Verizon NEBS™ Compliance: Qualification Requirements for Printed Board Assemblies Manufactured with Lead-Free Solder for use in Telecommunications Equipment

Verizon Technical Purchasing Requirements
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CHANGE CONTROL RECORD:

Version	Date	Action*	Reason for Revision
1	7/01/2009	New	New Document
2	11/5/2009	Add	Add effective date to document
3	1/18/2010	Change	Corrections made to document numbering scheme
4	8/24/10	Change	Updated testing requirements, added exemption header and manufacturing changes. Renumbered sections
5	7/01/12	Change	Updated to make provision for Option A and Option B Qualification routes and to reflect lessons learnt from executing program with key suppliers to Verizon. Sections renumbered.
* **New, Add, Delete, Change, Reissue**			

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*With much appreciated technical and business contributions, guidance and assistance from key Verizon suppliers, their board assembly partners and other industry stakeholders.

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1 PURPOSE

The purpose of this Verizon Technical Purchasing Requirement (TPR) document is to specify the Qualification Requirements for Printed Board Assemblies (PBAs) manufactured with 'lead-free' (Pb-free) solder alloys that are intended for use in Telecommunications Equipment purchased by Verizon. The goal is to help assure that the equipment in which the PBAs are used will meet the service life and reliability requirements in Verizon applications.

2 SCOPE

This TPR applies to all PBAs used in equipment purchased by Verizon unless listed as exempt in Section 9 of this document.

3 INTRODUCTION

This updated TPR specifies two options for accomplishing qualification of PBAs manufactured with Pb-free solder. The first option, as previously specified and now designated as Option A, is prescription based. It corresponds to the standard 'Qualification Testing' approach of GR-357-CORE. The second option, now included and designated as Option B, is performance based. It corresponds to the acceptable alternative 'Technology Qualification' approach of GR-357-CORE. The qualification tests and requirements contained in either of these two options shall be used by equipment manufacturers and their selected testing laboratories as the minimum set of tests and requirements needed to qualify Pb-free PBAs for Verizon. Additional manufacturer-specific tests may be added as needed to properly exercise the materials, technology, design and manufacturing processes used by the Original Equipment Manufacturer (OEM) and/or its Contract Manufacturing (CM) partner/s.

4 REFERENCES

In all instances of test planning and test execution, the specified version of the referenced GR document shall be used. Where no version is specified, the most recent Verizon-accepted version of the referenced GR shall be used.

GR-63-CORE	NEBS™ Requirements: Physical Protection Issue 3, March 2006
GR-78-CORE	Generic Physical Design Requirements for Telecommunications Products and Equipment Issue 1, September 1997
GR-357-CORE	Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment Issue 1, March 2001
VZ.TPR.9306	NEBS Requirements for the Physical Design and Manufacture of Telecommunication Products and Equipment
IEC/MIL/etc.	Various reference test methods and procedures

5 ACRONYMS

Acronyms used in this document include:

CO	Central Office
CEMH	Controlled Environmental Manhole
CEV	Controlled Environmental Vault
D/EUT	Device/Equipment Under Test
ENIG	Electroless Nickel Immersion Gold
HASL	Hot Air Solder Leveled
IST	Interconnect Stress Test
ITL	Independent Testing Laboratory
MSL	Moisture Sensitivity Level
OSP	Organic Solder Preservative or Outside Plant
PB	Printed Board (bare, unpopulated board, laminate or substrate)
PBA	Printed Board Assembly (Card, Plug-n, PCB and PWB also used)
P/TVM	Process/Technology Validation Module
RT	Remote Terminal
RoHS	Restriction on Hazardous Substances
SAC	SnAgCu (Tin, Silver and Copper)
SMOBC	Solder Mask Over Bare Copper
TCR	Test Conformance Report
TV	Test Vehicle
WEEE	Waste Electrical and Electronic Equipment

6 DEFINITIONS

Pb-free Material: Refers to homogenous material where the weight concentration of lead (Pb) is less than 1000 ppm and where homogenous refers to material that cannot be further separated into its constituent parts by simple mechanical means.

RoHS: Refers to the European Union (EU) Directive 2002/95/EC for the Restriction of Hazardous Substances which restricts the use of six hazardous substances in electronic products unless specifically exempted. The six restricted substances and their weight concentration thresholds are:

1. Lead and its Compounds: Lead (Pb) < 1000 ppm
2. Mercury and its Compounds: Mercury (Hg) < 1000 ppm
3. Hexavalent Chromium and its Compounds: Hexavalent Chromium (Cr+6) < 1000 ppm
4. Cadmium and its Compounds: Cadmium (Cd) < 100 ppm
5. Polybrominated Biphenyls, Esters & Oxides PBB, PBBE and PBBO < 1000 ppm
6. Polybrominated Diphenyl Esters: PBDE < 1000 ppm

Notes:
The following terms are not EU definitions but are widely used within the electronics industry when referring to RoHS conformance. The most commonly used terms are:

- **RoHS 5 or RoHS 5/6 compliant** which refers to products that use the 'lead in solder' exemption enabling the products to be assembled with Tin-Lead (SnPb) solder and which may use Pb-containing components and bare Printed Board (PB) finishes that become part of the final solder joint. Any other uses of Pb are restricted to those defined by additional RoHS exemptions. The other five restricted substances do not exceed their RoHS-allowed weight concentrations except as permitted by other specific exemptions within the RoHS legislation.

- **RoHS 6 or RoHS 6/6 compliant** which refers to products that do not use the 'lead in solder' exemption and hence employ Pb-free solder in their assembly. RoHS 6 assemblies contain lead only as allowed by other specific exemptions. The other five restricted substances do not exceed their RoHS-allowed weight concentrations except as permitted by other specific exemptions within the RoHS legislation.

7 EFFECTIVE DATE

The effective date of this TPR was July 1, 2010. As of that date, all equipment supplied to Verizon using PBAs assembled with Pb-free solder alloys were required to meet the qualification testing and reporting requirements of Option A of this document. With this revision of the TPR, this requirement has now been expanded to require PBA conformance to either Option A or Option B as defined herein.

8 APPLICABILITY

This TPR applies to PBAs used in equipment supplied to Verizon which are installed in environmentally controlled (CO and CEV) and uncontrolled (protected OSP) facilities and spaces, and in Optical Network Terminals (ONTs) installed at outdoor customer premises. The PBA technologies covered include Single-Sided Surface Mount Technology (SMT), Through-Hole Technology (THT) and Mixed SMT and THT Double-Sided Technologies.

The qualification tests and requirements specified in this document apply to all PBAs, components and bare PBs containing Pb-free solder, and which are designed and manufactured in conformity to GR-357-CORE, GR-78-CORE and within the Technology and Reliability boundaries specified in Section 12 below.

9 EXEMPTIONS

The following PBAs are exempt from the requirements of this document:

a. PBAs manufactured with traditional tin-lead solder (i.e., 60/40 nominal weight percentage composition).

b. PBAs in ONTs, Set Top Boxes, Broadband Home Routers and DSL Modems installed at indoor customer premises.

c. PBAs in measurement and test equipment used to configure, provision, monitor and/or repair network equipment.

10 PERPETUAL PRODUCT CONFORMANCE

10.1 Initial Qualification

Suppliers may demonstrate initial PBA conformance to the qualification requirements in this document through a singular series of testing and reporting to Verizon. Perpetual PBA conformance may be achieved based on the supplier maintaining essentially the same PBA materials, design rules and manufacturing processes, the same manufacturing plant locations and making no substantial Bill of Material (BOM) changes since initial product acceptance by Verizon.

10.2 Re-Qualification

PBAs initially qualified to the requirements of this document shall be re-qualified if:

1. Significant/extensive material, design rule or BOM changes have been made or
2. Assembly is planned to be transferred to another manufacturing facility that has not demonstrated equivalent assembly capability as specified in Section 10.3 below.

10.3 Equivalent Manufacturing Lines/Facilities

Assembly of a PBA may be moved between assembly sites without re-qualification of that PBA provided that these sites have demonstrated equal capability to execute the required Pb-free assembly processes in a similarly reproducible, defect free and high quality manner. This equivalence may be demonstrated by assembling the subject PBA at each facility and demonstrating equivalent process capability by:

1. Conducting a manufacturing facility analysis to confirm adequate process control for each major process, e.g., paste printing, component placement, SMT reflow, wave solder, manual/automated inspection, segregation of SnPb and Pb-free material flows, etc.

2. Destructive physical analysis of PBA samples from each facility to confirm the quality and reproducibility of the Pb-free solder joints for each major component type present, e.g., BGA, LGA, lead-frame, QFN, through hole and the integrity of through holes and vias.

Alternatively, equivalence of assembly facilities may be demonstrated in a generic manner for all PBA designs by execution of (1) and (2) above using a Verizon accepted Pb-free assembly test vehicle. Such a test vehicle must represent the supplier's full design spectrum by including a broad range of device package types, sizes, I/O count and pitch; soldering processes including SMT reflow and wave if appropriate; and design rules (e.g., component spacing, via pitch, etc.) More information on the use of an assembly qualification test vehicle can be found in Section 15.3.

11 BACKGROUND

11.1 General

EU Directives on Waste Electrical and Electronic Equipment (WEEE) and on Restriction of Hazardous Substances (RoHS) prohibit the use of lead (Pb) in electronic equipment sold in the European Union unless specifically exempted. This legislation went into effect July 1, 2006 requiring most segments of the electronics industry to discontinue use of tin-lead (SnPb) solders.
In response to this legislation, the global supply chain began an aggressive transition to Pb-free compatible components and materials while phasing out more and more SnPb compatible parts. In addition to the general decrease in SnPb component availability, many of the newest component technologies are being supplied only in Pb-free compatible packages forcing severe design and manufacturing compromises on those suppliers continuing to assemble with SnPb solder.

This situation has resulted in significant effort over the last few years to find a replacement for the tin-lead solder traditionally used in the manufacture of electronic equipment. Much work has been done and is continuing to be done to find an acceptable replacement for leaded solder. To date, no globally-accepted Pb-free solder solution has been identified.

11.2 Reliability Impact of Pb-free Assembly Technology

The above cited supply chain constraints are making it increasingly difficult to continue using traditional SnPb soldering processes to manufacture PBAs. As a result, Verizon is receiving increased requests from suppliers to consider accepting PBAs manufactured with Pb-free solders. The properties of Pb-free solders are very different from those of today's well characterized SnPb eutectic solder. The higher melting temperature of Pb-free solders requires use of new, high glass transition temperature (T_g) PB laminate materials, components capable of withstanding the higher temperatures and new manufacturing process control parameters. Although extensive industry R&D has greatly expanded the knowledge base of Pb-free solder technology, transition to Pb-free solder assembly is still in its early stages. Qualification testing to date has been done in a piece-meal fashion. Comprehensive qualification has not been done. Further, for PBA reliability estimates, it is necessary to know the steady state failure rate of the Pb-free solder joint to determine whether it must be taken into account when estimating the failure rate of PBAs or whether it is sufficiently low for its contribution to be ignored as is currently done for SnPb solder joints. This document consolidates the fragmented industry work done to date to qualify Pb-free solder assembly. It provides Pb-free PBA qualification requirements for use by all suppliers to Verizon which, in Verizon's view, will help assure network equipment will meet the service life and reliability requirements in Verizon applications.

11.3 Areas of Concern with Pb-free PBAs

A typical fully equipped 7-foot rack contains approximately 4 million individual solder joints. Failure of only one of these joints may potentially cause a service outage which can have a major adverse impact on Verizon. PBAs assembled with traditional SnPb solder have had a long history of satisfactory performance in telecommunication applications. However, PBAs assembled with Pb-free solder have not yet been fully accepted for such use because of the newness of this technology and the various concerns cited above, i.e., the properties of Pb-free solders are very different from those of today's well characterized SnPb eutectic solders; their higher melting points require use of new, high glass transition temperature (T_g) PB laminate materials as well as components capable of withstanding these higher temperatures. In addition, the new assembly processes used to attach the components to the bare PB laminate needs to be properly controlled for the assembly to not be degraded.

The four major areas of concern with Pb-free technology are:

- Long term reliability of the components that comprise the Bill of Materials (BOM)
- Long term reliability of the Pb-free solder joints that must provide electrical connectivity and robust mechanical attachment between component terminations and the circuit board metallization (pads)
- Long term reliability of new Pb-free compatible bare PB laminate materials that must support stable conductive paths between the thousands of device terminations on a modern PBA without mechanical failure or change in electrical properties that might impact circuit performance over the product's service life
- Ability to reproducibly execute the various assembly process steps without introducing quality defects that can impact reliability.

11.4 Establishing Pb-free PBA Qualification Requirements

Industry has made significant progress in characterizing Pb-free solders and compatible materials providing improved data to guide Original Equipment Manufacturer (OEM) supplier choices. However, since Pb-free compatible materials and assembly technology are still evolving, choice of Pb-free solder alloy, component package technology, PB laminate and assembly process conditions can vary significantly between suppliers. Some choices may be more fully characterized than others. As a result, this document has been prepared to enable suppliers to move forward with Pb-free products while establishing qualification criteria to ensure that their Pb-free technology choices provide products that meet Verizon's service life and reliability requirements.

Effective qualification of a Pb-free PBA requires demonstration of:

1. The Pb-free solder alloy's ability to provide good electrical interconnection and robust mechanical attachment of the component terminations to the PB's copper pads/traces
2. Solder joint fatigue life compatible with PBA service life requirements for the many different device package types used
3. The circuit board laminate's ability to withstand the higher temperature of Pb-free solder assembly processes without formation of reliability impacting defects
4. Quality and reproducibility of Pb-free assembly processes to ensure freedom from defects (e.g., excessive solder voiding, solder bridging, component mis-alignment, inadequate solder volume, etc.) that can result in early failures and degraded product reliability.

These items are addressed and demonstrated by either of the two qualification options detailed below.

11.5 Pb-free Solder Qualification Options

Analysis of methods used to qualify PBAs manufactured using Pb-free solder technology has identified two qualification options that Verizon considers acceptable at this time:

a. **Option A – Prescription Based Approach**
   This method involves qualifying a Pb-free test PBA that is representative of all board designs from the manufacturer by subjecting it to the 'catalog of tests' specified in Table 5 below. If the test PBA conforms to the specified test requirements, then that specific PBA, and all other PBA designs from the same manufacturer, using the same board materials, design rules, components and of similar complexity produced on the same assembly line/s as the test PBA, are deemed to be qualified. This method requires that all key components used conform to GR-357-CORE and the PBA materials, design rules and manufacturing processes used conform to GR-78-CORE. It also requires a component, physical design and manufacturing facility analysis at the assembly site to verify that the manufacturer specific Technology and Reliability boundaries, the manufacturing processes and process controls used and the quality and reliability tests done in manufacturing conform to the above two listed GRs. Details for qualification via Option A are provided in Section 14

below. Determination of Pb-free PBA acceptability for this qualification option is based on satisfactory demonstration of conformance to the tests, examinations, calculations, or combinations of these as specified in Table 5.

b. **Option B – Performance Based Approach**
This method involves qualifying the Pb-free technology using test vehicles (aka process and/or technology validation modules) designed to exercise the PBA materials, design rules, complexity and processing capability of the assembly facility used by the manufacturer. In this case, if the test vehicles and assembly facility processing capability conform to the performance requirements specified in Tables 6, 15.1 and 15.2 below, all board designs from the equipment manufacturer, produced on the same manufacturing line as the test vehicles are deemed to be qualified. This method requires investment of extensive time and resources to develop and broadly apply specialized test vehicles, procedures and performance requirements for both the components used (similar to GR-357) and the PBA design and assembly (similar to GR-78) to establish the reliability of all aspects of the technology used in the manufacturer's Pb-free PBAs. It also requires a component, physical design and manufacturing facility analysis at the assembly site to verify the ability of the assembly line to properly process the test vehicles. However, the upfront investment of resources to develop procedures and qualify the technology can enable rapid and efficient subsequent qualification for a wide range of assemblies that use that qualified technology. Details for qualification via Option B are provided in Section 15 below. Determination of Pb-free PBA acceptability for this qualification option is based on satisfactory demonstration of conformance to the tests, examinations, calculations, or combinations of these as specified in Tables 6, 15.1 and 15.2 and may require expert risk assessment to interpret and verify conformance of the performance features.

Both of the above qualification options address the Verizon concerns with Pb-free PBAs cited above. It is expected that, as other acceptable Pb-free qualification methods are developed, they will be added to this document as additional alternative Pb-free qualification options.

12 TECHNOLOGY AND RELIABILITY BOUNDARIES

Technology and Reliability boundary criteria and options within which acceptable performance has been demonstrated are specified in Tables 1 through Table 3 below. The PBA supplier may declare expanded boundary criteria from those specified. Acceptability of these supplier expanded boundary criteria and/or options will be determined based on conformity to the PBA qualification criteria of this document.

12.1 Material Criteria

Table 1 – Material Criteria for Backplanes and Daughter Cards

Feature	Press Fit Backplanes	SMT / PTH / Press Fit Daughter Cards
Laminate	Pre-preg (B stage): woven glass, flame retardant epoxy (FR-4), with a minimum T_g = 130°C CORES (C stage): woven glass, flame retardant epoxy (FR-4), with a minimum T_g = 135°C	Pre-preg (B stage): woven glass, flame retardant epoxy (FR-4), with a minimum T_g = 130°C CORES (C stage): woven glass, flame retardant epoxy (FR-4), with a minimum T_g = 135°C
Number of Inner Layers	50 maximum	34 maximum
Flux	Hot oil reflow (Shipley Evenflow 1073 or equivalent)	Hot oil reflow (Shipley Evenflow 1073 or equivalent)
Solder Mask	Thermally Cured (PC401, SR1000 or equivalent)	LPI (Taiyo, Enthone, Morton or equivalent)
Legend Ink	Thermally or UV Cured	Thermally or UV Cured

12.2 Component Criteria

Table 2 – Component Criteria for Backplanes and Daughter Cards

Feature	Press Fit Backplanes	SMT / PTH / Press Fit Daughter Cards
Attachment Process	Wave or Re-Flow Solder	Wave or Re-flow Solder
SMT Resistor Size Range	0201 through to 2512	0201 through to 2512
THT Resistor Hole Size	1.0 mm maximum	1.0 mm maximum
SMT Capacitor Size Range	0201 through to 2512	0201 through to 2512
THT Capacitor Hole Size	1.0 mm maximum	1.0 mm maximum
P-Dual in-line package	48 Pins maximum	48 Pins maximum
C-Dual in-line package	48 Pins maximum	48 Pins maximum
Quad Flat Pack	240 Pins maximum	240 Pins maximum
C-Leadless Chip Carriers	80 Pins maximum	80 Pins maximum
P-Leadless Chip Carriers	80 Pins maximum	80 Pins maximum
Small Outline ICs	80 Pins maximum	100 Pins maximum
Ball Grid Array Pitch	1.27 to 0.5 mm	1.27 to 0.5 mm

SMT = Surface Mount Technology; THT = Through Hole Technology
C = Ceramic; P = Plastic

12.3 Bare Board Criteria

Table 3 - Physical Criteria for Backplanes and Daughter Cards

Feature	Press Fit Backplanes	SMT / PTH / Press Fit Daughter Cards
Board Thickness	0.500” max.	0.140” max.
Panel Size	18” × 24” (or smaller)	18” × 24” (or smaller)
Line Width/Spacing	0.005”/0.005” nominal	0.003”/0.003” minimum
Aspect Ratio	18:1 max.	14:1 max.
Drilled Hole Size	0.028” nominal	0.010” nominal via 0.040” nominal through hole
Finished Hole Size	0.024” nominal	0.008” nominal via 0.025” nominal through hole
Finished Hole Size Tolerance	±0.002”	+0.003”, -0.010” via ±0.003” through hole
Dielectric Thickness	0.004” nominal	0.004” nominal – Pre-preg 0.001’ nominal – BC Core
Layer Count	52 layers max.	36 layers max.
Copper Thickness (inner signal layer)	1 oz. nominal	1 oz. nominal
Copper Thickness (inner power and ground layers)	2 oz. nominal	2 oz. nominal
Copper Thickness (outer layers)	0.5 oz. nominal	0.5 oz. nominal

Feature	Press Fit Backplanes	SMT / PTH / Press Fit Daughter Cards
Board Surface Finish (Specify which used)	Solder Mask over bare Copper with Hot air solder level (SMOBC/HASL)	Solder Mask over bare Copper with Hot air solder level with or without gold tips
	Organic Solder Preservative (OSP)	Organic Solder Preservative (OSP)
	Electroless Nickel Immersion Gold (ENIG)	Electroless Nickel Immersion Gold (ENIG)
	Matte Tin (Sn) Electroplate	Matte Tin (Sn) Electroplate
	Immersion Tin	Immersion Tin
	Immersion Silver	Immersion Silver
Surface Mount Pitch	N/A	20 mils nominal
Solder Alloy	Tin Silver Copper (SAC) solder alloy with > 3% silver, e.g. SAC 305. Specify exact alloy used. If less than 3% silver used, supplier must provide fatigue life test data.	Tin Silver Copper (SAC) solder alloy with > 3% silver, e.g. SAC 305. Specify exact alloy used. If less than 3% silver used, supplier must provide fatigue life test data.

13 QUALIFICATION REQUIREMENTS FOR LEAD-FREE PBAs

13.1 General

Qualification requirements for PBAs manufactured with Pb-free solders used in telecommunications equipment purchased by Verizon are detailed either in:

a. Table 5 – Option A Qualification Requirements for Pb-free PBAs: PBA Testing or in
b. Table 6 – Option B Qualification Requirements for Pb-free PBAs: Test Vehicle Evaluation

The tests specified in these tables are not exhaustive. They represent a reasonable set of known state-of-the art tests and procedures that, in Verizon's view, would help assure that PBAs manufactured using Pb-free solder alloys will meet the service life and reliability requirements in Verizon applications. Additionally, but not in lieu of the requirements specified herein, PBA manufacturers may include in the test report the results of any other manufacturer-specific tests they consider applicable to and necessary for properly exercising the materials, technology, design and manufacturing processes used for their specific PBAs. These manufacturer-specific tests and test results will supplement information in the *Pb-free Test Conformance Report (TCR).*

13.2 Execution of Qualification Tests

Verizon requires that manufacturers submit samples of their PBAs to a Verizon-Certified Independent Testing Laboratory (ITL) and/or other Verizon acceptable laboratory as appropriate to conduct qualification testing and verification of conformance to the Pb-free PBA test requirements specified in this document. To view an up-to-date listing of Verizon-Certified ITLs, along with lab locations and scope of approvals, log on to the World Wide Web to access the Verizon NEBS Compliance web page at http://www.verizonnebs.com/tcppage.html.

Conformance to the tests listed at the material, component or test vehicle levels of these tables may be declared by the manufacturer based on the manufacturer's internal test data, its supplier-provided test data or its CM-provided test data. However, all tests in the tables at the PBA level shall be executed by the manufacturer selected, Verizon-Certified ITL and/or other Verizon acceptable laboratory.

13.3 Reporting of Qualification Results

Tables 5 and 6 are designed to not only provide the required tests and declarations but to also provide the required format for reporting the design/measured values and summarizing their conformance to requirements.

Reporting of the test results shall be done by the ITL and/or the equipment manufacturer as appropriate. The equipment manufacturer shall provide this *Pb-free PBA Test Conformance Report* to Verizon as part of the NEBS testing and reporting program for the equipment in which the PBAs are used

13.4 Test References

The test references cited in Tables 5 and 6 are intended to outline the general test methods and procedures to be used to evaluate the applicable requirement. The test conditions specified in these Tables shall be used, and where applicable, shall override those specified in the cited reference. Other test methods (IEC, Joint Electron Device Engineering Council [JEDEC], etc.) may be acceptable alternatives to the cited references. However, the use of alternative test methods, procedures, sampling plans, etc. will require demonstration that the proposed procedure is equivalent to or is better (from a user's viewpoint) than the specified procedure.

13.5 Sample Size and Accept Criteria

13.5.1 Sub-PBA Level

At the material, component, bare board and test vehicle level, the sample size and accept criteria used shall be as appropriate for the specified test.

13.5.2 PBA Level

At the PBA level, the number of PBA samples used shall be selected to ensure a minimum of 3891 solder joints are used for each test with an accept number of 1 (LTPD of 0.1%). Parallel or sequential testing may be used to maximize test coverage and to optimize use of test samples. Where sequential testing is used, precautions shall be observed to ensure no destructive tests are done within the test sequence.

14 OPTION A QUALIFICATION – PBA TESTING

14.1 General

Option A is a Prescriptive-Based approach. For this option, the PBA qualification tests specified in Table 5 were selected based on their ability to accelerate the underlying potential failure mechanism/s. Some examples of these tests and the associated failure mechanism/s accelerated are given in Table 4. Use of this qualification option requires that the test PBA, and all other PBAs represented by the test PBA that are to be qualified, are designed and manufactured in conformity to the requirements of GR-357-CORE and GR-78-CORE and within the known Technology and Reliability Boundaries as defined in Tables 1 through 3 above or as expanded by the supplier based on supporting data provided to Verizon. Verification of conformance to these latter boundary conditions and of implementation of proper assembly processes and process controls are to be determined by a component, physical design and manufacturing analysis at the designated assembly site. Determination of Pb-free PBA acceptability for this qualification option is based on satisfactory demonstration of conformance to the tests and other requirements specified in Table 5.

14.2 Test Acceleration Effectiveness

The qualification tests prescribed in Table 5 were selected based on their ability to accelerate the underlying failure mechanism/s. Some examples of these tests and the associated failure mechanism/s accelerated are as given in Table 4 below:

Table 4 – Failure Accelerating Tests for Pb-free PBAs

Failure Mode and/or Failure Mechanism	Stabilization Bake	Temp. Cycle/ Thermal Shock	Temperature Cycling/Humidity	Temperature Cycling/Vibration	Power Cycling	Temperature/ Humidity Bias	Mech. Shock/ Acc./Vibration	Salt Fog/Mixed Flowing Gas	Reverse Bias/ Temp.	Dynamic Operation/ Temp.	Board Bend	In-Circuit and Functional	X-Ray/Sectioning Examination	External Visual	SIR/SEC/EMR
TCE Mismatch		●			●										
Tensile Fracture of Solder Joint							●				●	●	●		
Creep Failure of Solder Joint			●	●							●	●	●	●	
Fatigue Failure of Solder Joint		●	●	●	●		●					●			
Component Temination Fracture							●								
Whisker Growth		●	●	●											
SMT Attach Defect		●					●			●			●		
PB Plated Hole Fracture			●	●											
PB Surface Contamination	●								●	●					●
PB Surface Leakage	●								●	●					●
Foreign Materials/Particles							●						●		
Cracked SMT Component		●					●			●					
Cracks in Solder Joint		●							●	●			●	●	
Voids in Solder Joint		●							●	●			●	●	
Solder Mask Defects		●							●						
Open Copper Tracks		●							●	●					
Shorted Copper Tracks		●	●			●		●	●	●					
Lifted Copper Pads		●							●	●				●	
Electromigration										●					●
Intermetallic Formation	●	●								●			●	●	
Solder Joint Embrittlement	●	●					●				●				
Corroded Component Termination		●				●		●	●	●				●	

14.3 Table 5: Qualification Requirements for Pb-free PBAs – PBA Testing

Detailed 'Option A' test requirements for Pb-free PBAs are specified in Table 5 below:

<u>Notes on Table 5</u>

- Conformance to the tests listed at the Material and Component Levels of Table 5 may be declared by the manufacturer based on manufacturer internal and/or supplier provided data
- Conformance to the tests listed at the PBA Level shall be executed by a Verizon-Certified ITL
- Table 5 is designed to not only provide the required tests and declarations but to also provide the required format for reporting the design/measured values and summarizing their conformance to requirements. The last column of table 5 shall be left blank in the supplier's qualification report.

Table 5 – Option A: Qualification Requirements for Pb-free PBAs – PBA Testing

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
Material Level Criteria/Declarations					
1.	T_g : Glass transition temperature of all polymeric materials	TPR-9306 and GR-1221: R4-24	≥ 95°C except for PB laminates (see item 9 below)		
2.	T_{HDT} : Heat distortion temperature of all polymeric materials	TPR-9306 and this document	≥ 100°C for connectors ≥ 150°C for all other polymeric materials		
3.	OIT: Oxidative Induction Time of any PETP material used	TPR-9306 ASTM D 3895 and GR-20[138]	20 minutes minimum after aging at 90°C for 14 days		
4.	Melt Flow/Melt Volume Index of all polymeric materials	This document	Verify conformity to specification per ASTM D1238		
5.	Thermal Aging of all polymeric materials	GR-771: 6.4.1 and GR-771: R5-11[85]	90°C for 30 days; 1. No visible deterioration, deformation, melting or cracking. 2. < 20% degradation in mechanical tensile properties		
6.	Component outer encapsulation material	TPR-9306 GR-78: [695, 696]	Shall withstand 85°C minimum		
7.	Printed board laminates, solder masks, legend and marking inks, repair polymer and adhesive materials	This document	Shall withstand 85°C minimum		
8.	Glass Transition temperature of Label Attach Adhesives T_g	GR-1221: R4-24	≥ 95°C		
9.	Glass Transition temperature of bare PB laminates	This document	Shall exceed 135°C		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
Component /Bare Board (PB)/Test Vehicle Level Criteria/Declarations					
10.	Component Solderability	MIL-STD-883 G, 2003.8	255°C ± 5°C; 5 secs. max		
11.	Component Resistance to Solder Heat (For rework)	MIL-STD-202 G, Method 210F	350°C; 30 secs. min.		
12.	Bare Printed Board Solderability	IPC/EIA J-STD-003A Methods A, D or E as appropriate	255°C ± 5°C; 5 secs. max		
13.	Surface Insulation Resistance	GR-78 Section 13.1.4 78: R14-4	$1x10^4$ megohms min.		
14.	Solvent Extract Conductivity	78: R6-193	1 µg/cm^2 max.		
15.	Electro Migration Resistance	GR-78 Section 13.1.4 R13-19 R13-20	1. < 1 decade ohmic change and 2. No filament growth		
16.	Whisker Growth Evaluation	1. JEDEC 22A121; IEC-68-2-82; IEC-PAS-62483 2. JESD201	1. Whisker Density: ≤ 10/mm^2 (None to Low) 2. Whisker Length: ≤ 45µm		
17.	Time to delamination at 260 ±3°C after conditioning for 1000 hrs. at 85°C and 85% RH	IPC – 650 – 2.4.24.1 (TMA)	T260 = 20 minutes minimum Note: Items 17, 18 and 20 may each use one of three test samples that were simultaneously preconditioned.		
18.	Thermal Stress (Solder Float) after conditioning for 1000 hrs. at 85°C and 85% RH	GR-78 14.3.4	20 seconds at 550°F (287°C). No wedge void, delamination, or other damage under non- magnified visual examination. Note: Items 17, 18 and 20 may each use one of three test samples that were simultaneously preconditioned.		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
19.	Voltage Breakdown	GR-78 R6-199	No breakdown or flashover		
20.	Shear strength of SMT solder joint after conditioning for 1000 hrs. at 85°C and 85% RH	JIS Z3198-7 or equivalent (specify)	Record initial value and final value after conditioning. Change in shear strength shall not exceed 5%. Note: Note: Items 17, 18 and 20 may each use one of three test samples that were simultaneously preconditioned.		
Printed Board Assembly (PBA) Level Criteria/Requirements					
21.	Initial X-Ray Inspection	MIL-STD-883 G, 2012.7	< 10% voids in the volume of the solder joint		
22.	Initial External Visual Examination	This document	With back lighting at 10X magnification; No visible damage, debris, cold joints, contamination or evidence of filament growth		
23.	In Circuit (ICT) and Functional (FCT)	This document	Shall pass ICT and FCT @ 25°C before and after all tests		
24.	Mechanical Shock (Impact) – not operating	MIL-STD-202 G, 213B 5 cycles in each of two directions for three axes (30 impacts total) using a 20g, 11 msec, half sine pulse per impact	Shall pass FCT before and after conditioning; No physical damage to the solder interface under non- magnified visual examination.		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
25.	Mechanical Vibration	MIL-STD-883 G, 2007.3 Maximum of 20g or 0.060" peak-to-peak; 10 to 2kHz in 4 minutes; 12 sweeps per axis;	Shall pass FCT before and after conditioning; No physical damage to the solder interface under non- magnified visual examination.		
26.	Thermal Shock	MIL-STD-883 G, 1011.9 ΔT = 55°C(-5°C to +50°C); two chamber method; Dwell ≥ 5 minutes at temperature extremes or until thermal stability is reached. 20 cycles	Shall pass FCT before and after conditioning; No physical damage to the solder interface under non- magnified visual examination.		
27.	Temperature Cycling (Dry – not operating)	GR-1209: 5.4.1.5 100 cycles	Shall pass FCT before and after conditioning; No physical damage to the solder interface under non- magnified visual examination.		
28.	Damp Heat Cyclic (not operating)	GR-1209: 5.4.2.1 Controlled Environment (C) 5.4.2.2 – Uncontrolled Environment (U) 42 cycles	Shall pass FCT before and after conditioning; No physical damage to the solder interface under non- magnified visual examination.		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
29.	Thermal Cycling with Mechanical Vibration and X-Ray	IEC-68-2-53 GR-1209: 5.4.1.5 C = -5 to +50°C U = -40 to +65°C; Dwell times at temp. extremes = 16 minutes minimum; 5 to 2kHz random vibration applied 8 minutes before end of temp extreme periods	Shall pass FCT before and after conditioning; < 10% volume voids in and < 25% areal voids in the solder joint under X-Ray examination With back lighting at 10X magnification, no visible cracks or evidence of filament growth on solder joint surface		
30.	Power Cycling at Steady Temperature	MIL-STD-202G Method 108A This document T_{AMB} = + 50°C (C) or +65°C (U); 100 hours; Power on for 10 minutes; Power off for 10 minutes	Shall pass FCT before and after conditioning. With back lighting at 10X magnification, no visible cracks or evidence of filament growth on solder joint surface		
31.	Corrosion Resistance - Salt Fog (this test may be omitted if other corrosion resistance tests, e.g., MFG and Hydroscopic Dust tests are done)	MIL-STD-202G Method 101E This document 35°C , 10 days, 5% solution	Shall pass FCT before and after conditioning. With back lighting at 10X magnification, no visible cracks or evidence of filament growth or corrosion on solder joint surface		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
32.	Corrosion Resistance - Mixed Flowing Gas	GR-63 Sect. 4.5 and 5.5.2	Shall pass FCT before and after either Indoor (C) or Outdoor (U) conditioning. With back lighting at 10X magnification, no visible cracks or evidence of filament growth or corrosion on solder joint surface		
33.	Corrosion Resistance - Hydroscopic Dust	GR-63 Sect. 4.5 and 5.5.3	Shall pass FCT before and after either Indoor (C) or Outdoor (U) conditioning. With back lighting at 10X magnification, no visible cracks or evidence of filament growth or corrosion on solder joint surface		
34.	Board Bend Fatigue	IPC 9702 or IPC 9704 – specify which	Cylinder Dia. = 2”; Bend = Lengthwise; Bend at CL; Deflection = 1:6; Span = 90 mm; Displacement = 2.0 mm; Shall pass FCT before and after 100 cycles conditioning with no physical damage; Record cycles to failure;		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
35.	ICT Stress Simulation and Solder Joint Cross Section Metallurgical and Microstructure Examination and Analysis	This document. Use ICT engagement fixture or equivalent	5 cycles of engagement with fixture. Shall pass ICT and FCT before and after conditioning. Assess solder joints for intermetallics, cracks and void formation on: 1. Five non-failed control joints (pre test) 2. All failed joints during test 3. Five samples of non-failed joints tested 4. Compare failed and non-failed joints to the control sample and assess for acceptability Solder joints shall show proper stand-off height and wetting wth no evidence of physical damage or intermetallic formation		
36.	Dynamic Operation at High Temperature – Dry (HTOL)	MIL-STD-202G Method 108A This document T_{AMB} = + 50°C (C) or +65°C (U); 1000 hours;	Shall pass FCT before and after conditioning. With back lighting at 10X magnification, no visible cracks or evidence of filament growth on solder joint surface		
37.	Failure Rate Estimation	This document (As a guide, the failure rate of a SnPb solder joint is estimated at 4 x 10^{-4} FITS at 40°C and 90% UCL)	Record all solder joint failures from the entire test program. Use this number together with an estimate of all joints tested, time on test and a default Activation Energy of 0.8 eV to estimate the joint failure rate.		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
38.	Pb-free solder alloy thermal fatigue life (characteristic life)	IPC 9701A or equivalent	All Pb-free solder alloys other than SAC with ≥ 3% silver must have IPC 9701A test results showing a characteristic life ≥ that of SnPb eutectic solder		
Other Supplemental Supplier PBA Level Testing Done (if any)					
39.					
40.					

End of Table 5

15 OPTION B QUALIFICATION – TEST VEHICLE EVALUATION

15.1 General

Option B is a Performance-Based approach. This option requires the equipment supplier to develop, implement and maintain detailed component management and physical design practices and procedures to ensure the components, laminates and solder alloys used for Pb-free assemblies are properly qualified for their intended application. In addition, it requires the supplier to develop suitable Test Vehicles (TVs), aka Process Validation Modules (PVMs) or Technology Validation Modules (TVMs), which are representative of the PBAs to be qualified to exercise the materials, technology, design and manufacturing process controls used. Finally, it requires the supplier to conduct a component, physical design and manufacturing analysis at the designated assembly site to verify the assembly processes used are capable, properly implemented and adequately controlled. Determination of Pb-free PBA acceptability for this qualification option is based on satisfactory demonstration of conformance to the tests, examinations, calculations, or combinations of these as specified in Tables 6, 15.1 and 15.2 and may require expert risk assessment to interpret and verify conformance to the performance features.

As previously stated, the four major areas of concern with Pb-free technology are:

- Long term reliability of the components that comprise the Bill of Materials (BOM)
- Long term reliability of the Pb-free solder joints that must provide electrical connectivity and robust mechanical attachment between component terminations and the circuit board metallization (pads)
- Long term reliability of new Pb-free compatible printed circuit board materials that must support stable conductive paths between the thousands of device terminations on a modern PBAs without mechanical failure or change in electrical properties that might impact circuit performance over the product's service life
- Ability to reproducibly execute the various assembly process steps without introducing quality defects that can impact reliability.

Verizon recognizes that the reliability of a PBA is the sum of the contributions from each of its individual constituent element provided no reliability impacting quality defects are introduced by the assembly process. Hence, a Pb-free assembly will be considered qualified by Verizon if its three constituent elements; 1) electronic components, 2) Pb-free solder joints, and 3) circuit board have demonstrated acceptable long term reliability as described in Section 15.2 and it is assembled at a facility proven capable of executing all relevant assembly processes with high quality/reproducibility as described in Section 15.3. Moreover, if all Pb-free compatible electronic component types, solder alloys and laminate constructions used by a supplier in the realization of its PBAs have been proven reliable via the methods of Sections 15.2.1, 15.2.2, and 15.2.3 respectively and the supplier's assembly facilities have met the assembly quality criteria of Section 15.3 then all Pb-free PBAs constructed with this proven and qualified technology shall be considered "Acceptable" by Verizon.

15.2 Demonstrating Reliability of a PBA's Constituent Elements

Acceptance of a Pb-free PBA requires demonstration of the reliability of its three constituent elements via the processes/test methods described in sections 15.2.1 through 15.2.3 below or via such alternative methods as may be agreed upon with Verizon.

15.2.1 Establishing Pb-free Compatible Component Reliability

Pb-free components (e.g., integrated circuits) are electrically identical to their SnPb counterparts at the chip level and can be expected to exhibit the same FIT rates. However, failure by some Pb-free component suppliers to use packaging materials (e.g. underfill, substrate laminate, adhesives, etc.) compatible with higher Pb-free soldering temperatures or inclusion of SnPb parts rated for lower soldering temperature in a Pb-free BOM can result in reduced PBA reliability due to component thermal damage during Pb-free assembly. Inclusion of components having a whisker prone Pb-free termination finish can also adversely impact long term PBA reliability by enabling growth over time of conductive tin whiskers that can short circuit closely spaced conductors or component leads. Demonstration of reliability for Pb-free components requires confirmation that all components meet the test requirements listed in Table 6 Items 1-4 for thermal compatibility and tin whisker mitigation. Conformance may be declared by the manufacturer based on the manufacturers' internal or supplier-provided data. However, Verizon reserves the right to request objective evidence of conformance such as documentation of a component procurement/management system that ensures all Pb-free BOM components meet the above requirements.

15.2.2 Establishing Pb-free Solder Alloy/ Solder Joint Reliability

The two basic causes of solder joint failure in telecommunications equipment are solder assembly defects and long term wear-out due to thermal fatigue. While both impact product reliability, assembly defects are the primary cause of solder joint failure during normal service life. This is recognized as a quality issue often detected by stress testing (e.g. mechanical shock/vibration, thermal shock/cycling, etc.) and mitigated by proper qualification and control of the solder assembly process as required in Section 15.3. In the absence of assembly defects, inherent solder joint reliability is determined by the basic wear-out mechanism of thermal fatigue. Normal temperature variations in the use environment cause cyclic stress on solder joints due to differences in thermal expansion between the component, circuit board, and intervening solder ultimately resulting in solder joint failure. Hence, solder joint reliability (for both SnPb and Pb-free assembly) is strongly dependent on both composition/physical properties of the particular solder alloy and component style/construction (e.g. ceramic BGA, plastic BGA, QFN, QFP, etc). To satisfactorily establish the long term reliability of Pb-free solder joints, it is necessary to demonstrate that they have thermal fatigue life comparable to or longer than standard SnPb eutectic solder joints.

Testing in accordance with IPC 9701 is the de facto standard for assessing thermal fatigue reliability of solder joints for a specific device package style. This test method establishes a solder joint failure distribution over time by subjecting a statistically significant sample of components, soldered onto test boards, to thermal cycling (typically 0°C to 100°C; 10 to 60 min dwell time at temperature extremes) and provides an accepted means of comparing reliability/life performance of different solder/component systems. Verizon has reviewed industry developed data comparing IPC 9701 test results for multiple package styles soldered with both Pb-free and SnPb alloys. Based on this data, Verizon will accept Tin Silver Copper (SAC) solder joints having 3% or more silver as comparable in reliability to traditional SnPb eutectic provided the assembly qualification process (Section 15.3) demonstrates freedom from quality defects that can compromise their inherent long term reliability. Alternative Pb-free solders, including SAC alloys containing less than 3% silver, must be qualified for use in Verizon product by providing IPC 9701 test results demonstrating fatigue life performance comparable to that of SnPb eutectic. Solder alloy used for surface mount assembly of the submitted Pb-free product and status of IPC 9701A test compliance demonstrating comparable Pb-free and SnPb solder life performance shall be provided in Table 6 Items 5 and 6.

15.2.3 Establishing Circuit Board Reliability for Pb-free Compatible Laminates

Pb-free assemblies require the use of new board laminate materials compatible with the higher temperature required for Pb-free solders. Higher soldering temperatures (typically 240°C to 260°C) associated with Pb-free processing exacerbate board laminate defects such as material decomposition, delamination, and CAF (Conductive Anodic Filament) formation. Over time, these can impact reliability by causing localized changes in the physical integrity and dielectric properties of the board affecting circuit performance, creating spurious conducting paths between metal features or disrupting trace continuity. The many new high T_g (glass transition temperature) laminates developed for use with Pb-free assembly have demonstrated different levels of resistance to these defects depending not only on the laminate composition but also on the specific details of the bare PB design, construction and fabrication (e.g., number of layers, via spacing, etc.). The limited field experience with Pb-free compatible laminates in the many possible material and board design configurations characteristic of network element PBAs is of concern to Verizon and, hence, confirmation of their reliability is required as part of this Pb-free product qualification.

Pb-free PBAs acceptable to Verizon must use circuit board laminate materials specifically formulated for compatibility with Pb-free soldering and meet the requirements of Table 6 Items 7-14 to minimize the potential for laminate material performance to adversely impact overall PBA reliability. Conformance to these requirements may be declared based on data provided by the laminate supplier or developed internally by the manufacturer through use of a suitable Laminate Material Test Vehicle. Verizon reserves the right to review the manufacturer's supporting data and evaluate the suitability of any specialized Laminate Material Test Vehicle used by the manufacturer to fulfill this requirement.

Since the reliability of a product bare PB is dependent on both the material properties of the laminate and critical physical characteristics (e.g. number of layers, thickness, via spacing, resin content, etc.) of the fabricated circuit board, conformance with Items 7-14 is necessary but not sufficient to qualify the reliability of actual product circuit boards. In addition, conformance with the conditions specified in Table 6 Items 15-18 must be demonstrated either with actual product boards or with an appropriate board test vehicle. An acceptable test vehicle must use the same laminate material as the product board being qualified and have similar or more challenging construction (e.g. layer count, thickness, resin content, minimum via size and spacing, etc.). Use of a test vehicle allows qualification of a family of similar product circuit boards while enabling use of specialized test structures specifically designed to measure the required critical circuit board performance parameters. Verizon reserves the right to review the manufacturers' test vehicle design to ensure it adequately represents the actual product PBs to be qualified and that the test structures implemented accurately measure the reliability parameters required in Table 6.

15.3 Demonstrating Assembly Facility Quality, Reproducibility and Equivalence

15.3.1 Pb-free Assembly Test Vehicle

Establishing long term reliability for each of the constituent element of a Pb-free assembly is necessary but not sufficient to prove reliability of the whole. Defects introduced due to poor assembly quality are the principal cause of unacceptable reliability and product failures during normal service life. Suppliers seeking qualification of PBAs by the Option B qualification route must demonstrate that all locations assembling them can do so in a reproducible and consistent manner without introducing reliability impacting quality defects. This shall be done through an on- site audit to ensure implementation of adequate process controls and execution at each of the assembly locations of a Pb-free assembly 'test vehicle' acceptable to Verizon. Assembly test vehicle solder joint quality shall be validated via comprehensive destructive physical analysis.

An acceptable Pb-free assembly test vehicle must be representative of the technologies and processing (both first pass and rework) used in assembling the Pb-free PBAs to be qualified. The test vehicle must include:

- Representative examples of the range of component types (e.g. package styles, body size, pitch, and I/O count) used in the Pb-free PBAs to be qualified
- The Pb-free solder alloy used in assembling the PBAs to be qualified
- Circuit board construction (size, thickness, number of layers, via spacing, etc.) comparable to that of the most complex PBA to be qualified
- Examples of any specialized parts placement schemes (e.g. full back to back, off-set back to back, very narrow inter-component spacing) used on the PBAs to be qualified
- Use of all soldering methods (e.g., surface mount, through hole, rework, etc.) employed in assembling the Pb-free PBAs to be qualified.

Table 15.1 provides an example of the features of a test vehicle demonstrating the breadth of technology coverage needed to fully represent a typical supplier's mix of Pb-free PBAs.

Features of a Typical Pb-free Assembly Test Vehicle

- 16 x 20 x 0.110 inch, 12 layer, thermally massive board
- BGAs up to 52mm x 52mm with pitch down to 0.8mm
- QFPs with 0.5mm and 0.4mm pitch
- LGAs with 1.0mm, 0.8mm, and 0.5mm pitch
- QFNs to 0.4mm pitch
- Back to back and dual row 0.5mm pitch QFNs
- DIMMS and Brick Power Module through-hole components
- Discretes: 0402s, 0201s, resistor networks, aluminum electrolytic capacitors and Gig-Array connectors
- Back to back and half back to back mounted BGAs
- Range of spacing (3.8mm down to 1.27mm) between BGAs and between discretes to demonstrate rework capability

Table 15.1 - Features of a typical Pb-free Assembly Test Vehicle

A supplier-specific test vehicle features table similar to Table 15.1 shall be completed to provide a record of compliance with the requirements for acceptance of a Pb-free product PBA via demonstrated reliability of the Pb-free test vehicle used in its implementation. This supplier-specific test vehicle features table shall be included in the supplier TCR.

15.3.2 Demonstration of Quality and Reproducibility of Assembly Facility Processes

To demonstrate both quality and reproducibility of assembly processes used, a minimum of five Pb-free test vehicle assemblies shall be built at each location to be qualified. At the macroscopic level, acceptable performance shall be defined as freedom from defects upon visual inspection at 10x magnification. Additionally, the solder joints of representative components from each test vehicle shall be cross sectioned and microscopically examined to confirm:

- Proper wetting of soldered surfaces
- Adequate solder volume
- Appropriate intermetallic formation indicative of a viable solder bond
- Proper registration with solder pads
- Adequate solder ball collapse for BGA devices
- Acceptable level of solder voiding
- Acceptable hole fill for through-hole soldered components
- Freedom from barrel cracking and excessive copper dissolution in plated through- holes
- Freedom from pad cratering

Specific acceptance criteria are provided in Table 6 items 19-30.

In lieu of a specially designed Pb-free assembly test vehicle, the product PBA to be qualified may itself be used as the assembly quality test vehicle. Moreover, if it contains the same range of components/technology found in other Pb-free PBAs it can serve to qualify the assembly facility for those products as well. Since a dedicated, non-product assembly test vehicle can be designed to be representative of a large range of PBAs and can use less expensive components or even dummy components, this usually proves to be a more economically viable qualification alternative.

15.3.3 Assembly Facility Analysis

Successful execution of the Pb-free assembly test vehicle must be accompanied by an assembly facility audit demonstrating the assembly location’s implementation of effective means to ensure proper setup and day-to-day control of key processes critical to high quality Pb-free assembly including:

- paste printing
- parts placement
- SMT reflow
- wave soldering (if used)
- automated inspection (visual and x-ray)
- materials management to ensure proper handling/storage and prevent unintended mixing of Pb-free and SnPb materials (components and solder)

Audit details/documentation shall be made available to Verizon upon request. Successful process audits and test vehicle execution at multiple assembly facilities shall be considered proof of equivalent, high quality assembly capability within the technology and reliability boundaries represented by the assembly test vehicle.

15.4 Mitigation of Pb-free PBA Failure Modes/Mechanisms of Concern

A Pb-free product PBA’s freedom from the principal failure modes/mechanisms of concern to Verizon (as listed in Table 4) may be demonstrated either directly by testing of the PBA as detailed in Section 14 and Table 5 (Option A Qualification Route) or indirectly by suitable evaluation of test vehicles and component test results that are fully representative of the technology implemented in the product PBA as detailed in this Section 15 and Table 6 (Option B Qualification Route). Acceptable methods to demonstrate mitigation of Pb-free PBA Failure Modes/Failure Mechanisms of concern to Verizon for the Option B Qualification route are indicated in Table 15.2 below. Evidence that these concerns are adequately addressed shall be based on review and analysis of supplier-specific practices, procedures, documentation and measurement results included in the completed Table 6 section of the supplier TCR. The last column of Table 6 shall be left blank in the supplier’s qualification report.

Table 15.2 – Pb-free PBA Failure Modes/Mechanisms Addressed by Tests and Evaluations

Failure Mode and/or Failure Mechanism	Acceptable Methods to Demonstrate Mitigation of Failure Mechanisms of Concern				
	Component compliance with tin whisker mitigation, test and acceptance standards	Component compliance with industry MSL tests and acceptance standards	IPC 9701 testing of multiple device package styles and Pb-free solder alloys	Test vehicle evaluation of Pb-free laminates as supplied and as fabricated into representative PB	Qualification of assembly facility/ processes by test vehicle assembly and process control audit
TCE Mismatch			•	•	
Solder Joint Tensile Fracture			•		•
Creep Failure of Solder Joint			•		•
Solder Joint Fatigue Failure			•		
Component Termination Fracture			•		•
Whisker Growth	•				
SMT Attach Defect					•
PB Plated Hole Fracture				•	•
PB Surface Contamination				•	•
PB Surface Leakage				•	•
Foreign Materials/Particles					•
Cracked SMT Component		•			•
Cracks in Solder Joint			•		•
Voids in Solder Joint					•
Solder Mask Defects					•
Open Copper Tracks				•	•
Shorted Copper Tracks				•	•
Lifted Copper Pads				•	•
Electromigration				•	•
Intermetallic Formation			•		•
Solder Joint Embrittlement			•		•
Corroded Component Termination					•

Pb-free PBAs that 1) conform to the technology boundaries of the assembly test vehicle 2) whose components, solder joints and laminate meet the reliability conditions of Sections 15.2.1, 15.2.2 and 15.2.3 respectively and are 3) assembled by a facility qualified per the conditions of Section 15.3 shall be deemed acceptable to Verizon.

15.5 Table 6: Qualification Requirements for Pb-free PBAs – Test Vehicle Evaluation

Detailed 'Option B' requirements for Pb-free PBAs are specified in Table 6 below:

Table 6 – Option B: Qualification Requirements for Pb-free PBAs – Test Vehicle Evaluation

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
Pb-free Compatible Component Requirements					
1.	Thermal compatibility of IC components with Pb-free process / assembly conditions	JEDEC-J-STD-020D	Semiconductor devices shall be capable of withstanding the maximum body temp (as defined by Classification Temp Tc) at which the component manufacturer guarantees the component MSL for Pb-free devices		
2.	Component termination finish tin whisker mitigation	JEDEC/IPC Joint Publication JP002	Termination finish of components used in Pb-free assemblies shall conform to the specified guidelines for tin whisker mitigation		
3.	Tin whisker susceptibility	JEDEC JESD22A121A	Component terminations shall be tested in accordance with indicated standard to characterize potential for tin whisker growth		
4.	Tin whisker acceptability	JEDEC JESD201A	Component termination finishes tested in accordance with JESD22A121 shall not demonstrate whisker growth in excess of the stated Class 2 maximum allowable length • Whisker Length: $\leq 45\mu m$		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
Pb-free Solder Alloy Acceptability/Qualification					
5.	SAC solder alloy composition	This Document	Tin/Silver/Copper (SAC) Pb-free solder alloy must contain at least 3% silver to be qualified by default as having reliability ≥ SnPb eutectic solder		
6.	Pb-free solder alloy thermal fatigue life	IPC 9701A	All Pb-free solder alloys other than SAC having ≥ 3% silver must have IPC 9701a test results showing characteristic life ≥ that of SnPb eutectic solder		
Pb-free Product PB Qualification: Laminate Material Requirements					
7.	FR4 Cure Type (Dicy vs. Non-Dicy) (Not applicable to non-FR4 materials)	This Document	Non-Dicy (phenolic) or proprietary. Must be specifically formulated for Pb-free processing. Dicy materials acceptable only if specifically formulated for Pb-free applications.		
8.	Material fill status	This Document	Filled materials are required for boards greater than0.236 mm (0.093 inches) thick or greater than 12 layers, or containing 2 (or more) ounce internal copper layers		
9.	Decomposition Temp, T_d (5% weight loss by TGA)	ASTM Method 3850 or IPC-TM-650 Method 2.3.40 or IPC-TM-650.2.4.24.6	≥ 325 °C		
10.	Time to Delamination (T-260 °C)	IPC-TM-650 Method 2.4.24.1	≥ 30 Minutes		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
11.	Time to Delamination (T-288 °C)	IPC-TM-650 Method 2.4.24.1 modified per paragraph 6.1 to 288 °C	≥ 5 Minutes		
12.	Glass Transition Temperature (T_g)	IPC-TM-650 Method 2.4.24, TMA, DSC, or DMA Acceptable	> 135 °C for all products > 165 °C for products with more than 10 layers, >6:1 aspect ratio, or containing BGAs		
13.	Z-axis CTE, α_1, below T_g	IPC-TM-650 Test method 2.4.41	< 60ppm at 50% resin content or qualify materials for via reliability/z-axis expansion by using IST, Air-to-Air, or Liquid-to-Liquid thermal cycling compared to baseline material data.		
14	Z-Axis CTE (%) 50 °C - 260 °C	IPC-TM-650 Test Method 2.4.41	< 3.6%		
Pb-free Product PCB Qualification: PCB Test Vehicle Requirements					
15.	Test Vehicle Critical Physical Characteristics	This Document	Test vehicles for demonstrating Pb-free product circuit board reliability/robustness must use the same laminate material and have physical structure of equal or greater complexity (e.g. layer count, via size/pitch, thickness, etc.)		
16.	Resistance to Pb-free reflow induced material damage	This Document	No visible defects (delamination, blistering, etc.) after 6X reflows at 260 °C ±3 °C		
17.	CAF Resistance	IPC0TM-650 Method 2.6.25 or equivalent	No evidence of CAF formation after 6X reflows at 260 °C for closest hole spacing on product PBAs		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
18.	Thermal stability of dielectric const. Dk and dissipation factor, Df	This Document	Change in Dk < 0.20 and change in Df < 0.010 after 6X reflows at 260°C		
Assembly Test Vehicle Qualification Criteria: Initial Assembly					
19.	Test vehicle similarity to product assemblies of highest complexity	This Document	Test vehicle must be physically/thermally representative of the most complex product PBAs to be qualified and present similar Pb-free soldering challenges (e.g. soldering method, joint/component package types, pitch, etc.)		
20.	Solder insufficients and solder shorts	IPC-A-610E	Results of X-ray inspection, automated optical inspection and first article inspection shall meet the acceptance criteria of IPC-A-610E		
21.	BGA and LGA solder joint voids	IPCA-610E	Solder voids in BGA and LGA solder joints must be $\leq 25\%$		
22.	Solder joint physical defects	IPC-A-610E	Solder joint standoff height, ball collapse, alignment, wetting, joint shape, and solder process or shrinkage type voiding identified in cross sectional analysis must conform to IPC-A-610E requirements		
23.	BGA/LGA solder joint Intermetallic growth	Identify thickness and composition of IMC via SEM/EDS at two locations (center and edge/corner) for each BGA cross section	Target IMC (Intermetallic Compound) growth $\leq 4.0\mu m$ after initial reflow		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
24.	Through-hole % solder fill and wetting	Perform metallographic cross sectioning of representative through-hole solder joints	Hole fill and wetting shall meet the requirements of IPC-A-610E		
25.	Copper dissolution in plated through-hole by Pb-free wave solder process	Perform metallographic cross sectioning of representative plated through-hole solder joints to detect deficient copper thickness at the knee	Copper thickness shall be at least 0.0005 inch at the knee following wave soldering.		
Assembly Test Vehicle Qualification Criteria - Rework					
26.	Solder insufficients, solder shorts and BGA voids	IPC-A-610E X-ray inspection	Void content ≤ 25% for all BGAs and LGAs cross sectioned. No solder shorts or insufficients		
27.	Solder joint physical defects	IPC-A-610E	Solder joint standoff height, ball collapse, alignment, wetting, joint shape, and solder process or shrinkage type voiding identified in cross sectional analysis must conform to IPC-A-610E requirements		
28.	BGA/LGA solder joint Intermetallic growth	Identify thickness and composition of IMC via SEM/EDS at two locations (center and edge/corner) for each BGA cross section	Target IMC growth ≤ 8.5μm after rework		
29.	Through-hole % solder fill and wetting	Perform metallographic cross sectioning of representative through-hole solder joints	Hole fill and wetting shall meet the requirements of IPC-A-610E		

Item Ref. #	Parameter/Test Item	Item Source Ref./ Test Procedure	Requirement/ Required Value	Measured/Design Value	Conforms? Y/N/NA Acceptable
30.	Copper dissolution in plated through-hole by Pb-free solder alloy	Cross section to determine copper thickness at the through-hole knee, e.g. junction of barrel and land.	Copper thickness shall be ≥ 0.0005 inch at the knee following rework		

End of Table 6

16 QUICK REFERENCE SUMMARY OF PB-FREE PBA ACCEPTABILITY CRITERIA

Detailed tests and methods for accomplishing qualification of PBAs manufactured with Pb-free solder have been presented in this document. A summary of the processes and criteria used for determining acceptability of these Pb-free PBAs is provided in Table 16.1 below:

Table 16.1 – Summary of Processes and Criteria for Determining Pb-free PBA Acceptability

Item Ref. #	Acceptability of Pb-free PBAs is based on Satisfactory Demonstration of Conformance to the following Criteria	
	Option A – Prescriptive Based PBA Testing	**Option B – Performance Based Test Vehicle Evaluation**
1.	Identification of the specific Pb-free solder alloy and the specific assembly site used to assemble the Pb-free PBAs	Identification of the specific Pb-free solder alloy and the specific assembly site used to assemble the Pb-free PBAs
2.	Analysis of the Technology and Reliability Boundaries used by the equipment manufacturer to verify conformance to (or expansion of) the known Technology and Reliability Boundaries specified in TPR-9307 - Table 4	Analysis of the Technology and Reliability Boundaries used by the equipment manufacturer to verify conformance to (or expansion of) the known Technology and Reliability Boundaries specified in TPR-9307 - Table 4
3.	Analysis of the equipment manufacturer's qualification report or component management practices and requirements for Pb-free components to verify conformance to applicable practices, procedures and requirements of GR-357 – Generic Reliability Assurance Requirements for Components	Analysis of the equipment manufacturer's qualification report, procedures and BOM as needed to verify that the thermal compatibility and whisker mitigation of Pb-free components used conform to the requirements of TPR-9307 Table 6, Items 1- 4

Item Ref. #	Acceptability of Pb-free PBAs is based on Satisfactory Demonstration of Conformance to the following Criteria	
	Option A – Prescriptive Based PBA Testing	**Option B – Performance Based Test Vehicle Evaluation**
4.	Analysis of the physical design and manufacturing practices used by the equipment manufacturer for its Pb-free laminates, PBA design and manufacturing processes to verify conformance to the requirements of GR-78 – Generic Requirements for the Physical Design and Manufacture of Telecommunication Products and Equipment	Analysis of the equipment manufacturer's qualification report or other procedures and requirements as needed for: 1. Pb-free solder alloy composition 2. Pb-free solder joint thermal fatigue life (based on accelerated thermal fatigue testing to the requirements of IPC 9701A or equivalent) 3. Laminate Material properties 4. Test Vehicle properties 5. Test vehicle qualification criteria 6. Test vehicle re-work criteria to verify conformance to the requirements of TPR-9307 Table 6, Items 5 – 14 and 26- 30.
5.	Verification that the equipment manufacturer's component, physical design and manufacturing control requirements are implemented at the PBA manufacturing site by analysis of a manufacturing facilities analysis report	Verification that the equipment manufacturer's component, physical design and manufacturing control requirements are implemented at the PBA manufacturing site by analysis of a manufacturing facilities analysis report
6.	Validation of conformance of functional PBAs or appropriate test vehicles to the applicable test requirements of TPR-9307 – Table 5	Verification of conformance of functional PBAs or appropriate board test vehicles to the test requirements of TPR-9307 Table 6, Items 15 - 18
7.	Assessment of conformance of functional PBAs to the solder joint microstructure and metallurgical requirements of TPR-9307 – Table 5, Item 35	Assessment of conformance of test vehicle solder joint microscopic examinations to the acceptance criteria of TPR-9307 Table 6, Items 19 - 30
8.	Analysis of the equipment manufacturer's Pb-free solder joint steady state FIT rate estimate at 40°C and 90% UCL to determine whether it is comparable to that of SnPb and can thus be ignored in PBA failure rate estimates or whether it has to be taken into account for such estimates.	Analysis of the equipment manufacturer's Pb-free solder joint steady state FIT rate estimate at 40°C and 90% UCL to determine whether it is comparable to that of SnPb and can thus be ignored in PBA failure rate estimates or whether it has to be taken into account for such estimates.

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