Pb-free v/s Tin-Lead Reliability Comparison for Telecom/High Reliability Applications

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Abstract

With the European Union's (EU's) RoHS directives coming into force in July 2006 for consumer electronics products, the transition to lead-free (Pb-free) solder has occurred at a rapid pace. This push has driven many OEM suppliers/manufacturers to adopt Pb-free solder and End of Life many of their conventional Tin-Lead (Sn-Pb) components. This has forced telecom or high reliability applications to adopt Pb-free solder compositions with many reliability anomalies unanswered. While there have been many studies published on long term reliability of Pb-free solder joints at the component level, there have been few studies focused on the time zero reliability of the joints at the printed circuit board assembly (PCBA) level. The goal of this study is to help the OEM suppliers and their customers (like service providers) to come up with a common PCBA test methodology that will help identify and weed out early, marginal manufacturing and design defects that would crop up due to transition to the Pb-free solder. A normalized reliability data comparison and impact of the test on Pb-free and Tin-Lead solder alloys using test vehicles is presented in this study. The sequential PCBA level evaluation methodology involves a series of tests that include Thermal Aging, Mechanical Shock, Vibration, Functional test over elevated temperature and Destructive Analysis (Dye & Pry and Cross-sectional analysis) . The solder joint reliability comparisons for different components are presented against this methodology using different PCBA constructions (test vehicles).

Keywords: pb-free, tin-lead, time-zero reliability testing, telecom, high reliability applications

1. Introduction

For more than a decade, lead (Pb) has proven to cause many health issues [1]. Electronic waste land fill (containing Pb) from consumer application has proved to cause serious health hazards. Issues were observed when these landfills started contaminating the local water sites [2,3]. Thus, a new regulatory reform was passed by the European Parliament and the Council of the European Union (EU) called ''Restriction of the Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment,'' Directive 2002/05/EC effective July 1, 2006. RoHS defined the minimum percentage of lead (0.1 wt%), mercury, cadmium and hexavalent chromium in any electronic products shipped to Europe. The conversion to Pb-free technology has raised quality and reliability concerns within sectors of the industry that deal with mission critical, high reliability and extended field life applications [4]. Due to these concerns, medical devices, servers, storage, network infrastructure / telecommunication systems, military products and monitoring devices were exempted from this regulation. With many OEM suppliers/manufacturers adopting Pb-free components, the hi-reliability industries like telecom are forced to accept Pb-free substitutes without many reliability concerns being systematically and rigorously addressed [5]. Many of the telecom customers like service providers are looking for a common methodology that can be implemented across their supply-base to set confidence in terms of quality and reliability at PCBA level with respect to Pb-free process. This paper is an effort to present a series of tests (common test methodology) that addresses the quality of the Pb-free products and generate a baseline, so that all high reliability/ telecom product manufacturers can establish a level of confidence in their Pb-free implementation strategy. This is done by following a common test protocol to weed out any time-zero reliability of these solder-joints at PCBA level and by comparing it against Sn/Pb solder joints of the same PCBA.

2. Test Mechanism and its Effects

Below are the tests in the order of sequence in which it was incorporated and the reasons for inclusion of these tests to weed out time-zero manufacturing defects.

i. ICT Testing: In-Circuit-Tests results in mechanical stress and flexing of the circuit boards while testing simple circuits on the PCBA. This additional stress testing in the back-end PCBA process can result in solder joint failure, especially precipitating failures due to poor joint quality during manufacturing process. ICT testing was repeated 5 times to encompass the worst end-use condition.

ii. Thermal Aging: This testing step is to grow intermetallic in the solder joints that will be comparable to growth of intermetallics compound (IMC's) with the product installed in the field. Increased growth of IMC's will make the solder joint inherently more brittle [6,7,8]. For poor quality joints, this could be a step that will enable to precipitate failures in the subsequent testing steps. A condition of aging at 125 C for 240 hours was used for this study.

iii. Mechanical Shock: This step is meant to weed out failures in interconnects that have high inertia (mass) components Ball grid array (BGA) components and would point to design weakness or manufacturing process issues [9]. Choosing the correct level of testing is critical to cause the required failure mode. The IEC 60068-2-27 with 30 G's 10 ms shock pulse was used in this study [10]. To remove the first order effect of product designs, both the Sn/Pb and Pb-free were tested under the same level.

iv. Vibration: This testing was incorporated to accelerate any cracks that are created in the manufacturing process and to highlight out weakness caused by the aging and micro cracks created by the shock testing. The choice of an appropriate vibration level, the clamping of the boards, the amplifications and the final vibration levels that the components are subjected to become critical as is shown in this study. This study was conducted using the NAVMAT 9692 6 G RMS for 30 minutes as the testing specification [11].

v. Functional testing over elevated temperature: Testing at elevated temperatures was incorporated to catch any marginal failures that are caused due to the prior tests but do not result in electrical failures at room temperature, such as hairline inter-metallic cracks that are closely coupled together. At the elevated temperatures, the cracks open up and would cause an evident electrical failure.

There are still significant unknowns relative to Pb-free solder joint reliability. The above sequence of tests is proposed method of gauging the performance of Pb-free joints with a combination of tests to weed out quality defects that can be present in a manufacturing process.

2. Test Methodology

The intention of the testing mentioned in this section was to expose problems related to Pb-free solder joints and material weaknesses associated with the higher temperatures of Pb-free solder processes at a circuit pack or PCBA level before being shipped to the end customer. Also, the intent of this methodology is to evaluate whether the Pb-free products are equal to or better than their Sn-Pb (Tin-Lead) versions. Functional testing at room temperature was added to the sequential testing as shown in figure 1 to catch any failures between the tests and help narrow down the reason of failure.

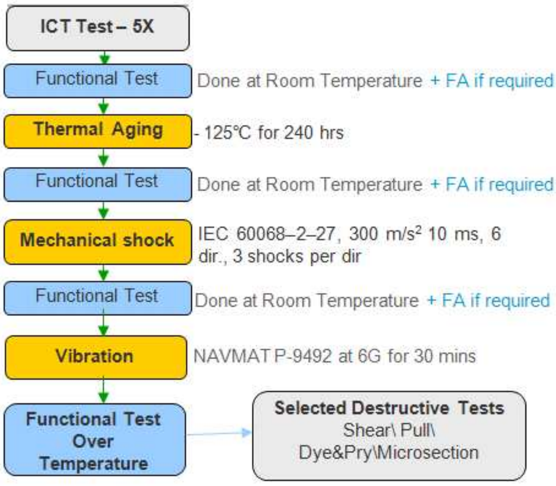


Figure 1: Proposed sequential testing.

The sequential testing was conducted on both Pb-free and its counter-mate Sn-Pb test vehicles. At the end of the test all the test vehicles (Pb-free and Sn-Pb) went through cross-sectional and dye and pry analysis to check for any anomalies or issues.

4. Test vehicle specification

Five different test vehicles (each for Sn-Pb and Pb-free) were used for the testing. Each test vehicle had varied components- (ball grid array-BGA, thin small outline package-TSOP, resistor, capacitors, inductors and connectors) that helped us analyze, understand and compare the impact of the test methodology on these components – Sn-Pb and Pb-free. Details of the test vehicle and components per board used are as shown in Figure 2, 3 and 4.

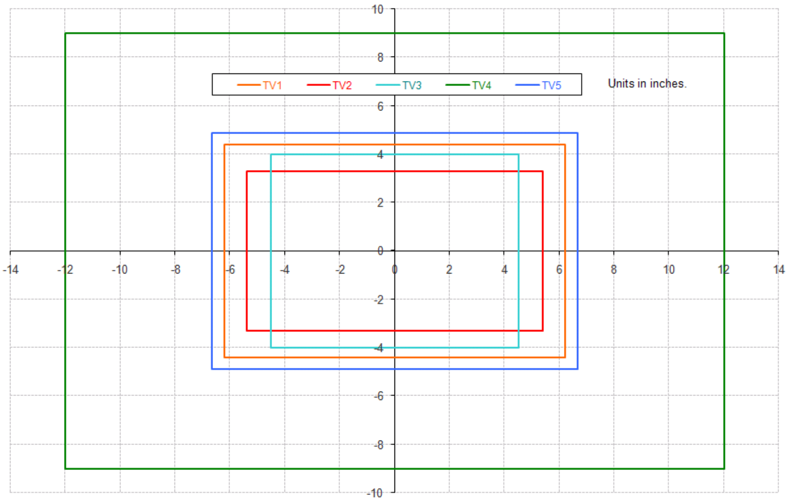


Figure 2: Comparative dimensions- (Length x Height) of 5 Test Vehicles

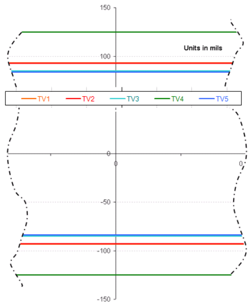


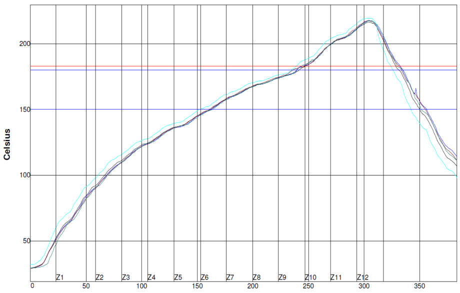
Figure 3: Comparative dimensions- (Thickness) of 5 Test Vehicles

	TV1	**TV2**	**TV3**	**TV4**	**TV5**
BGA	(1) BGA256, 17x17 mm, 1 mm (2) FBGA256,17x17 mm, 1mm. (3) FBGA456,23x23 mm, 1 mm (4) PBGA516,27x27 mm, 1mm (5) FPGA363,23x23 mm, 0.8 mm (6) BGA63,11x12 mm, 0.8mm.	(1) TBGA672,35x35(mm), 1mm	(1) PBGA783, 29x29 mm, 1mm (2) FGBA900, 29x29 mm, 1mm (3) PBGA701, 37.5x37.5 mm, 1mm (4) BGA324, 19x19 mm, 1mm (5) TBGA-672, 35x35, 1mm	(1) EBGA480, 23x23 mm, 1mm, (2) BGA320, 27x27 mm, 1.27mm, (3) FBGA456, 23x23 mm, 1mm, (4) TBGA600, 40x40 mm, 1mm, (5) FBGA117, 12x12 mm, 1mm, (6) FBGA256, 17x17 mm, 1mm	(1) PBGA844, 35x35mm, 1mm (2) CBGA360, 25x25mm, 1.27mm (3) TBGA364, 21x21mm, 1mm (4) HSLBGA364, 21x21mm, 1mm (5) 15-9921-02-R- Microprocessor, 27x27 mm, 1.27mm
Resistors + caps + inductors	(1) 1206 + same for caps (2) 0805 + same for caps (3) 0603 + same for caps (4) 0402 + same for caps (5) 2010 (6) 2512 + same for caps (7) 2816 for caps (8) 1812 for caps (9) 2412 for caps (10) 1210 for caps (11) 3914, aluminium cap	(1) 0402, (2) 0603, (3) 0805, (4) 1812 for caps, (5) 2816 for caps, (6) 1206 for caps, (7) 2412 for caps, (8) 1813 for inductor, (9) 4949 for inductor	(1) 402, (2) 805, (3) 603, (4) 1206, (5) 1210	(1) 0402, (2) 0603 , (3) 0805, (4) 1206 , (5) 2220	(1) 0402, (2) 0603, (3) 0805, (4) 2010, (5) 2512
TSOP	(1) SO16, 4.4x5.0 mm, 0.65 mm (2) TSSOP14,4.4x5.0 mm, 0.65 mm (3) SO8,3.0x3.0 mm, 0.65 mm (4) SSOP28, 5.3x10.20 mm, 0.65 mm (5) TSOP66, 10.16x22.22 mm, 0.65 mm (6) SO8,4.0x5.0 mm, 1.27 mm (7) SOT23, 5 lead , 1.75x3.0 mm, 0.95 mm, 1.95 mm (8) SSOP20, 7.2x5.3 mm, 0.65 mm (9) QSOP16, 4.0x5.0 mm, 0.65 mm (10) TSSOP48, 8.0x12.5 mm, 0.5 mm (11) TSSOP20,7.4x13.0 mm, 1.27 mm (12) PSOP5, 2.0x2.0mm, 0.65 mm (13) MSOP10, 3.0x3.0 mm,0.5 mm	(1) TSSOP-8 (2) TSSOP-20, 7.5x6.1(mm), 0.65mm (3) TSSOP-48, 12.5x6.1, 0.5mm (4) SSOP-5 (5) SSOP-16 (6) PSOP-5 (7) TSOP66, 22.22x10.16(mm), 0.65mm	(1) TSOP66, 4x16mm, (2) TSOP6, 3 x 2.85 mm (3) TQFP100, 20 x 14mm, 1mm (4) TQFP80, 16 x 14mm, 0.65mm	(1) SO8 (3x3)mm, .65mm, (2) SO14 (8.75x4)mm, 1.27mm, (3) TSSOP14 (4.5x5.1)mm, .65mm, (4) QSOP16 (3.99x5)mm, .635mm, (5) TSSOP20 (13x7.4)mm, 1.27mm, (6) SSOP24 (15.2x7.4)mm, 1.27mm, (7) SSOP30 (6.2x11.8)mm, .65mm, (8) LQFP32 (7x7)mm, .8mm, (9) TQFP32 (7x7)mm, .8mm, (10) TSOP54 (22.22x10.16)mm, .8mm, (11) TQFP64 (11.8x11.8)mm, .5mm, (12) LQFP208 N/A	(1) QSOP-20, 150mil wide plastic (2) TSSOP-20, 173 mil Wide plastic (3) TSSOP-14, Body width 4.4mm ,1.27mm (4) SSOP-20, Body width 4.4mm, (5) QSOP-16, 150mil wide plastic (6) TSSOP-48, 346x346mm (7) TSSOP-24 (8) SSOP-14, Body width 5.3mm (9) TSSOP-16, Body width 4.4mm (10) TSSOP-56, 346x346mm (11) TSOP-56, 346x346mm (12) QSOP-20
Dimension of the PCBA	**(12.4 x 8.78)" x 0.0932" [Overall thickness]**	**(10.76 x 6.56)" x 0.093" [Overall thickness]**	**(9 x 8)" x 0.085" [Overall thickness]**	**(24 x 18)"x 0.125 " [Overall thickness]**	**(13.3 x 9.74)" {With handling edge (13.3 x 10.37)"} x .084" [Overall Thickness]**

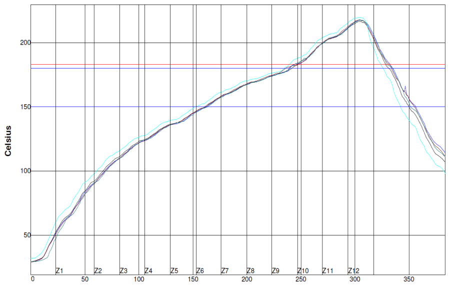
Figure 4: Comparison table for the components per Test Vehicle

5. Reflow Profile

The reflow profiles were optimized to meet component vendor requirements for both Sn-Pb and Pb-free while attaching to its respective test vehicles. The Sn-Pb test vehicles had an average preheat ramp-rate of about 1 oC/sec with 77 seconds above the reflow temperature and an average cooling rate of 1.25 ^{o}C/sec. The Pb-free test vehicles had an average preheat ramp-rate of 1.25 ^{o}C/sec with 60 seconds above the reflow temperature and average cooling rate of 1.6 oC/sec. Figure 5 below shows sample reflow profile for TV 3.



TV3: Sn-Pb



TV3: Pb-free

Figure 5: Sample reflow profile of TV3.

6. Test Results

All the Sn-Pb and Pb-free test vehicles were electrically functional at the end of the sequential testing. Destructional analysis was performed to analyze and compare the impact of testing on solder joint for all the test vehicles (Pb-free and Sn-Pb). figure 6 shows the average comparison of all the components per Test vehicle per solder alloy in terms of average crack propagation seen from dye and pry and cross-sectional analysis

All of the test vehicles with the exception of TV5 had some cracks that were observed through physical destructive analysis-(dye & pry and cross-section analysis). BGA's were seen to have maximum impact as compared to the rest of the components (for most of the Pb-free and Sn-Pb test vehicles). Most of the mechanical cracks were noticed at the corner solder joint indicating excessive stresses due to the testing being the initiator. Cracks were present on BGA's on both the package and PCBA side. In certain instances of cross sectioning BGA, pad cratering was observed. No mechanical anomalies or cracks were observed for resistors, capacitors, inductors, TSOP's and connectors on any of the test vehicles (Pb-free or Sn-Pb test vehicles). It might be reasoned that these components due to their low stiffness and robust interconnects are able to withstand the sequence of test conditions better than BGA's

It can be inferred that mechanical cracks can be prevalent while still not resulting in imminent electrical failure of the product. It was concluded based on the nature of the cracks that the cracks were not generated during the manufacturing process but were likely initiated during the testing sequence. Vibration testing was assessed as the most stringent and was suspected as one of the prime reasons for inducing defects. This was later validated by coupon testing as mentioned in Section 8 of this paper.

Figure 7 to Figure 10, summarizes the dye and pry and cross section analysis from component perspective per test vehicle.

(51-100%)	Severe cracks or Dye penetration observed
(26-50%)	Cracks or Dye penetration observed.
(1-25%)	Minor cracks or Dye penetration observed.
.(0%).	No cracks or Dye penetration observed.
PC	Pad cratering observed.

	TV1				TV2			
	Dye and Pry Observation		Cross-section Observation		Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Resistors + caps + inductors	No	No	No	No	No	No	No	No
TSOP	No	No	No	No	No	No	No	No
Connectors	N/A	N/A	No	No	N/A	N/A	.---.	.---.
Dimension of the PCBA	(12.4 x 8.78)" x 0.0932" [Overall thickness]				(10.76 x 6.56)" x 0.093" [Overall thickness]			

	TV3				TV4				TV5			
	Dye and Pry Observation		Cross-section Observation		Dye and Pry Observation		Cross-section Observation		Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	No	Yes	Yes	Yes(PC)	No	No	No	Yes	No	No	No	No
Resistors + cap inductors	No	No	No	No	No	No	No	No	No	No	No	No
TSOP	No	No	No	No	No	No	No	No	No	No	No	No
Connectors	N/A	N/A	No	No	N/A	N/A	No	Minor Delam	N/A	N/A	No	No
Dimension of t PCBA	(9 x 8)" x 0.085" [Overall thickness]				(24 x 18)"x 0.125 " [Overall thickness]				(13.3 x 9.74)" {With handling edge (13.3 x 10.37)"} x .084" [Overall Thickness]			

Figure 6– Summary of destruction analysis for Components per Test vehicle

	TV1			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	(1) FBGA256, 17x17, 1mm (51-100% cracks) (2) FBGA456, 23x23,1mm (26-50% cracks) (3) BGA256,17x17, 1mm (1-25% cracks) (4) BGA63, 11x12, 0.8mm (1-25% cracks) (5) PBGA516,27x27 mm, 1mm (No cracks) (6) FPGA363,23x23 mm, 0.8 mm (No cracks)	(1) FBGA256, 17x17, 1mm (51-100% crack) (2) FBGA456,23x23,1mm (1-25% crack) (3) BGA63,11x12, 0.8mm (1-25%crack) (4) BGA256,17x17, 1mm (No cracks) (5) PBGA516,27x27 mm, 1mm (No cracks) (6) FPGA363,23x23 mm, 0.8 mm (No cracks)	(1) FBGA256, 17x17, 1mm (1-25% cracks) (2) FBGA456, 23x23,1mm (51-100% cracks) (3) BGA256,17x17, 1mm (No cracks) (4) BGA63, 11x12, 0.8mm (No cracks) (5) PBGA516,27x27 mm, 1mm (No cracks) (6) FPGA363,23x23 mm, 0.8 mm (1-25% cracks)	(1) FBGA256, 17x17, 1mm (No cracks) (2) FBGA456, 23x23,1mm (51-100% cracks) (3) BGA256,17x17, 1mm (No cracks) (4) BGA63, 11x12, 0.8mm (No cracks) (5) PBGA516,27x27 mm, 1mm (No cracks) (6) FPGA363,23x23 mm, 0.8 mm (No cracks)
Resistors + caps + inductors	No cracks	No cracks	No cracks	No cracks
TSOP	No cracks	No cracks	No cracks	No cracks
Connectors	N/A	N/A	No cracks	No cracks
Dimension of the PCBA	(12.4 x 8.78)" x 0.0932" [Overall thickness]			

(51-100%)	Severe cracks or Dye penetration observed
(26-50%)	Cracks or Dye penetration observed.
(1-25%)	Minor cracks or Dye penetration observed.
.(0%).	No cracks or Dye penetration observed.
PC	Pad cratering observed.

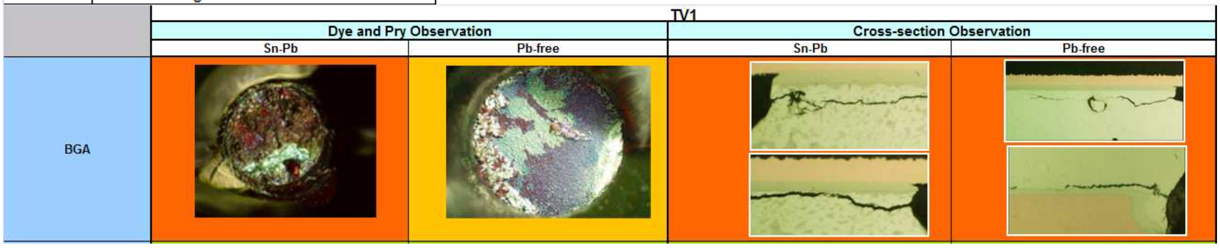


Figure 7: TV1-Summary of components after the testing

	TV2			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	(1) TBGA672,35x35, 1mm (25-50% cracks)	(1) TBGA672,35x35, 1mm (51-100% cracks)	(1) TBGA672,35x35, 1mm (No cracks)	(1) TBGA672,35x35, 1mm (51-100% cracks)
Resistors + caps + inductors	No	No	No	No
TSOP	No	No	No	No
Connectors	N/A	N/A	.---.	.---.
Dimension of the PCBA	(10.76 x 6.56)" x 0.093" [Overall thickness]			

(51-100%)	Severe cracks or Dye penetration observed
(26-50%)	Cracks or Dye penetration observed.
(1-25%)	Minor cracks or Dye penetration observed.
.(0%).	No cracks or Dye penetration observed.
PC	Pad cratering observed.

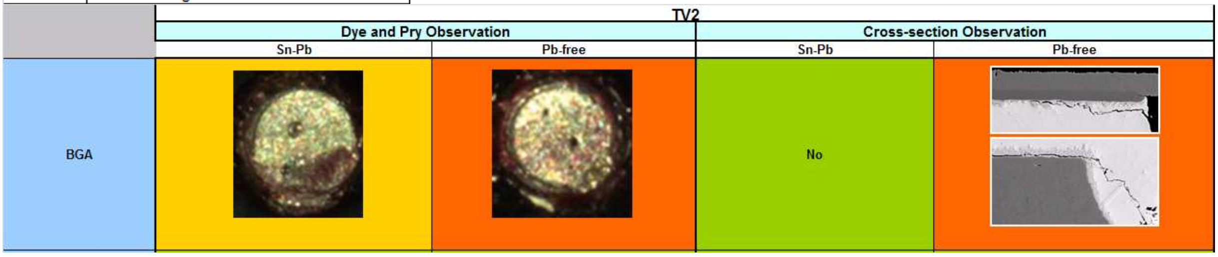


Figure 8: TV2-Summary of components after the testing

	TV3			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	No	(1) PBGA783, 29x29 mm, 1mm (2) FGBA900, 29x29 mm, 1mm (3) PBGA701, 37.5x37.5 mm, 1mm (4) BGA324, 19x19 mm, 1mm (5) TBGA-672, 35x35, 1mm (26-50% crack)	(1) PBGA783, 29x29 mm, 1mm (2) FGBA900, 29x29 mm, 1mm (3) PBGA701, 37.5x37.5 mm, 1mm (4) BGA324, 19x19 mm, 1mm (1-25% crack) (5) TBGA-672, 35x35, 1mm	(1) PBGA783, 29x29 mm, 1mm (Pad cratering, No cracks) (2) FGBA900, 29x29 mm, 1mm (1-25% crack) (3) PBGA701, 37.5x37.5 mm, 1mm (pad cratering, 51-100% crack) (4) BGA324, 19x19 mm, 1mm (1-25% crack) (5) TBGA-672, 35x35, 1mm
Resistors + caps + inductors	No	No	No	No
TSOP	No	No	No	No
Connectors	N/A	N/A	No	No

(51-100%)	Severe cracks or Dye penetration observed
(26-50%)	Cracks or Dye penetration observed.
(1-25%)	Minor cracks or Dye penetration observed.
.(0%).	No cracks or Dye penetration observed.
PC	Pad cratering observed.

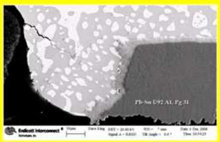
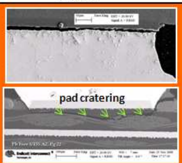
	TV3			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	No			 PC

Figure 9: TV3-Summary of components after the testing

	TV4			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	No	No	No	(1) EBGA480, 23x23 mm, 1mm, (1-25% crack) (2) BGA320, 27x27 mm, 1.27mm (No crack) (3) FBGA456, 23x23 mm, 1mm (No crack) (4) TBGA600, 40x40 mm, 1mm (No crack) (5) FBGA117, 12x12 mm, 1mm (No crack) (6) FBGA256, 17x17 mm, 1mm (No crack)
Resistors + caps + inductors	No	No	No	No
TSOP	No	No	No	No
Connectors	N/A	N/A	No	Minor Delamination

(51-100%)	Severe cracks or Dye penetration observed
(26-50%)	Cracks or Dye penetration observed.
(1-25%)	Minor cracks or Dye penetration observed.
.(0%).	No cracks or Dye penetration observed.
PC	Pad cratering observed.

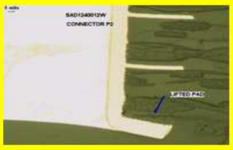
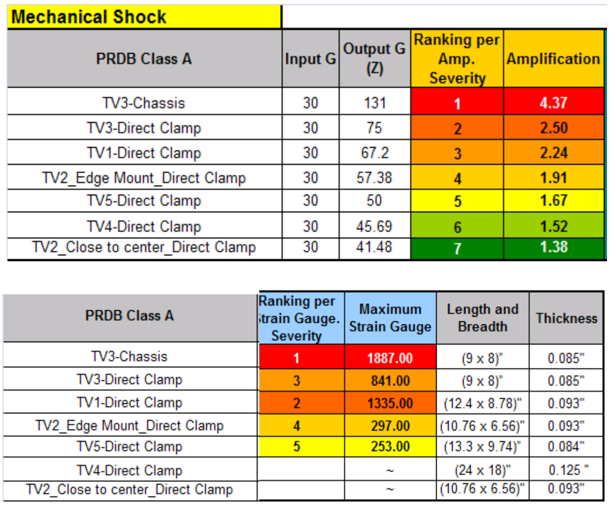
	TV4			
	Dye and Pry Observation		Cross-section Observation	
	Sn-Pb	Pb-free	Sn-Pb	Pb-free
BGA	No	No	No	
Connectors	N/A	N/A	No	

Figure 10: TV 4-Summary of components after the testing

7. Test Challenges

The sequential testing had some unique challenges, especially during mechanical shock and vibration. Challenges were in the form of fixturing, mechanical standoff design and location of fixturing for different test vehicles. It was seen that for a known input, depending on how the test vehicles were mounted or fixtured to the testing equipment, the amplifications differed greatly. All the solder joints experienced varying levels of vibrations across different test vehicles/PCBA. Strain gauges and accelerometers were added to the components close to the solder joints to measure the impact of the amplification. Examples of sequential testing challenges are as below:

i. Fixturing- For the same mechanical shock input it was seen that TV3 in a chassis had 1.74 time greater amplification than TV3 directly mounted to the testing equipment. Also TV3 mounted in a chassis produced the maximum amplification (4.37 times) as compared to other test vehicles. Incidentally the TV3 resulted in the maximum strain measurement near the component corner during shock testing. Figure 11 summarizes amplification and strain gauge measurements per test vehicle.



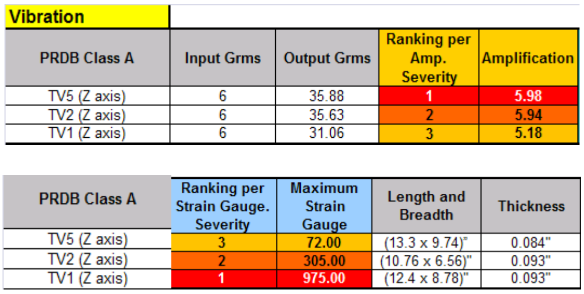
Mechanical Shock

PRDB Class A	Input G	Output G (Z)	Ranking per Amp. Severity	Amplification
TV3-Chassis	30	131	1	4.37
TV3-Direct Clamp	30	75	2	2.50
TV1-Direct Clamp	30	67.2	3	2.24
TV2_Edge Mount_Direct Clamp	30	57.38	4	1.91
TV5-Direct Clamp	30	50	5	1.67
TV4-Direct Clamp	30	45.69	6	1.52
TV2_Close to center_Direct Clamp	30	41.48	7	1.38

PRDB Class A	Ranking per train Gauge. Severity	Maximum Strain Gauge	Length and Breadth	Thickness
TV3-Chassis	1	1887.00	(9 x 8)"	0.085"
TV3-Direct Clamp	3	841.00	(9 x 8)"	0.085"
TV1-Direct Clamp	2	1335.00	(12.4 x 8.78)"	0.093"
TV2_Edge Mount_Direct Clamp	4	297.00	(10.76 x 6.56)"	0.093"
TV5-Direct Clamp	5	253.00	(13.3 x 9.74)"	0.084"
TV4-Direct Clamp		~	(24 x 18)"	0.125 "
TV2_Close to center_Direct Clamp		~	(10.76 x 6.56)"	0.093"

Figurer 11: Comparison table of amplification & strain gauge measurement per test vehicle

For the same input vibration applied, TV5-Z axis mounted directly to the testing equipment produced the maximum amplification (5.98 times). However the value was close to the rest of the test vehicles (TV2-Z axis with 5.94 times and TV1-Z axis with 5.18 times amplification). In this instance maximum strain measurement did not correspond to maximum amplification. TV1-Z axis direct-mount produced the maximum strain gauge measurement. TV5-Z axis produced the minimum strain measurement as expected given that TV5 was bigger and bulkier than rest of the test vehicles. Figure 12 summarizes the amplification and strain gauge measurements per test vehicle



Vibration

PRDB Class A	Input Grms	Output Grms	Ranking per Amp. Severity	Amplification
TV5 (Z axis)	6	35.88	1	5.98
TV2 (Z axis)	6	35.63	2	5.94
TV1 (Z axis)	6	31.06	3	5.18

PRDB Class A	Ranking per Strain Gauge. Severity	Maximum Strain Gauge	Length and Breadth	Thickness
TV5 (Z axis)	3	72.00	(13.3 x 9.74)"	0.084"
TV2 (Z axis)	2	305.00	(10.76 x 6.56)"	0.093"
TV1 (Z axis)	1	975.00	(12.4 x 8.78)"	0.093"

Figurer 12: Comparison table of amplification & strain gauge measurement per test vehicle

For the same input vibration applied, TV5-Z axis mounted directly to the testing equipment produced the maximum amplification (5.98 times). However the value was close to the rest of the test vehicles (TV2-Z axis with 5.94 times and TV1-Z axis with 5.18 times amplification). In this instance maximum strain measurement did not correspond to maximum amplification. TV1-Z axis direct-mount produced the maximum strain gauge measurement. TV5-Z axis produced the minimum strain measurement as expected given that TV5 was bigger and bulkier than rest of the test vehicles. Figure 12 summarizes the amplification and strain gauge measurements per test vehicle

ii. Mechanical standoff design- For mechanical shock it was seen that TV4 and TV5 with a better and distributed standoff design helped in minimizing amplification and strain gauge measurements.

iii. Location of fixturing- For mechanical shock it was seen that clamping the boards close to the center than the edge helped reduce amplification. For example TV2 showed 1.38 times lower amplification by clamping it to its center than its edges.

Summary of testing observation and recommendations:

1. There were certain techniques that were inferred through significant iterations before getting to the final test condition to ensure minimal variations between the test vehicles. They were:
    - Direct mounting of the test vehicle induced less amplification to the board as compared to mounting it on a chassis.
    - Mounting closer to the center of the board helped in reducing the amplification of the board.

- Better mechanical stand-off designs (distributed evenly between the edge and center of the board) helped reduce the amplifications
- For areas in the test vehicle that have cut-outs, additional stiffness needs to be provided to keep amplification and strains within reasonable levels

2. Irrespective of direct mounting of the boards, vibration testing had almost the same amplification.
3. Due to the high G RMS (stringent requirements) controlling the amplification during vibration testing had greater challenges and required damping techniques to keep the output G RMS close to input.
4. The stringent vibration testing not only created consistency issues (input to output G RMS), but also induced unintended or false solder joint failures. This defeated the purpose of having a test methodology to capture defective solder joint defects due to assembly process.

8. Validating Test Methodology: Vibration Testing

While there were no electrical failures, it was apparent that the test conditions were inducing failures mechanisms in test vehicles, both Sn-Pb and Pb-free. Based on a review of industry literature, historic product mechanical test data and observations from test vehicle testing (section 7) it was hypothesized that the vibration testing could be inducing these cracks. In order to validate this hypothesis an unbiased evaluation using coupon level testing (Sn-Pb coupons) were performed. Sn-Pb coupons selected were good representative manufacturing defect-free samples. This was validated through mechanical shock testing of the coupons from the same manufacturing lot. Coupon testing details are as shown below:

- Dimension of the Printed Circuit Board (PCB): [9 x 9] inch, 93 mil. thickness.
- Daisy chain package: [45 x 45] mm High CTE substrate, 1mm pitch. (No Silicon or Lid)
- Sample size- 2.
- Resistance was monitored insitu during the vibration testing with the help of a daisy chain package with the setup as shown in figure 13.

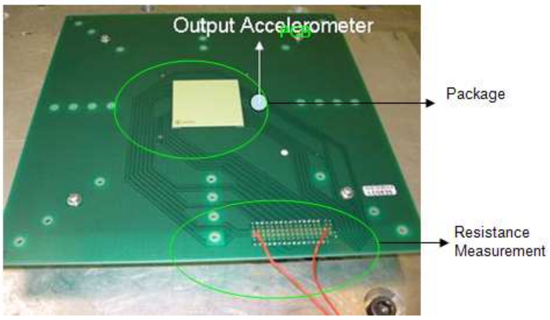


Figure 13: Tin-Lead test coupon

- Test Setup: The stand-off locations were at 6 inches distance apart with the package mounted in the center to generate the fundamental resonant frequency at 200Hz to simulate a typical product as shown in figure 14.

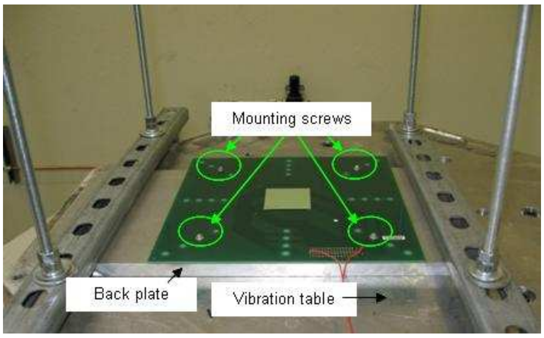


Figure 14: Test setup

- Test specification: 6 G RMS, random Vibration profile for a frequency of 20 to 2000 Hz as per specification [5].
- Test Results:-
  - Both the test coupons failed (electrically and also mechanically) in 3 minutes for this mounting configuration.
  - With an input of 6 G RMS, a properly mounted PCBA experienced an output acceleration of approximately 22 G RMS The output profile is also shown in figure 15.
  - The failure was seen mainly through the bulk solder. Pad catering was also observed in the cross-sectional analysis as shown in Figure 16. Figure 17 shows the resistance measurement.
- Thus Sn-Pb coupons helped validate the hypothesis that the vibration test was inducing mechanical cracks or defects in good solder joints.

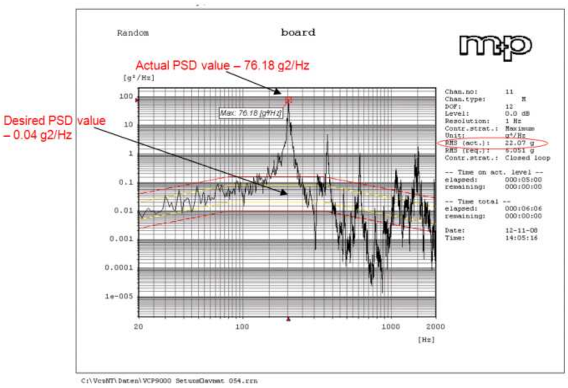


Figure 15: Vibration profile.

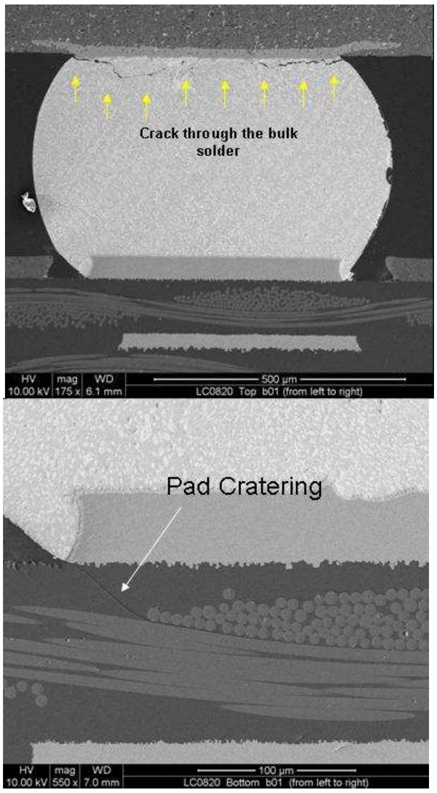


Figure 16: Failure in Sn-Pb coupons

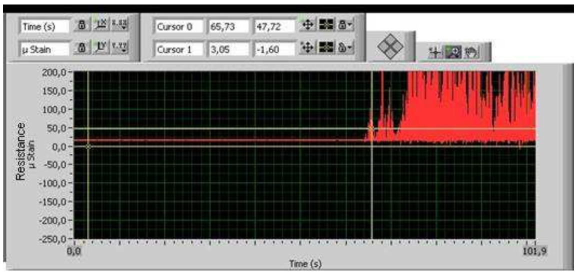


Figure 17: In-situ resistance measurement during vibration testing

9. Conclusion

- At the end of sequential testing all the test vehicles (Sn-Pb and Pb-free) were electrically functional but had mechanical cracks or anomalies, especially both Sn-Pb and Pb-free BGA packages.
- No mechanical cracks or anomalies were observed for resistors, capacitors, inductors, TSOP (Thin Small Outline Package) and connectors. All of the components were electrically functional at the end of the test.
- The proposed vibration test was difficult to implement consistently across PCBAs, resulting in 'false' failures even in defect-free or good Pb-free solder joints. This was validated through the use of Sn-Pb test-coupons.
- Due to the inconsistency in vibration testing results, a modified sequential testing sequence is proposed. The sequence being: - ICT test - 5 times, Functional test at room temperature, Thermal aging (125 C for 240 hours or 85C for 480 C), Mechanical shock (IEC 60068-2-27 with 30 G's 10 ms shock pulse) and Functional test at elevated temperature. Destructional analysis (Dye & Pry and Cross-sectional Analysis) can be performed on failed units to root cause the issue.
- The modified testing sequence will help weed out early/marginal assembly and design defects (from solder joint perspective) and eliminate any chances of inducing defects in solder joints due to testing.

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