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White Paper

Modification of Existing NEBS Requirements for Pb-Free Electronics

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Executive Summary

Thorough review of the relevant NEBS requirements identified several areas of concerns regarding a risk-free transition to Pb-free technology. These areas included

- *Current restrictions on electroplated tin are likely being ignored to some degree*
- *Manufacturing tests need to be revised to take into account higher Pb-free temperatures*
- *More rigorous assessments, including testing and sectioning, of printed board damage is required*
- *Specific guidance must provided to allow system purchasers the capability to assess if sufficient reliability has been demonstrated*

1. Introduction

This document is designed as a discussion on possible modifications or additions to the existing NEBS requirements to ensure sufficient reliability of telecommunications equipment containing Pb-free printed board assemblies. Documents to be reviewed within this objective will include *GR-63, NEBS Requirements: Physical Protection* and *GR-78, Physical Design and Manufacture of Telecommunications Products and Equipment.*

2. Background

The NEBS (Network Equipment-Building System) family of requirements provides standards for telecommunication equipment used in central and remote office locations. As a general rule of thumb, twenty-one documents fall under NEBS

- GR-63-CORE Network Equipment-Building System (NEBS) Requirements: Physical Protection
- GR-1089-CORE Electromagnetic Compatibility and Electrical Safety - Generic Criteria for Network Telecommunications Equipment
- GR-1217 Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware
- GR-1221 Generic Reliability Assurance Requirements for Passive Optical Components
- GR-2930 Network Equipment Building System NEBS Raised Floor Generic Requirements for Network and Data Centers
- GR-2969 Generic Requirements for the Design and Manufacture of Short-Life Information Handling Products and Equipment
- GR-3028 Thermal Management In Telecommunications Central Offices: Thermal GR-3028
- GR-357 Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment
- GR-468 Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment
- GR-63 NEBS Requirements: Physical Protection
- GR-78 Generic Requirements for the Physical Design and Manufacture of Telecommunications Products And Equipment
- SR-3580 NEBS Criteria Levels
- SR-4087 Physical Design Certification of Bare Printed Boards
- SR-4407 Adhesive Certification
- SR-4408 Flux Certification

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- SR-4409 Legend Ink, Marking Ink and Adhesive Label Certification
- SR-4410 Solder Mask, Conformal Coating, and Repair Polymer Certification
- SR-4568 Separable Electrical Connector Certification
- SR-4808 Printed Board Assembly Certification

- SR-4935 Connector to Cable Assembly Certification
- TR-NWT-000930 Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment

For the purposes of Pb-free printed board assemblies, only five documents within the NEBS family seem to be relevant

- GR-63 NEBS Requirements: Physical Protection
- GR-78 Generic Requirements for the Physical Design and Manufacture of Telecommunications Products And Equipment
- GR-2969 Generic Requirements for the Design and Manufacture of Short-Life Information Handling Products and Equipment
- SR-4808 Printed Board Assembly Certification
- TR-NWT-000930 Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment

The NEBS family of requirements is designed to ensure the extremely high reliability of central and remote office equipment is maintained regardless of supplier or design. However, the basis of these test requirements and design rules are based on a foundation of knowledge derived from experience with SnPb-containing printed board assemblies.

The reliability of future central and remote office equipment fabricated with Pb-free solder may be comprised if the current NEBS family of requirements is not modified in some manner to taken into account new risks and new behaviors affiliated with Pb-free printed board assemblies.

To identify potential shortcomings, a mapping of the risks that are new or elevated in Pb-free printed board assemblies to the relevant NEBS requirements is presented in the following section.

3. Risk with Pb-Free Printed Board Assemblies

Based upon results reported in the literature and an understanding of the physics and chemistry of Pb-free materials, the following behaviors are known risks with Pb-free printed board assemblies.

3.1 *Tin Whiskering*

The elimination of Pb from printed board assemblies, as mandated by RoHS legislation out of the European Union, has resulted in the introduction of pure tin platings on components and printed wiring boards. These platings are known to whisker and the propensity and degree of whiskering is currently not predictable or controllable.

3.1.1 The current NEBS response to this issue is as follows:

GR-78, Section 3.3 Materials and Finishes Requirements; Finishes; R3-20 [57]

Electroplated tin finishes subject to whisker growth shall not be used. Proven methods of preventing whisker growth from electroplated tin finishes have included a full reflow of the tin finish, an annealing process applied to drawn tinned copper wire, and codeposition with 2% (by weight) or more, of lead. Where a supplier attempts to meet the intent of this requirement by careful control of manufacturing parameters (e.g., the case of surface mount components where the reflow process may be incomplete), a review of the process shall be available to the Network Operator or its designated representative.

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GR-78, Section 6.1.1.5 Printed Wiring Board Requirements; General; Materials; Conductor Materials and Finishes
Tin shall not be used as a conductor or contact finish unless subjected to an approved reflow process. Tin plating, with a minimum of 2% lead, is acceptable and does not require reflow (see Requirement 3-20).

3.1.2 Potential Risks
The current approach is comprehensive in terms of preventing tin whiskering, but may be unrealistic given the pervasive use of tin plating among component manufacturers. Given the current lack of test requirements to confirm the absence of electroplated tin, it is likely that current and future central office and remote equipment contain electroplated tin.

3.1.3 Recommendations
Additional tests /analyses should be added to confirm the absence of electroplated tin or physical design requirements should be modified to identify acceptable testing methodologies and a broader range of acceptable mitigation strategies.

Confirmation of electroplated tin can be performed using X-Ray Fluorescence (XRF) on critical components. Critical components can be defined by the maximum whisker length and the spacing between leads. For matte tin, the relevant pitch is less than or equal to 0.8 or 0.65 mm. For bright tin, the maximum whisker length is greater than the coarsest pitch of 2.54 mm.

Existent testing methodologies are primarily defined by JEDEC (JESD22A121.01, JESD201, JP002), with influence from iNEMI. DfR is also aware of company-specific requirements. Mitigation strategies are defined and categorized in the recent GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems.

3.2 *Sulfidation of Silver Plating*
The exposure of immersion silver finish on printed wiring boards to high sulfur environments can result in the formation of silver sulfide compounds

3.2.1 The current NEBS response to this issue is as follows:
GR-78, Section 6.1.1.5 Printed Wiring Board Requirements; General; Materials; Conductor Materials and Finishes; R6-8 [178]
Silver shall not be used as a conductor or contact finish. This restriction also applies to the use of silver in conductive polymeric materials used in the manufacture of PWBs, unless acceptable reliability data is provided to the Network Operator or its designated representative.

3.2.2 Potential Risks
If this prohibition on silver finishes is ever lifted, the current test requirement of steam aging, as per section 6.1.3.6, is insufficient
GR-78, Section 6.1.3.6 Printed Wiring Board Requirements; General; Manufacturing; Solderability, R6-49 [219]
All PWBs shall meet the standard solderability requirement per J-STD-00387. All PWBs processed to the point of component assembly shall meet Category 2 solderability requirements of J-STD-003, April 1992. Where multi-stage soldering processes are used, PWBs shall continue to meet this requirement between each soldering process. Category 3 with steam aging shall be used when the storage time can be greater than 6 months. If expected storage times are exceeded, PWBs shall be retested before use.

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In addition, there is some degree of uncertainty as to the ability of 14-day exposure to the current GR-63 Gaseous Contaminants Test Method (Section 5.5.2) to initiate failures observed in field conditions.

3.2.3 Recommendations

This may require some degree of additional research into sulfidation of immersion silver platings.

3.3 *Shrinkage Cracks*

Pb-free solders can be more susceptible to shrinkage cracks during solidification. These shrinkage cracks tend to have minimal influence on reliability accept in the case of non-plated through hole solder joints.

3.3.1 The current NEBS response to this issue is as follows:

GR-78, Section 7.2.2.2 PWB Assembly Requirements; PWB Assemblies – Through Hole Mounted Components; Manufacturing; Soldering - Non-Plated-Through Hole Solder Joints

- R7-188 [606] Non-plated-through hole solder joints to the PWBs of PWB assemblies shall have a solder connection that covers at least 75% of the lead or soldered-in terminal periphery available for soldering.
- R7-189 [607] Non-plated-through hole solder joints to the PWBs of PWB assemblies shall have a solder connection that covers at least 75% of the conductor land available for soldering.
- R7-190 [608] Where leads, wires, or terminals are soldered to non-plated through holes in PWB assemblies, the leads, the wires or terminals, and the conductor path or land to which the soldered connection is made shall all show evidence of wetting; the solder may not be recessed below the surface of the board.

3.3.2 Recommendations

Incorporation of acceptability requirements as per IPC-610, version D, with an additional statement regarding the degree of circumferential cracking.

3.4 *Damage to the components and printed wiring board*

Exposure to the elevated temperatures from Pb-free assembly can and has resulted in the introduction of latent damage to components and printed wiring boards.

3.4.1 The current NEBS response

GR-78 has several sections addressing potential damage to components and printed wiring boards. Section 6.1.3.6 has several requirements regarding cracking, but these specifications seem to apply to printed board manufacturing and not the cracks or damage that could occur after assembly.

Section 6.3.1.1 Printed Wiring Board Requirements; Printed Wiring Boards for Surface Mounting; General Requirements; Materials – Laminates, R6-214 [384]

Laminates used for surface mount PWBs shall be capable of surviving assembly soldering and repair temperature extremes and durations without significant degradation.

Section 6.3.1.2 Printed Wiring Board Requirements; Printed Wiring Boards for Surface Mounting; General Requirements; Materials - Solder Masks, R6-215 [385]

Solder masks used on PWBs for surface mounting shall be capable of surviving assembly soldering and repair temperature extremes and durations without significant degradation.

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Section 7.1.2.2 PWB Assembly Requirements; General; Assembly Design; Components, R7-19 [437]
Since soldering techniques used for surface mount assemblies often subject components to greater thermal stresses than conventional wave soldering techniques, component qualification tests shall be conducted after exposing components for surface mounting to processing temperature extremes (e.g., immersion in molten solder). In view of possible changes due to mechanical stresses, qualification tests for leadless components shall be conducted with the components mounted on a laminate similar to that to be used in manufacturing (e.g., FR-4 laminate).

Section 7.1.3 PWB Assembly Requirements; General; Manufacturing

- **Soldering, R7-86 [504]:** There shall be no charring of PWB assemblies (beyond brown discoloration), as a result of soldering.
- **Solder Masks, R7-97 [515]:** Blistering, cracking, and peeling of solder mask coatings on PWB laminates shall not be allowed after assembly soldering.
- **Mechanical Damage and Defects**
- **O7-109 [527]:** It is desirable that printed wiring board assemblies are free of mechanical damage and defects. However, minor damage and defects can occasionally occur during the manufacturing process.
- **R7-110 [528]:** Damage to PWB assemblies, however minor, shall not affect a significant percentage of product.
- **R7-111 [529]:** The restrictions applied to bare PWBs for mechanical damage, laminate and processing defects shall also apply to the boards of assembled PWBs (see Sections 6.1.3.11 and 6.1.3.12).
- **R7-112 [530]:** Defects such as measling and crazing shall not be propagated because of any soldering operation.

Section 7.3.1.5 PWB Assembly Requirements; PWB Assemblies – Surface Mounted Components; Materials; Solder Masks
As Section 13.2 states, solder masks for use in surface mount assembly processes shall be capable of withstanding processing temperature extremes encountered in such processes.

GR-63 also has a high relative humidity exposure (Section 5.1.13, High Relative Humidity Exposure at 40°C and 90% to 95% for 96 hours with controlled temperature to and from 40°C) and a more complex cycle of varying temperature and humidity (Section 5.1.2, Operating Temperature and Relative Humidity, that could be used to screen for these potential defects, but are unlikely to be successful due to their limited duration.

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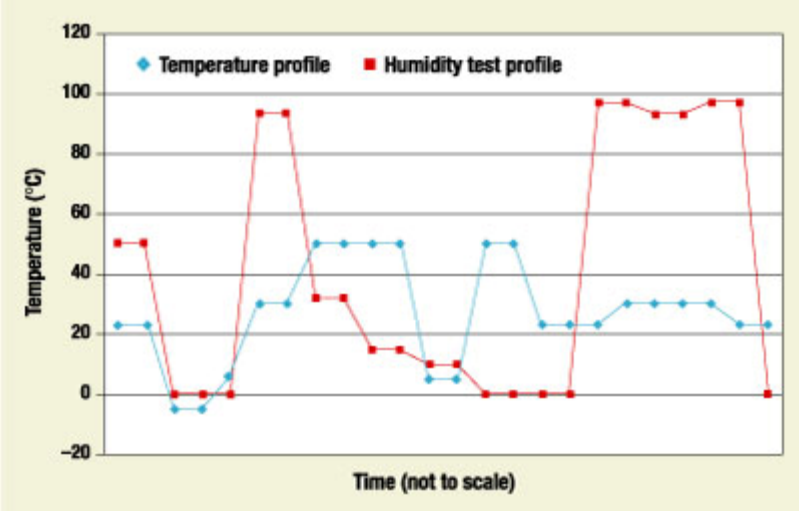

3.4.2 Potential Risks

Current requirements are either too vague or do not provide sufficient testing and analysis to capture the existence of assembly-induced defects, especially those within the printed wiring board.

3.4.3 Recommendations

Additional tests and analyses
Conductive anodic filament (CAF) testing as per IPC TM-650
Cross-sectioning under prescribed areas after preconditioning
Identifying accept/reject criteria

3.5 *Long-Term Reliability (Temperature Cycling, Vibration)*

The degradation behavior of Pb-free solder is known to be different than SnPb solder. How this influences field reliability is dependent upon the design of the printed board assembly, the use environment, and the expected lifetime.

3.5.1The current NEBS response to this issue is as follows:

GR-78, Section 2.2 Requirements for All Products; Electrical and Mechanical Integrity, R2-21 [32]

Where a novel or new technology is introduced by an equipment manufacturer, the manufacturer shall demonstrate the reliability of such technology. Accelerated testing will typically be required; alternate approaches such as mathematical modeling may be acceptable if validity can be demonstrated. Third-party (e.g., supplier) data may be acceptable.

GR78, Section 7.3.2 PWB Assembly Requirements; PWB Assemblies – Surface Mounted; Assembly Design

- Components
  - **IP7-207 [625]** It is desirable that for surface-mount-on-PWB designs, components in leaded packages with leads providing some compliance to accommodate TCE differences between components and substrate are used in preference to the equivalent components in leadless packages.
  - **CR7-208 [626]** Where practical, surface-mount-on-PWB designs that use leadless packages for devices subject to power cycling shall be avoided. This applies to devices that are frequently turned on and off and experience a significant temperature change when switched between quiescent and operating states.

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- Thermal Considerations, R7-209 [627]
  In surface-mount-on-PWB designs, maximum surface mount solder joint temperatures shall be at least 50°C below the solidus temperature of the solder used. This requirement applies to systems under full electrical loading, operating at the maximum ambient temperatures specified in GR-63-CORE[2].

GR-78, Section 7.3.3 PWB Assembly Requirements; PWB Assemblies – Surface Mounted Components; Reliability

- **R7-212 [630]:** The reliability of the particular surface mount technology used on PWB assemblies shall be demonstrated by the equipment manufacturer by means of accelerated testing; where the validity of mathematical models has been satisfactorily demonstrated experimentally, these may be accepted in lieu of actual testing. Reliability test data shall be made available to the Network Operator, or its designated representative, upon request.
- **R7-215 [633]:** For PWB assemblies containing surface mounted components, significant changes shall not be made to PWBs, components, materials, or processes without supporting reliability test data.

GR-78, Section 7.3.4.8 PWB Assembly Requirements; PWB Assemblies – Surface Mounted Components; Manufacturing; Ball Grid Array (BGA) Assembly, R7-238 [656]
The circuit designer and/or circuit pack assembler shall be responsible to the system purchaser to prove that the reliability of the BGAs used on circuit packs is sufficient to function reliably over the life of the product. The proof shall be done using thermal cycling of the component itself, or by analogy to other BGA packages having the same lead configuration.

GR-63 does provide environmental test methods, but none of the test methods are sufficiently severe or of sufficient duration to confirm long-term reliability. At this stage of product acceptance, reliability is presumed to have been addressed in other NEBS requirements that cover subsystems.

3.5.2 Potential Risks
Current requirements are too vague and provide no guidance to the system purchaser or Network Operator as to what is an acceptable demonstration of reliability for Pb-free printed board assemblies.

3.5.3 Recommendations
Identification of models to either predict reliability or to extrapolate reliability from accelerated testing results
Recommendation on accelerated testing

Temperature/Humidity,
Mechanical Shock

1. 5.1.1.1 Transportation and Storage: Low-Temperature Exposure and Thermal Shock .
2. 5.1.1.2 Transportation and Storage: High Relative Humidity Exposure . .
3. 5.1.1.3 Transportation and Storage: High-Temperature Exposure and Thermal Shock .
4. 5.1.2 Operating Temperature and Relative Humidity . .
5. 5.1.3 Operating Altitude . .

5.1.4 Temperature Margin Determination .
5.1.5 Surface Temperature Test Procedures .

6. 5.1.6.1 Infrared Measurement Equipment .

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