

ISSUE PAPER

Reliability Assessment of Lead-free Electronics in the Aerospace, Defense and High Performance Electronics Industries

Pb-free Electronics Risk Management (PERM) Consortium Steering Committee
July, 2010

PERM RECOMMENDATIONS

The Pb-free (Lead-free) Electronics Risk Management (PERM) Consortium established a task team to develop a lead-free electronics reliability assessment document for the aerospace, defense and high performance (ADHP) industries. The team accessed the best technical information, research results and available data, and consulted with all the leading experts in the field, both within and outside the ADHP industries. Based on their work the PERM Steering Committee found that:

> The technical knowledge and data necessary to perform quantitative reliability assessments for ADHP lead-free electronic systems do not yet exist. Based on our current state of technical understanding, the Steering Committee concludes that the aerospace, defense and high performance electronics industries do not presently have the technical knowledge or data necessary to provide a level of confidence in reliability assessments for lead-free electronics equal to that currently available for traditional tin-lead electronics[1]. It is premature to rely solely on MIL-STD-810, MIL-HDBK-217, and RTCA DO-160 for qualification of systems containing lead-free assemblies in critical, high-reliability, harsh environment applications without rigorous assessment of application requirements[2].

[1] This conclusion is stated emphatically in the Preface to the Phase I Report of the Lead-free Manhattan Project (ACI Technologies, Inc., 2009, All Rights reserved under government contract no. N00014-08-D-0758), *"It is the judgment of the team that the use of Pb-free electronics in products whose life-cycle includes operation in and through harsh environments, poses technical risks that can lead to degraded reliability and reduced lifetimes. Quantification of these technical conclusions with valid statistical confidence bounds remains a gap."*

[2] The attached Appendix lists some, but not all, of the methods that could be used to mitigate program risks.

Lead-free electronics can impact avionics system reliability in ways that are both quantifiable and non-quantifiable. The two basic reliability issues are: (1) potentially higher probability of failures due to tin whiskers in applications involving pure tin finishes on part terminations, and (2) reduced solder joint reliability in applications employing assembly alloys with significantly different material properties than the traditional tin-lead alloys.

With currently available scientific knowledge and data it is difficult, if not impossible, to quantify either the causes or the effects of tin whiskers on avionics system reliability; thus the current industry consensus for assuring system reliability with respect to tin whiskers is to document the methods used to mitigate their effects. This approach is similar to that taken for aerospace software reliability[3].

The traditional operating reliability metric for conventional tin-lead electronics is thermal cycling performance, which coincidentally is an area where lead-free solder assemblies tend to do well. But for lead-free electronics this is a misleading reliability indicator because application failures for lead-free circuit card assemblies are at least as likely to be a result of the vibration and mechanical shock environment. The industry-wide effort to improve performance in this operational arena is largely responsible for the continuing introductions of new lead-free solder alloys. Solder joint reliability traditionally has been quantified in reliability predictions for aerospace, defense and high performance electronics. The task team's specific findings include:

1. Currently, there are up to five "candidate" lead-free assembly solder alloys that are potential replacements for tin-lead alloys. This may change as the commercial electronics supply chain (which is beyond ADHP control) responds to market pressures. There is no consensus that any of these solders will emerge as the "winner." Since the ADHP industries must depend on various supply chains at lower levels, it is likely that we always will be using more than one lead-free solder alloy.
2. Most of the "candidate" solder alloys are based on the tin-silver-copper (SAC) system. The SAC alloys are ternary near-eutectic or eutectic metal alloys that tend to exhibit precipitation hardening qualities. Thus their structural, thermodynamic and mechanical properties can vary significantly from one another and also vary over time.
3. Based on the above, the existing data from lead-free electronics reliability research requires a deep technical understanding in order to interpret them for reliability assessment purposes. Also, much of the early reliability research was conducted before the structural metallurgy differences were well understood and its relevance to reliability prediction may be limited.
4. There is very little information, or data, regarding reliability of lead-free electronics system performance in ADHP applications.
5. The currently available reliability models for lead-free electronics reliability quantification are all based on those developed for tin-lead. There is a growing consensus among technical experts that they are not applicable to lead-free electronic systems, especially for ADHP applications.
6. Available data from lead-free electronics research indicate that the failure rates of lead-free assemblies are not constant, in significant contrast to the traditional constant failure rate assumption used almost exclusively for tin-lead assemblies.
7. The effects of combined environments, e.g., thermal cycling and vibration, have never been well understood, even for tin-lead systems. This was not a serious concern for tin-lead systems because there is a huge bank of successful performance data that gave confidence in the existing level of understanding. This is not the case for lead-free electronics.

[3] RTCA/DO-178B, "Software Considerations in Airborne Systems and Equipment Certification."

Appendix

Listed below are some, but not all, methods that could be used to mitigate program risks related to lead-free electronics.

- Careful tracking of printed circuit board and lead-free materials
- Careful accounting of solder processing including cool down rates and a metallurgical quantification of the as-solidified solder metallurgy
- Comparison between the qualification levels and the use environments in vibration and shock
- Reliability monitoring with periodic inspections including verification of whisker mitigation methodology effectiveness
- Requiring cross-sectioning after qualification to ensure that no pad cratering occurred
- Require periodic metallurgical examination of fielded hardware to verify the state of solder aging
- Verification and monitoring of use environments
- Purchasing extra spares
- Developing environmental stress screening protocols that will catch manufacturing defects without substantially reducing product life
- Performing long term reliability growth testing in less accelerated environments
- Evaluating not only safety requirements, but also dispatch and availability requirements
- Implementing special rework and repair infrastructure to avoid alloy mixing
- Planning on re-qualifying "five-year old fielded hardware" in the future
- Planning for non-repairable assemblies