A Standardized Reliability Evaluation Framework for Connectors - Stress Levels and Test Recommendations

Holly-Dee Rubin
Nokia
Murray Hill, NJ, USA
Holly.Rubin@nokia.com

Vincent C. Pascucci
TE Connectivity
Harrisburg, PA, USA
vcpascuc@te.com

Jeffrey Toran
Amphenol ICC
Etters, PA, USA

Robert Druckenmiller
Amphenol ICC
Etters, PA, USA

Michael Lipschutz
The Dow Chemical Company
Marlborough, MA, USA

Phil Conde
Dell
Austin, TX, USA

Vasu Vasudevan
Dell
Austin, TX, USA

Jyoti Gupta
Keysight Technologies
Colorado Springs, CO, USA

Yen-Han Oon
Keysight Technologies
Penang, Malaysia

Cindy Han
Wistron
Hsinchu, Taiwan

***Abstract*—The iNEMI Connector Reliability Test Recommendations Project was organized to address the need for standardized reliability qualification methods for connectors. In previous work, the team reviewed current standards and defined connector interconnect tiers. Using existing standards as a basis, a generalized protocol for evaluating connector reliability based on the defined connector interconnect tiers and stresses expected in use was proposed.**

In the current work, the team makes recommendations for specific stress level definitions for connectors used in office/consumer, high-end systems, portable, wireless, and industrial applications. The stress levels are mapped to those expected for connector tier 4. Recommendations are made for test conditions associated with each of the stress levels

In addition, the project group concluded that with some modifications, the EIA 364-1000 standard, Environmental Test Methodology for Assessing Performance of Electrical Connectors and Sockets used in Controlled Environment Applications, can be extended to connectors intended for use in uncontrolled environments. These modifications include adding dust preconditioning, thermal shock preconditioning, and mechanical shock to the test sequences. The group also identified gaps in current standards/knowledge to help guide future improvement in the recommended testing.

***Keywords*—component, connector, reliability**

I. Introduction/Scope

There is a need within the electrical connector industry for a standardized method for assessing reliability. Trends driving the need for harmonized reliability testing include an increase in the number of interconnects found in many systems and the use of electronics in more and more applications across a diverse range of environmental conditions. Currently, several standards [1-4] exist for evaluating connector reliability in various applications. Connectors appropriate for a given application are likely to be tested to different conditions. Without standardized reliability testing of electrical connectors across types and use cases, identifying appropriate connectors for a given application is a major challenge.

In Phase 1 of this project, current standards pertaining to connector reliability were reviewed. The concept of connector tiers was revisited, and industry input gathered to standardize tier definitions. A phase 2 project was proposed to develop recommendations for specific stress levels and test conditions to be used to evaluate expected degradation mechanisms of connectors used in defined application classes [5]. Once developed, these recommendations could form the basis for standardized reliability evaluation procedures for each application class. This paper reports the results of the phase 2 work. Specifically, the team focused on defining test conditions appropriate for the expected field stresses and degradation mechanisms for tier 4 (board-to-board or board-to-subassembly or subassembly-to-subassembly) connectors. The scope includes industrial equipment and the following iNEMI product sectors: office/consumer, high-end systems, and portable & wireless devices. Connector types are limited to separable electronic connectors (including both separable and non-separable ends of the connector) and signal contacts. The scope excludes optical connectors used for mating of fiber optics, connectors intended for power supplies or AC power applications and RF connectors. This paper documents stress levels and reliability test plan guidance and could form the basis for standardized reliability test procedures for tier 4 connectors. The approach taken may be used to define stress levels and test plan guidance for other tiers. It could also be used to increase industry awareness and help guide standards development of testing that would allow designers to more easily compare connectors during initial system design.

The response variable of interest in this paper is limited to low-level contact resistance (LLCR) because it is used to detect most connector degradation mechanisms. Other measurements and recommended tests such as low nanosecond events, contact discontinuity, current induced temperature rise, insulation resistance, dielectric withstand voltage, dimensional stability, etc. are still recommended as required by the relevant standard. Absence of these tests from this paper does not preclude them as a requirement.

II. CONNECTOR TIERS (APPLICATION CLASSES) AND ENVIRONMENTAL STRESS LEVELS:

The connector application classes, or tiers, defined in phase 1 range from on-chip interconnects (tier 1) through interconnections used for long-haul/telecom (tier 7) [5]. Not all levels are applicable to separable connectors. The phase 2 project team focused on developing a reliability evaluation methodology based on tier 4, defined in phase 1 to include board to board connectors. The phase 2 project team further refined the description to explicitly include those connectors used for board to subassembly and subassembly to subassembly interconnection.

In the following sections, stress levels that may be experienced by connectors are defined. The team targeted defining three to five levels for each of the standard environmental stresses used to probe connector degradation mechanisms (i.e. temperature, corrosive gases, vibration, etc.). These stress levels are intended to cover the range of anticipated stresses experienced by a connector independent of its tier. However, only a subset of these levels may actually apply to any given tier. For the specific case of tier 4 connectors, all the generic stress levels apply unless otherwise indicated. Recommendations are made for standard tests associated with each stress level. If the stress levels anticipated to be encountered in use are known, then the guidance in this paper can be used to determine recommended tests to assure the connector will operate reliably. The stress level that most closely matches the application use condition should be selected. If the expected stresses exceed those in one level, the next higher level should be used. Both the stress levels and recommended tests are derived from existing standards whenever possible. While the stress levels, test plans, and test parameters are expected to apply to most connectors used in the in-scope applications, there will always be applications with special test needs that will require agreement between customer/supplier.

III. TEST SEQUENCE RECOMMENDATIONS

EIA 364-1000 [3] contains recommended test sequences that simulate product application conditions and that might activate potential degradation/failure mechanisms such as wear, corrosion, loss of contact force, etc. The sequences are currently defined for assessing electrical connector/socket performance in controlled environment applications. With some modifications, these sequences should also be applicable for uncontrolled environments and thus form the basis for this set of recommendations.

To assess the connectors for application conditions broader than controlled environments, the project team recommends additions to the test sequences in EIA 364-1000 and highlighted in Table 1. The rationale for these additions is as follows.

A. Addition of dust as precondition to test sequences 2 and 3

Because the impact of dust is likely to be increased when a connector is exposed to humidity or vibration, in certain applications it is recommended to add a dust precondition to test sequences 2 and 3. Some dusts are hygroscopic, so in addition to physically preventing contact of mating surfaces, they may accelerate moisture activated failure mechanisms. The precedent for the inclusion of dust preconditioning in these two test sequences can be found in Telcordia GR-1217 [4], which requires dust preconditioning prior to temperature/humidity cycling and vibration testing for connectors intended for use in indoor or outdoor environments for the reasons specifically mentioned above. Test specimen mated condition during the dust exposure should be specified and is dependent on whether the user expects the connector to be exposed in the field in an unmated configuration. Most, but not all, tier 4 connectors are likely to remain mated during field exposure.

B. Addition of thermal shock test as precondition to test sequences 4 and 5

Thermal shock can affect how a connector is seated and can cause physical damage to connector housings. Because many connectors can be expected to experience thermal shock during transportation if not during use, the team recommends adding a thermal shock test as a precondition in test sequences 4 and 5.

C. Inclusion of mechanical shock in test sequence 3

While often not a concern in the application classes currently covered in EIA-364-1000, connectors can experience mechanical shock during operation. It is recommended to add mechanical shock to test sequence 3 since this sequence already includes mechanical testing (vibration) and also because mechanical testing is typically performed in sequence in generic product qualifications.

TABLE 1. RECOMMENDED TEST SEQUENCES

Test Order	**Tests Required for All Connectors**			**Tests for Connectors with Noble Metal Finish**	**Tests for Connectors with Tin Plate (optional for <0.38 um Gold plate)**	**Tests for Connectors with surface treatment or short wipe length (<0.127mm)**	**Tests for Connectors with more than 50 mate/unmate cycles**
	Test Sequences						
	1	**2**	**3**	**4**	**5**	**6**	**7**
1	Contact Resistance	Contact Resistance	Contact Resistance	Contact Resistance	Contact Resistance	Contact Resistance	Dielectric Withstanding Voltage
2	Mate/Unmate Cycles (preconditioning)	Mate/Unmate Cycles (preconditioning)	Mate/Unmate Cycles (preconditioning)	Thermal Shock (preconditioning)	Thermal Shock (preconditioning)	Mate/Unmate Cycles (preconditioning)	Contact Resistance
3	Temperature Life	Dust (preconditioning)	Temperature Life (preconditioning)	Mate/Unmate Cycles (preconditioning)	Mate/Unmate Cycles (preconditioning)	Dust	Mate/Unmate Cycles
4	Contact Resistance	Thermal Shock	Dust (preconditioning)	Temperature Life (preconditioning)	Temperature Life (preconditioning)	Contact Resistance	Contact Resistance
5	Reseating (mate/unmate)	Contact Resistance	Vibration	Contact Resistance	Contact Resistance	Thermal Cycling (disturbance)	Dielectric Withstanding Voltage
6	Contact Resistance	Temp/Humidity Cycling	Mechanical Shock	Mixed Flowing Gas	Thermal Cycling	Contact Resistance	
7		Contact Resistance	Contact Resistance	Contact Resistance	Contact Resistance	Reseating (mate/unmate)	
8		Reseating (mate/unmate)		Thermal Cycling (disturbance)	Reseating (mate/unmate)	Contact Resistance	
9		Contact Resistance		Contact Resistance	Contact Resistance		
10				Reseating (mate/unmate)			
11				Contact Resistance			

IV. STRESS LEVELS AND RECOMMENDED TESTS

A. *Temperature life test*

Exposure to elevated temperature, typically referred to as temperature life or heat age testing, will cause stress relaxation of the contact spring resulting in loss of normal force between the contact spring and opposing mating surface. As normal force is a primary factor in the initial creation and maintenance of the electrical interface, a reduction in normal force due to stress relaxation may reduce the mechanical stability. This can reduce the ability of the contact to resist motion at the interface when subjected to changes in temperature, vibration, or shock which may then create electrical instability due to fretting corrosion in unplated, non-noble plated, or thin noble plated contacts or in noble plated contacts where the plating is damaged. Interface motion may also result in the contact moving onto areas of corrosion or contamination.

When performing temperature life testing the test temperatures are often limited by the possibility of causing degradation mechanisms other than stress relaxation, e.g. damage to a connector housing and degradation of lubricants. The result is a test with a low acceleration rate and thus extended and often impractical test times. To address this, the proposed test conditions utilize the fact that stress relaxation occurs most rapidly early in life. Therefore, the majority of lifetime stress relaxation can be achieved in a relatively short time.

An example of this can be seen in Fig. 1. For this particular brass alloy, a test replicating two years of stress relaxation typically achieves 90% of the relaxation expected after ten years at the same temperature. Testing at a given temperature to a full ten year life equivalence would require an order of magnitude increase in the test duration while causing only minor additional stress relaxation. Due to this behavior, for each operating temperature class condition, it is proposed to have only two lifetimes The first lifetime is a maximum of 8,760 operating hours (1 year continuous operation equivalent). The second lifetime is for applications with greater than 8,760 operating hours up to 87,600 operating hours. The test conditions for operating up to 8,760 hours are based on an actual operation time of 8,760 hours. The test conditions for greater than 8,760 up to 87,600 operating hours are based on operation for 17,520 hours (2 year continuous operation equivalent).

To define the temperature classes the first consideration was to define an upper temperature which encompassed the majority of applications for a tier 4 interconnect. A typical limit for non-high temperature connectors, 105 °C, was chosen [3][1]. Concerning lower temperature applications, since all typical contact materials have minimal stress relaxation at typical room ambient conditions, it was decided to define one application level for all applications with a maximum contact temperature of 30 °C.

For temperatures classes between 30 °C and 105 °C, it was

[1] For high temperature connectors, an additional high temperature limit classification that is not included in [3] is added here.

decided that three temperature ranges would generally ensure parts are tested at a sufficiently severe level while not more severely than necessary. However, even with three test levels between 30 °C and 105 °C, long test durations would be needed because minor changes in operating temperature can significantly affect the rate of stress relaxation and the test time required. For example, the proposed temperature life Class 4 temperature range is 81 °C to 105 °C. Evaluating all parts intended to be rated somewhere within this range and for more than 8,760 operating hours at the upper-temperature limit for the class would require approximately 3 months at a test temperature of 120 °C and six months are 115 °C. Higher test temperature would substantially reduce these test times. But as noted previously, the test temperature is often limited by other factors such as housing temperature ratings.

To address this issue, the creation of two sets of test conditions is proposed: one for typical applications and one for critical applications. Typical applications are defined as those where connectors are rarely if ever used at the upper end of the temperature range of the class and which may not be run continuously. Critical applications are those in which parts are expected to be regularly used near or at the upper end of the class temperature range. Critical applications may also be those in which failure may result in injury or significant cost.

Test conditions proposed for typical applications are based on operating temperatures representing the upper 67th percentile of the temperature classes proposed above, specifically 47 °C, 72 °C, and 97 °C for classes 2, 3, and 4. For critical applications, the test conditions are based on operation at the upper temperature of the class. For Class 1, test conditions are based on operation at the upper temperature of that class, 30 °C, as the times for testing are practical regardless of whether the application might be considered typical or critical and stress relaxation is typically minimal in either case.

An obvious concern in this approach is the potential risk if a connector qualified to the typical application conditions is inadvertently used in a critical application. Fortunately, the risk is generally limited. Consider a comparison of typical brass or Ph-Br (phosphor-bronze) contacts used in the proposed Class 4 operating temperature range (81 °C to 105 °C) and an operating lifetime greater than 8,760 hours. Using the proposed test conditions from the critical application table, stress relaxation would be approximately 61% for common brass contact alloys and 29% for a common Ph-Br alloy. Using instead test conditions from the typical applications table stress relaxations would be approximately 56% for brass and 24% for Ph-Br. Thus, under the typical application class, the brass contact would experience 92% of the expected relaxation that would occur in the critical application conditions. The Ph-Br contact would experience 83% of the expected relaxation that would occur in critical applications.

Having established a set of application classes and lifetimes, specific test temperatures and exposure times could then be established. These were developed using the Larson-Miller model [6]. A material constant of 20 was used as this has often been found to be suitable for most contact brass and Ph-Br alloys.

When selecting the appropriate application class from Table 2 note that maximum operating temperature is the expected temperature of the contact when it is powered and operating within any associated enclosure housing the systems in which it is used. Concerning applications in which the contact may operate at different temperatures depending on loading, the maximum operating temperature typically dominates the total stress relaxation even if representing only a small portion of the operating time. Therefore, in such applications, the application temperature-life level selection should be based on the maximum operating temperature and the expected time at or near that temperature.

1) Gaps

Recommendations for contact alloys other than brass and phosphor-bronze are not included; the appropriate test temperatures and times can be derived by using the Larson-Miller model and appropriate material constants.

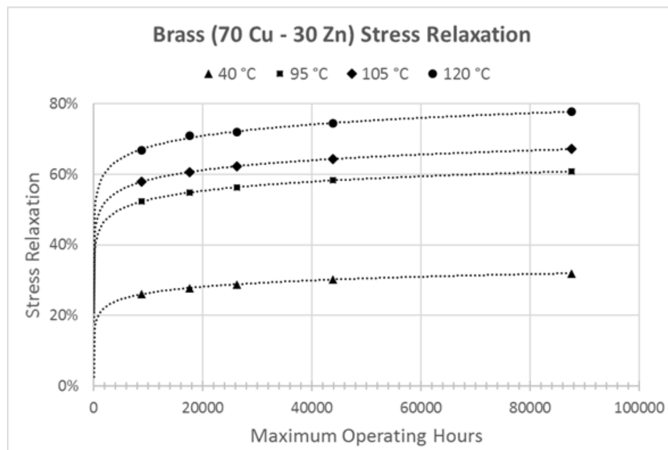

Fig. 1. Stress relaxation of a typical contact brass alloy – data points indicate 1, 2, 3, 5 and 10 years of continuous operation

TABLE 2. TEMPERATURE LIFE TEST RECOMMENDATIONS

Level	**Op. Temp.**	**App. Type**	**Operating hrs ≤8,760**	**Operating hrs >8,760 to 87,600**
1	≤ 30 ºC	Typical Critical	61 hrs, 60 ºC	115 hr, 60 ºC
2	31 ºC to 55 ºC	Typical	220 hrs, 70 ºC 51 hrs, 80 ºC	421 hrs, 70 ºC 96 hrs, 80 ºC
		Critical	787 hrs, 70 ºC 177 hrs, 80 ºC	1527 hrs, 70 ºC 337 hrs, 80 ºC
3	56 ºC to 80 ºC	Typical	577 hrs, 90 ºC 142 hrs, 100 ºC	1115 hrs, 90 ºC 269 hrs, 100 ºC
		Critical	1920 hrs, 90 ºC 456 hrs, 100 ºC	3767 hrs, 90 ºC 879 hrs, 100 ºC
4	81 ºC to 105 ºC	Typical	687 hrs, 115 ºC 352 hrs, 120 ºC	1331 hrs, 115 ºC 676 hrs, 120 ºC
		Critical	2117 hrs, 115 ºC 1069 hrs, 120 ºC	4159 hrs, 115 ºC 2082 hrs, 120 ºC

B. Dust

The purpose of the dust test is to evaluate the ability of the connector contacts to meet electrical performance requirements when subjected to dust. There are three types of degradation mechanisms that potentially may occur when contacts are exposed to dust. Exposure to dry dust may result in

- Excessive contact wear due to the abrasive nature of the "dust" particles.
- Elevated contact resistance if contact mating/unmating cannot successfully remove the dust from the wear track.

When exposed to hygroscopic dust

- Corrosion may occur if the dust absorbs moisture from the surrounding air, which then creates a compound that is corrosive to the top plating, underplate or base metal.

1) Proposed Stress Levels

The stress levels were selected based on a review of relevant IEC and Telcordia standards [7-10]. Ultimately it was decided to simplify/combine into 3 levels:

- Level 1: weather protected (or indoor) locations with precautions to minimize dust. These locations are not close to coarse dust/sand sources and have some temperature and humidity control with humidity typically maintained below 65%.
- Level 2: locations without precautions to minimize dust, close to dust/sand sources, and relative humidity that can exceed 65%.
- Level 3: locations near processes producing sand/dust or locations with high proportions of wind-driven sand or dust in the air and potentially high humidity or moisture condensation.

2) Guidance for the selection of level and type of dust

It is recommended that the dust type (benign or corrosive) be selected according to the level of the application environment for which the connector is designed. Benign dust should be considered for many office environment applications in non-industrial areas. Corrosive dust may be present in certain geographic regions or when equipment is known to be located near sources of corrosive dust, such as some industrial areas.

Where not already required by standards or user specifications, the guidance in Table 3 can be used. Determine the application level as defined in the first column and the type of dust expected in the application (benign, corrosive, or sand). Since dust can be applied either as a preconditioning step or for use in a standard dust test, guidance is provided for both. "Optional" means it is left to the connector manufacturer to decide whether or not to qualify with a dust exposure, or the connector user to decide whether to require this if not already done by the manufacturer. "Recommended" testing is testing recommended by the authors of this paper.

3) Gaps

There is no single specification for dust that can capture all possible dust size distributions and compositions that may be found in the environment. Some specific items missing from current standard dust compositions include

a. Particle sizes < 2um. In equipment that makes use of filters or other means to prevent the ingress of large particles, small particles can predominate.

b. The current "corrosive" dust defined in EIA/ECA-364-91 [11] may not adequately represent the dust composition found in many parts of the world.

c. A literature review is suggested to understand currently known interaction effects of dust concentration, particle size, temperature, and humidity on connector contact resistance. Based on the results of the review, it may be possible to develop proposals for what corrosive dust should be in standards when it should be used, and associated test conditions or to identify research activities needed to either develop or support any proposal.

Corrosive dust compositions are present in both indoor and outdoor environments in some areas of the world and have reportedly caused connector failures [12]. This paper offers suggested guidance on when a corrosive dust composition should be used. Further research and standards development activities are encouraged.

TABLE 3. TEST RECOMMENDATIONS

	Dust Type anticipated (select types anticipated in the environment)			
Level[a]	**Benign**[b]		**Corrosive**[c]	
	Pre-Condition	***Dust Test***	***Pre-Condition***	***Dust Test***
Level 1	Optional		Optional	
Example applications	Business Office, Data Center		Warehouse, Industrial environment	
Level 2	Recommend		Recommend	
Example applications	Ground-Based, Portable Electronics, Transportation vehicles - cabin			
Level 3[d]	Recommend		Recommend	
Example applications	To be defined			

a. Note that several current standards only require benign dust composition.

b. Benign dust per EIA 364-91, A.1

c. Corrosive dust per EIA 364-91, A.2

d For level 3, where driving dust and sand is present, it is also recommended to perform testing such as that in IEC60512-11-8 [13], where LLCR is not the primary response variable.

[2] "Dust" is a generic term used either for a single compound 'abrasive dust' such as SiO_2 or for a mixture of compounds & fibers.

C. *Thermal Shock*

The thermal shock test is used to evaluate connector performance when exposed to rapid temperature changes such as may occur during transportation or normal operation. The primary potential degradation mechanisms are:

- *Contact wear:* micro-motion caused by coefficient of thermal expansion/contraction.
- Physical damage of the connector (housing typically) due to stresses resulting from large internal temperature gradients. Other physical damage may include cracking or rupture of conductors mounted internally to the connector housing, damage to plating, and degradation of crimps.

1) General

The test conditions and parameters below are defined for "air to air" thermal shock exposure.

Examples of situations that could cause sudden air temperature changes to electronic equipment during transportation, storage, or operation include:

- The equipment is moved from an air-conditioned enclosure to outside the enclosure in high temperature or from a heated enclosure in a cold region to outside the enclosure into a cold temperature.
- Equipment is in a non-weather protected environment and subjected to rapid cooling from rain or melting snow.
- Ascent from a high-temperature ground environment to high altitude.

2) Proposed Stress Levels:

Stress levels are defined in Table 4. The levels encompass temperatures expected during transportation/storage and operation. Minimum temperatures arise during transportation and were defined based on specifications that ranged from -40 to -65 °C [10,14, 15]. Maximum temperatures occur during operation, include temperature rises expected at the connector, and are based on some typical maximum temperatures that connector housings can withstand. When selecting the appropriate stress level for a given application, the upper temperature selected should be equivalent to (or close to) the Temperature Life test temperature parameter. Consideration should also be given to whether the materials used in the equipment can withstand short-duration exposure to the recommended hot and cold temperatures.

The thermal shock experienced by a connector may be influenced by the system/equipment mass. Testing per this method is expected to be more severe (typically) than what the connector experiences in the end-use equipment.

3) Recommended Tests:

Recommended tests and test conditions, inclusive of dwell times, are per EIA 364-32[16]. Note that dwell times are dependent on specimen mass.

The recommended test conditions are shown in Table 5. The recommended test conditions for test sequence 2 reflect transportation, storage, and normal operation temperature extremes. If thermal shock is expected to occur during operation, appropriate test condition recommendations still need to be developed but in the interim, use of the Table 4 test conditions is recommended. For test sequences 4 and 5, preconditioning is intended to reflect non-operating transportation/storage conditions and therefore Level 1 is appropriate. The project team recommends further refinement of thermal shock test levels to accurately reflect expected transportation temperature extremes.

4) Gaps

The recommended test condition for transportation induced thermal shock is based on minimum transportation conditions and maximum operating conditions, is similar to current thermal shock requirements such as those in Telcordia GR-1217 and is selected from conditions in EIA 364-32. Given the large Level 1 ΔT of 140 °C (ΔT=max - min temperature), the recommended test conditions may be more appropriate for thermal shock expected in equipment operation in extreme environments. Consideration should be given to use of conditions specific to non-operational transportation such as those provided in IEC 60721-3-2 [14] which have a maximum ΔT of 95 °C. Development of operational thermal shock stress levels and test conditions are also suggested, with consideration for both the number of cycles required during operational life and ΔTs that are more representative of those expected in operation.

There is a lack of guidance on how to decide if in-situ low-level contact resistance measurements should be performed during testing. In-situ resistance measurement is appropriate to consider when operation during thermal shock is a required part of the intended application. If in-situ resistance measurements are required, performance criteria should be adjusted for thermal coefficient of resistance effects.

TABLE 4. RECOMMENDED TEST EXTREMES FOR STRESS LEVELS

Stress Level	Temperatures	Use Case
1	-55 °C to +85 °C	Portable equipment; equipment mounted in weather protected & movable enclosure. Equipment mounted in a non-weather protected environment.
2	-65 °C to +105 °C	
3	-65 °C to +125 °C	
4	Custom	More severe environments requiring harsher testing than those above.

TABLE 5. NUMBER OF CYCLES

Stress Level	Test condition	Comment
1	I	-55 °C to +85 °C temperature range, minimum 5 cycles
2	II	-65°C to +105°C temperature range, minimum 5 cycles
3	III	-65°C to +125°C temperature range, minimum 5 cycles
4	Custom	To be defined in the referenced connector specification, customer specification or industry association specification.

[3] Rapid temperature change is considered to be 'air temperature change rate >10C/minute.

D. Vibration

Vibration testing is used to evaluate the electrical and mechanical performance of connector contacts and housings when subjected to vibration. If a connector is susceptible to contact interface motion within the expected vibration range of the use conditions, then a large number of interface motion cycles will occur. Resulting degradation typically occurs rapidly leading to failure during the vibration test or failure in subsequent testing where damage to the interface can make the contact susceptible to degradation caused by other stresses. The primary degradation mechanisms are:

- *Wear:* Vibration may create movement at the contact electrical interface resulting in wear through the surface plating layer(s). Exposed lower plating layers or the contact base metal typically do not provide an optimized contact interface relative to the actual contact area and corrosion protection.
- *Fretting Corrosion:* Cyclic motion on a non-noble metal surface can cause a buildup of corrosion products that can increase contact resistance. It is most often associated with, though not limited to, tin plated contacts. Fretting corrosion can also be associated with thin noble metal plated contacts where the noble plating has been damaged and the lower non-noble plating layer(s) or the base metal is exposed.

1) Proposed Stress Levels and Recommended Tests

Table 6 provides guidance for vibration testing of connectors. Use classes are based on a combination of amplitude and frequency range, e.g. light amplitude/mid-frequency. Typical applications which may be representative of the use classes are shown. Knowledge of the actual amplitude and frequency range expected at the intended location of the connector mounting should guide the selection of the appropriate use class. This is an important consideration as even with a single source of vibration the vibration levels at various locations within a piece of equipment will vary due to stiffness at specific enclosure locations, resonant frequencies, etc. Guidance for test durations is provided in the test specifications listed. Test durations are typically limited to 15 minutes to 8 hours in each of three mutually perpendicular axes.

Note that connector vibration tests are not considered to be accelerated tests from the perspective of LLCR stability. Performing vibration at tests at amplitudes significantly greater than expected use conditions or at frequencies significantly outside of expected use conditions may cause connector failures which will not normally occur in actual use.

NOTE: These are standard profiles that may not be appropriate for all applications. Many industry groups (e.g. automotive, aerospace) have created customized test profiles that are tailored specifically for applications in those industries.

TABLE 6 STRESS LEVELS AND RECOMMENDED TEST CONDITIONS

Stress Level (Amplitude Category)		**Frequency / Type**		
		Low Frequency Sine	***Mid Frequency Random***	***High Frequency Random***
Level 1 (Light)	***Example Application***	Industrial Rotating Machinery - Light Vibration or Equipment Mounted Adjacent to Heavy Rotating Machinery	Business Office, Data Center - Light Vibration	Transportation Vehicles - Passenger Cabin
	Test Condition	IEC 60068-2-6 [17] 10-55 Hz, 0.015-inch DA, 2 hrs / axis	EIA-364-28 [18] TC VII, Letter B 1.6 g, 15 min / axis 20-500 Hz	EIA-364-28 TC V, Letter A 5.4 g, 3 hrs / axis 50-2000 Hz
Level 2 (Moderate)	***Example Application***	Industrial Rotating Machinery - Moderate Vibration	Business Office, Data Center	Transportation Vehicles - Moderate Vibration
	Test Condition	IEC 60068-2-6 10-55 Hz, 0.03-inch DA, 2 hrs / axis	EIA-364-28 TC VII, Letter D 3.1 g, 15 min / axis 20-500 Hz	EIA-364-28 TC V, Letter C 9.3 g, 3 hrs / axis 50-2000 Hz
Level 3 (Severe)	***Example Application***	Industrial Rotating Machinery - Severe Vibration	Ground-Based, Portable Electronics, Rough Service - Commercial	Transportation Vehicles - Engine Compartment[a]
	Test Condition	IEC 60068-2-6 10-55 Hz, 0.06-inch DA, 2 hrs / axis	EIA-364-28 TC VII, Letter E 4.9 g, 1 hrs / axis 20-500 Hz	EIA-364-28 TC V, Letter G 23.9 g, 4 hrs / axis 50-2000 Hz
Level 4 (Extremely Severe)	***Example Application***	Unbalanced Rotating Machinery	Ground-Based, Portable Electronics, Rough Service – Military[a]	High Performance Military Aircraft[a]
	Test Condition	IEC 60068-2-6 10-55 Hz, 0.12-inch DA or 10 g's, whichever is less, 2 hrs / axis	EIA-364-28 TC VII. Letter F 6.9 g, 2 hrs / axis 20-500 Hz	EIA-364-28 TC VI, Letter J 43.9 g, 8 hrs / axis 50-2000 Hz

[a.] These applications are out of scope for this paper and are included in table 6 for completeness only.

E. Mixed Flowing Gas

The mixed flowing gas (MFG) test is used to determine the corrosion susceptibility of connector contacts exposed to atmospheric pollutants, specifically corrosion of any exposed underlying non-noble metallization of noble metal plated contacts.

1) Proposed Stress Levels:

The stress levels generally quoted from AMP EN148-91 [19] are derived from the Battelle classes [20] and are based on connector application locations where the corrosion mechanisms described for each of the Battelle classes are anticipated to occur:

a) Level 1: Benign, non-industrial business-office and equipment environment, with good atmospheric control, such as by continuous air-conditioning and filtered air re-circulation.

b) Level 2: Typical conditions in business offices, control rooms, and telephone exchanges that are associated with light industrial areas, or where air-conditioning and other environmental controls are not operating in an efficient or continuous manner", or where high humidity levels are anticipated within the electronic equipment enclosure.

c) Level 3: Industrial and related locations, including many storage areas, where moderate amounts of pollutants and particulates are present in poorly controlled, uncontrolled, natural outside air-cooled environments, environments with evaporative cooling systems, or within equipment enclosures such as washing machines where high humidity levels and corrosive environments may be anticipated.

d) Level 4: Extremely corrosive heavy-industrial and/or highly polluted locations (for example paper mills, bleaching plants, and high-sulfur chemical and sewage treatment facilities), where the combined effects of combinations of environmental corrodents - as well as high humidity - can rapidly destroy the integrity of precious metal finishes and produce extremely heavy tarnish films on some base metal surfaces.

2) Recommended Tests and Test Times:

The recommended tests and test times are in Tables 7 and 8. The acceleration factors used in developing the test durations are based on the original Battelle Class 2 and 3 conditions developed with data from corrosion studies of European and North American environments in the 1970's and 1980's. The addition of sulfur dioxide to the test gas mixture increased corrosion rates and the acceleration factors should be revisited.

3) Gaps

a. Class 3a test times and conditions may be insufficient to represent actual corrosion rates and mechanisms in areas of the world with high concentrations of reduced sulfur in the atmosphere [22] such as India and the Asia-Pacific region.

b. Acceleration factors for Ag finishes are not well developed. The acceleration factors used in the standards are based on years of data correlating field corrosion rates with test corrosion rates exposure, primarily using gold plated contacts [23].

TABLE 7. RECOMMENDED TESTS

<table>
<tr><th>Stress Level</th><th>Test</th><th>Comment</th></tr>
<tr><td>1</td><td>Not applicable</td><td>No test needed because no corrosive degradation from gaseous contaminants such as H_2S, SO_2, NO_2 is expected</td></tr>
<tr><td>2</td><td>EIA 364-65 [21] Class 2a</td><td rowspan="2">MFG testing required for:
a) Gold finishes irrespective of the underplate.
b) Pd, PdNi: though not included in the Battelle study Pd has similar nobility to gold and Pd alloy plating systems have similar corrosion mechanisms
Re Ag: EIA test conditions are derived from those developed by Battelle Columbus Laboratories to replicate corrosion processes of contacts with gold plating systems. No correlation has been demonstrated between the corrosion of Ag plating systems in these MFG tests and the corrosion expected in typical application environments where Ag platings will be directly attacked by any Cl_2 or H_2S in the use environment.</td></tr>
<tr><td>3</td><td>EIA 364-65 Class 3a</td></tr>
<tr><td>4</td><td>Custom</td><td>Contacts unlikely to survive this environment and protective measures required; test recommendations depend on the measures selected.</td></tr>
</table>

TABLE 8. RECOMMENDED TEST TIMES

Field Life	5 yr	10 yr
Class 2A test time (hrs) (From EIA 364-1000)	168	336
Class 3A test time (hrs) [24]	240	480

F. Temperature Humidity Cycling

This test is used to evaluate the effects of humidity and temperature cycling on electrical connectors including stress induced on the housing materials, contact corrosion, and micro-motion at the contact interface. The high humidity levels are used to determine the potential effects of moisture absorption on the housing materials. This could lead to dimensional changes and physical, mechanical, and electrical isolation degradation. The temperature cycling may produce motion and dimensional changes caused by thermal expansion and contraction. This may allow moisture into areas that were previously partially sealed. These dynamic effects can potentially initiate corrosion at the contact interface.

1) Stress Levels and Recommended Tests:

Recommended stress levels and associated tests are in Table 9. Stress levels are broadly defined based on use in indoor or outdoor environments and under condensing or non-condensing conditions.

TABLE 9. STRESS LEVELS AND RECOMMENDED TESTS

Stress Level and Description	Recommended Test
Level 1: Equipment located in an indoor environment (ex: office) with good control on the overall environment. Located in noncondensing environments with <65%RH	EIA-364-31 [25], Method VIII, (24 cycles)
Level 2: Equipment located in an indoor/outdoor environment (more of an industrial environment) where there may be some environmental controls but not tightly maintained. Probably no direct exposure to moisture. Located in noncondensing environments with ≥65%RH	EIA-364-31, Method VII, Test Condition G (500 hrs)
Level 3: Equipment located in an outdoor environment with no temp/humidity controls. Wide ranges of temperature and humidity. Possible direct exposure to condensation moisture. Located in condensing environments	EIA-364-34[26], Test Condition C (504 hrs)

G. *Durability/Endurance(Mate/Unmate Cycles)*

The purpose of durability testing is to confirm that the physical integrity of the connector and/or socket is maintained after experiencing the number of mating/unmating cycles for which the connector and/or socket is designed to withstand during its lifetime.

1) Proposed Stress Levels

Table 10 describes the recommended stress levels. These were derived from EIA-364-09[27], Telcordia GR-1217 and a review of requirements across a range of applications and reflect the anticipated number of mate/unmate cycles expected during use.

2) Recommended Tests

Testing should be per EIA-364-09. The number of mating/unmating cycles should be commensurate with the number of cycles the connector and/or socket is expected to experience in its application during its useful life. While Level 1 or Level 2 stress will apply for most tier 4 connectors, there are occasional applications exceeding Level 2 requirements.

When required as a precondition, preconditioning and subsequent reseat requirements should be per EIA 364-1000.

a) Preconditioning: 5 cycles should be used for level 1, 20 cycles for level 2, and 50 cycles for level 3. Reseating should use 3 cycles for all levels.

b) Reseating: Should use 3 cycles for all levels.

Additional details about the test procedure, equipment, test specimen preparation, and test fixtures can be found in EIA documents.

TABLE 10. RECOMMENDED TESTS

Level	Number of Mate/Un-mate cycles
Level 1	25
Level 2	200
Level 3	>200[a]

[a.] number of test cycles to be determined by the expected application.

H. *Thermal Cycling*

The purpose of temperature cycle testing of electrical contacts and connectors is to evaluate the stability of the contact electrical interface when subjected to thermally driven expansion and contraction of the connector body and contacts. Mismatch in thermal expansion coefficients between connector materials may lead to micro-motion between the contact surfaces. Increased contact resistance may then result from fretting corrosion or a shift in the contact interface into an area with non- conductive contaminants or environmentally caused corrosion. Note that the temperature cycling recommendations do not include considerations for connector body solder attachment to printed circuit boards. IPC9701[28] can be referred to for solder attachment reliability evaluation.

1) Proposed Stress Levels:

One factor in defining use levels is the magnitude of the application temperature range or ΔT. Also, considered are the actual maximum and minimum temperatures of operation. These can affect the stress relaxation of the contacts and mechanical properties of plastic housings. These two factors were considered in conjunction with a review of various existing specifications providing guidance on operating and temperature cycling application classifications and related test conditions [1, 7-9, 28, 29] to define the four application levels in Table 11. Note the term "ambient temperature" refers to the temperature of the immediate surroundings of the connector. When in operation, most connectors are used within some type of enclosure with other electrical devices, therefore the connector ambient temperature is typically higher than the temperature outside of the enclosure.

a) Level 1: Indoor applications with good temperature control and thus having minimum temperatures above 10 °C. Ambient temperatures near the connector when in operation are typically below 55°C.

b) Level 2: Indoor applications with limited or no temperature control or outdoor locations in mild environments. Ambient temperatures near the connector will range from -15 °C to 55 °C.

c) Level 3: Outdoor locations without temperature controls. Ambient temperatures near the connector may range from -40 °C to 75 °C.

d) Level 4: Outdoor locations without temperature controls and significant potential for elevated temperatures due to system internal heating. Ambient temperatures near the connector may range from -40 °C to 95 °C.

When evaluating the expected maximum temperature in the application, the effect of current induced heating of the contacts must be considered. In applications with limited air circulation, a power contact operating at full current rating may have a temperature 30 °C or more above the ambient temperature near the connector.

2) Recommended Tests:

The recommended tests in Table 11 are derived from EIA/ECA 364-110[30].

TABLE 11. RECOMMENDED STRESS LEVELS

Temperature (°C)	Application Level				Comments
	1	*2*	*3*	*4*	
Lower Temperature	15	-15	-40	-40	500 cycles min Temperature profile per standards such as EIA/ECA-364-110
Upper Temperature	85	85	105	125	
ΔT	70	100	145	165	

I. Mechanical Shock

The mechanical shock test is used to evaluate connector performance after mechanical shock due to transportation or normal operation. Potential degradation mechanisms are:

- Contact wear: motion caused by the shock (e.g. partial mating/unmating).
- Physical damage of the connector, (e.g. housing cracking or contact deformation).

1) Proposed Stress Levels:

Stress levels are loosely based on IEC 60068-2-27 [31] severities but grouped to maintain the number of stress levels between 3 and 5 and to align with example use cases. Typical use cases associated with each level are included for reference in Table 12.

Mechanical shock testing is usually defined at the system level. The shock experienced by a connector is very dependent on system design. The shock levels provided here are starting points that can be used to determine initial suitability for use. Ultimately a system test by the connector manufacturer or user is required.

2) Recommended Tests:

Testing should be per EIA 364-27[32] to the maximum acceleration needed for the stress level range expected to be applicable for the connector in its application. Table 13 defines recommended test conditions at a maximum shock level for stress levels 1 - 3. All test conditions cited in the table specify a half-sine pulse which is the most general type of shock pulse across a wide range of use cases.

TABLE 12. MECHANICAL SHOCK STRESS LEVELS

Level	Acceleration	Example Use Case
1	10-30g	Stationary Computer and Communications Equipment in Office, Data Equipment Closet
2	>30-50g	General Purpose Industrial, General Purpose Land Transport and Land-Based Equipment; portable computers and communications equipment
3	>50-100g	Heavy Industrial, Harsh Transportation, Other Harsh Environment
4	>100g	More severe environments requiring harsher testing than those above

TABLE 13. TEST CONDITIONS

Stress Level	Test condition	Comment
1	H	Test condition H = 30 g acceleration maximum; 1 m-sec pulse; 18 shocks total (3 positive & negative in each of 3 perpendicular axis).
2	A	Test Condition A = 50 g acceleration; 11 m-sec pulse; 18 shocks total, (3 positive & negative in each of 3 perpendicular axis).
3	C	Test condition C = 100 g acceleration; 11 m-sec pulse; 18 shocks total, (3 positive & negative in each of 3 perpendicular axis).
4	Custom	To be defined in the referenced connector specification, customer specification or industry association specification.

V. CONCLUSIONS AND FUTURE WORK

The methodology for connector reliability assessment proposed in phase 1 [5] was developed further for tier 4 connectors by defining stress levels and associated test conditions, all of which are based on existing standards. With some modifications, the test sequences recommended in EIA 364-1000 can be extended to connectors intended for use in uncontrolled environments. A reliability evaluation for tier 4 connectors is suggested that consists of the revised test sequences with test levels based on the expected stress levels.

Gaps identified during this work provide an opportunity for additional activities. These potentially include defining a test vehicle for proof of concept of the defined methodology and/or extending the approach to other connector interconnect levels. Other recommended activities include additional research on corrosive dust impacts on connector reliability, conducting a literature survey to understand currently known interaction effects of dust concentration, particle size, temperature, and humidity on connector contact resistance, developing MFG tests/conditions that better predict corrosion susceptibility in the global market and corrosion mechanisms specific to silver platings, developing recommended stress levels and test conditions to reflect operational thermal shock, and developing a list of specialty tests with accompanying guidance for their use.

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