Electrovert Aquastorm 2000 inline cleaner.

Figure 2: Oven Profile Lead-Free

Figure 3: Oven Profile Tin-lead

Figure 5 shows an assembled test board with the mating connectors cut out and mated with the main test board connectors.

Figure 5. Test Board Assembled

THERMAL CYCLE TESTING

The test vehicles were placed into the thermal cycle chamber. In order to monitor the temperatures of all the boards within the thermal chamber, thermocouples were attached to the test boards. As the chamber cycled for one and a half cycles, the data from the thermocouples was collected and plotted to

establish a thermal profile. By changing ramp rates, temperatures, hold times, and the airflow, the thermal profile was adjusted until all test board temperatures were closely grouped and consistent. The parameters of the thermal profile are as follows: +125°C high temperature, -55°C low temperature, 10°C-12°C /minute transition ramp rate, and all boards were within ±5°C of each other during dwells at temperature extremes for at least 10 minutes. Figure 6 shows the thermal cycling profile for the daisy chain connectors. These assemblies were tested for a total of 2000 thermal cycles.

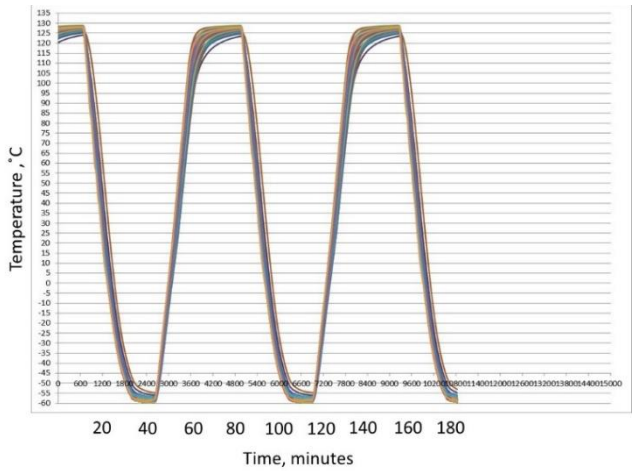


Figure 6: Thermal Profile for Connectors

After test board assembly, cables were soldered to each of the daisy chain electrical circuits. Test assemblies were arranged into a custom test fixture inside the chamber. The cables were run through a port in the chamber wall to a glitch detector system that measured the resistance of each circuit during thermal cycle testing.

SOLDER JOINT DETECTION METHODOLOGY

The practical definition of a solder joint failure is an electrical interruption lasting greater than 1μsec and having continuity greater than 300Ω. Electrical failure during the thermal cycling test was defined as; (1) electrical interruption lasting greater than 0.2 μsec, (2) interface resistance greater than 300Ω, and (3) 12 volt compliance limited to 1.3 mA. Electrical continuity was monitored every 30 seconds.

STATISTICAL ANALYSIS APPROACH

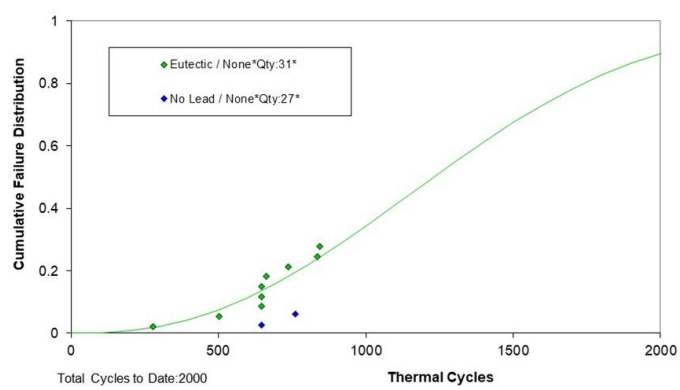
The solder joint thermal cycle integrity was statistically analyzed using regression analysis to determine the Weibull shape factor (β) and characteristic life (Θ) for the failure data. The Weibull function relates the cumulative failure distribution, F(n), to the number of thermal cycles at which a failure occurred, n, as defined in Equation 1.

$$F(n) = 1 - \exp\left(-\frac{n}{\theta}\right)^{\beta} \quad \text{\{Equation 1\}}$$

The characteristic life in a Weibull distribution, Θ, corresponds to the number of cycles at which 63.2% of the population is expected to have failed. This parameter is often referred to as "N63" and may be thought of as an indication of the approximate average life of the population. The shape factor (β) is often referred to as the Weibull slope and is a measure of how tightly grouped the failures are. A lower shape factor corresponds to a less uniform distribution of failure data across the population (i.e. a wider range of thermal cycles where failures are seen). A higher shape factor corresponds to a more uniform distribution of failure data with an upper limit of infinity if all samples fail at the same time. A shape factor of less than 1.0 is generally considered to be indicative of infant mortality or very early failure due to a manufacturing defect. Electronic components in thermal cycling that are undergoing "post infant mortality" failures have typically exhibited shape factors in the range of 4-8 depending on the particular component or connector style.

TEST RESULTS DISCUSSION

The test results for the LSHM connectors from 40 to 100 I/O and the LPAM/LPAF connectors from 40 to 80 I/O can be found in Table 2. All connectors tested were considered reliable with very few failures below 500 thermal cycles, which is considered a typical requirement for many military and avionics products. For the LSHM family of connectors, it was observed that the number of failures increased with increasing connector size and I/O count. There was also a cluster of failures between 500-1000 thermal cycles for one of the larger 100 I/O pairs of LSHM connectors as shown in Figure 7. Other than this cluster, the majority of connectors did not fail even when cycled to 2000 thermal cycles. The root cause of the cluster of failures between 500-1000 thermal cycles was not identified.



LSHM 100 I/O	# samples	# failed	% failed	1st fail	N63	slope	R^2	# in range
Eutectic	31	9	29.0%	277	1430	2.43	91%	1
No Lead	27	2	7.4%	645	n/a	n/a	n/a	0

Figure 7: LSHM-150-03.0-L-DV-A-S Mated to LSHM-150-01-L-DH-A-S Thermal Cycle Results

Table 2: LSHM and LPAF/LPAM Thermal Cycling Results

Vendor Part Number	Mate Vendor Part Number	Solder Process	#Failed/ #Samples	1st fail	N63	β
LSHM-120-01-L-DH-A-S	LSHM-120-06.0-L-DV-A-S	Tin-lead	0/32	n/a	n/a	n/a
		Lead-Free	2/18	500	n/a	n/a
LSHM-130-01-L-DH-A-S	LSHM-130-06.0-L-DV-A-S	Tin-lead	0/24	n/a	n/a	n/a
		Lead-Free	0/25	n/a	n/a	n/a
LSHM-140-01-L-DH-A-S	LSHM-140-06.0-L-DV-A-S	Tin-lead	2/31	729	n/a	n/a
		Lead-Free	0/19	n/a	n/a	n/a
LSHM-140-02.5-L-DV-A-S	LSHM-140-02.5-L-DV-A-S	Tin-lead	4/24	449	1808	2.33
		Lead-Free	0/22	n/a	n/a	n/a
LSHM-150-03.0-L-DV-A-S	LSHM-150-01-L-DH-A-S	Tin-lead	9/31	277	1430	2.43
		Lead-Free	2/27	645	n/a	n/a
LSHM-150-06.0-L-DV-A-S	LSHM-150-03.0-L-DV-A-S	Tin-lead	4/32	506	3995	1.87
		Lead-Free	3/26	54	n/a	.56
LPAF-10-03.5-S-04-2	LPAM-10-01.0-S-04-2	Lead-Free	1/24	500	n/a	n/a
LPAM-20-01.0-S-04-2	LPAF-20-03.5-S-04-2	Lead-Free	0/24	n/a	n/a	n/a

CROSS SECTIONAL ANALYSIS

After the completion of 2000 thermal cycles, cross sectional analysis was performed on a sampling of connectors in the test. Figures 8 and 9 show cross sectional photos of the smallest LSHM connectors tested (40 I/O). Figure 8 is the connector soldered with a tin-lead process and Figure 9 is the connector soldered with a lead-free process. All solder joints had good wetting angles and geometries. The tin-lead connectors passed 2000 thermal cycles without failure while the lead-free connectors had 2 failures around 500 thermal cycles.

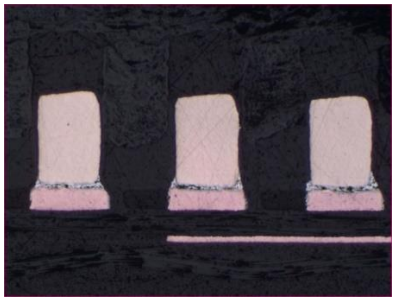


Figure 8: Tin-Lead, LSHM-120-06.0-L-DV-A-S

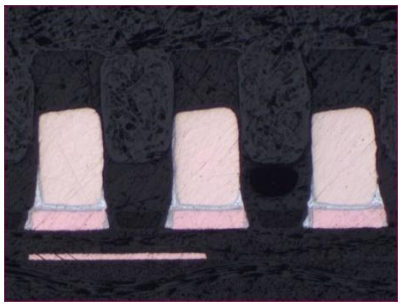


Figure 9: Lead-Free, LSHM-120-06.0-L-DV-A-S

Figures 10 and 11 are cross sectional photos of the largest LSHM connectors tested (100 I/O). Figure 10 is the connector soldered with a tin-lead process and Figure 11 is the connector soldered with a lead-free process. All solder joints had good wetting angles and geometries. Also both figures show solder joint fatigue and cracking, which occurred in the 500-1000 thermal cycle range.

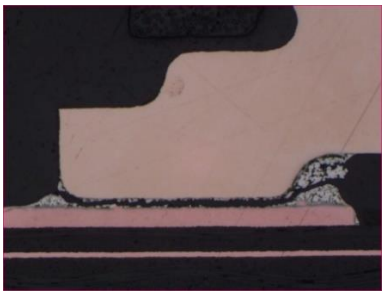


Figure 10: Tin-Lead, LSHM-150-03.0-L-DV-A-S

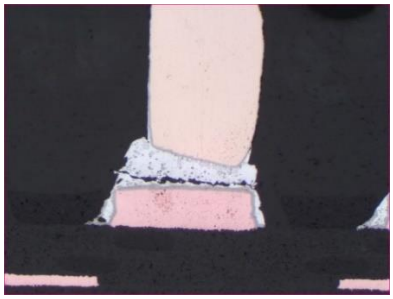


Figure 11: Lead-Free, LSHM-150-03.0-L-DV-A-S

The Samtec LPAM/LPAF connectors were tested as lead-free components in the lead-free soldering process. Figures 12 and 13 show typical solder joints after 2000 thermal cycles. All solder joints had good wetting angles and geometries. Of interest is that the solder volume used during the build was insufficient to completely fill the "eye of the needle" hole in the middle of the contact. Nevertheless, there were no failures in 2000 thermal cycles. It is important to note that this test addressed 40 and 80 I/O connector sizes. Sizes larger than this would need to be tested to verify solder joint reliability and may need additional solder to fill the "eye of the needle" hole.

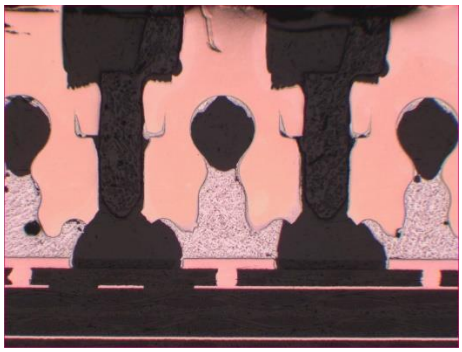


Figure 12: Lead-free, LPAM-20-01.0-S-04-2

Figure 13: Lead-free, LPAF-20-03.5-S-04-2

COMPARISON OF LSHM (FINE-PITCH LEADED CONNECTORS) AND SEAM/SEAF (AREA-ARRAY CONNECTORS)

Although not included in this test, the Samtec area-array connector family, SEAM/SEAF, has been thermal cycle tested between -55°C to +125°C and the results were published in a previous paper [1]. Figure 14 shows the SEAM/SEAF connectors, which are 30 positions long by 8 rows wide (240 I/O), that were included in the previous test. These connectors were assembled with tin-lead and lead-free soldering processes. Two stencil thicknesses were used: 4 mil and 6 mil thick. Figure 15 shows the cumulative failure results for thermal cycle testing.

The SAMTEC SEAM/SEAF connectors exhibited excellent tin-lead and lead-free thermal cycle performance with no failures occurring before 1500 thermal cycles.

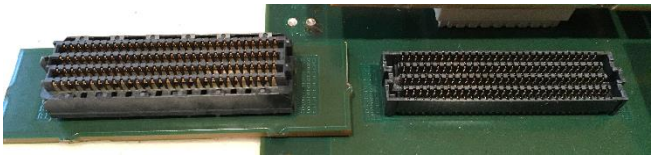
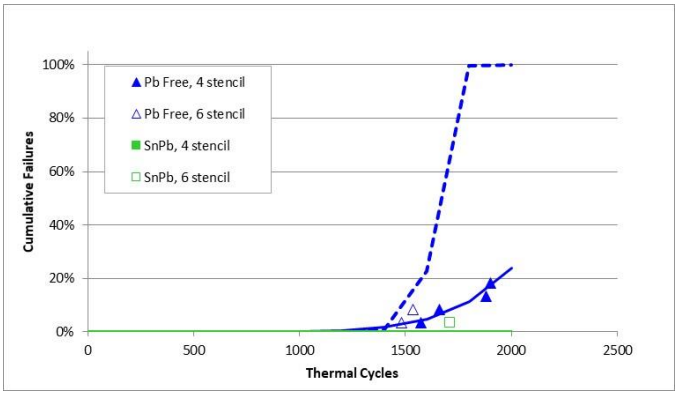


Figure 14: SEAM/SEAF Connectors Previously Tested



	#samples	# failed	% fails	first fail	N63	beta
Pb Free, 4 stencil	20	4	20%	1573	2368	7.71
Pb Free, 6 stencil	20	2	10%	1482	1686	25.99
SnPb, 4 stencil	20	0	0%	0	n/a	n/a
SnPb, 6 stencil	20	1	5%	1708	n/a	n/a

Figure 15: SEAM/SEAF 240 I/O Thermal Cycle Test Results

TRADEOFFS BETWEEN FINE-PITCH LEADED AND AREA-ARRAY TYPE CONNECTORS

Through the testing performed on the LSHM fine-pitch leaded connectors and SEAM/SEAF area-array connectors, several tradeoffs were identified that must be considered when analyzing the best fit for a given product application. There tradeoffs include maximum I/O count available, ease of assembly, defect identification, rework, solder joint reliability, and PCB footprint. One major difference between the SEAM/SEAF and LSHM connector series is the available maximum I/O count. The LSHM is available with up to 100 I/O while the SEAM/SEAF has been tested and qualified up to 300 I/O and available in up to 500 I/O. However, the connectors become more difficult to process as the length increases beyond 30 positions or 1.7 inches long. Table 3 summarizes the tradeoffs between the LSHM fine-pitch leaded connectors and the SEAM/SEAF area-array connectors.

Table 3: Tradeoffs between Fine-Pitch Leaded LSHM and Area-Array SEAM/SEAF

Connector Type	I/O Count	Ease of Assembly-Potential Issues	Defect Identification	Rework	Solder Joint Reliability	PCB Footprint Area in^2
Hockey Stick Leaded Connector **Samtec LSHM**	10-100	Good- Defects can occur with .5 mm pitch leads such as opens and shorts 5 mil stencil is optimal	Excellent with X-Ray Shorts and opens are easily identifiable with visual and x-ray inspection	Hand Rework And Hot Air Reflow Rework Station Sometimes it is possible to add solder by hand	Good Less consistent than SEAM/SEAF For 100 I/O: Meets 500 thermal cycles - 55°C to 125°C	.234 at 100 I/O
Area Array Connector **Samtec SEAM/SEAF**	40-*300	Good- Can become difficult to process over 30 positions long or 1.7 inches Host board warpage can effect yield- because of this a 6 mil stencil is optimal	Excellent with X-Ray Shorts and opens are easily identifiable with x-ray inspection	Hot Air Reflow Rework Station or Oven Required	Excellent For 240 I/O: Meets 1500 thermal cycles - 55°C to 125°C	.452 at 100 I/O .980 at 300 I/O

*Higher I/O accounts are available but not qualified

CONCLUSIONS

Below are the significant conclusions from this test:

- The vertical and horizontal LSHM connectors, with up to 100 I/O, have good solder joint thermal cycle reliability, with failures occurring after 500 thermal cycles.
- The vertical LPAM/LPAF connectors, with up to 80 I/O, have excellent solder joint thermal cycle reliability, with no failures occurring in 2000 thermal cycles.
- As shown in a previous test, the vertical SEAM/SEAF connectors, with up to 240 I/O, have excellent solder joint thermal cycle reliability, with failures occurring after 1500 thermal cycles.
- The choice of solder alloy (tin-lead and lead-free) was not a significant factor in influencing reliability.

The following tradeoffs should be considered when choosing between the fine-pitch high density LSHM connectors in this test and the area-array SEAM/SEAF connectors from a previous test:

- Higher I/O counts are available for the SEAM/SEAF connectors when compared to the LSHM connectors. The LSHM connectors are available up to 100 I/O while SEAM/SEAF connectors have been qualified up to 300 I/O. It is important to note that this test included vertical and horizontal LSHM connectors while the previous SEAM/SEAF test here only included vertical connectors.
- A 5 mil stencil is optimal for the LSHM connectors while a 6 mil stencil is optimal for the SEAM/SEAF connectors
- The solder joint reliability of the vertical SEAM/SEAF is excellent, with failures occurring after 1500 thermal cycles. The solder joint reliability of the LSHM is good with failures occurring after 500 thermal cycles.
- At 100 I/O, the LSHM footprint is roughly half that of the SEAM/SEAF footprint.

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