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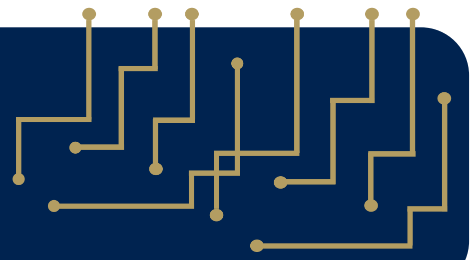

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American Competitiveness Institute
One International Plaza
Suite 600
Philadelphia, PA 19113
(610) 362-1200 • **FAX:** (610) 362-1290
HELPLINE: (610) 362-1320
WEBSITE: www.empf.org
www.aciusa.org

The EMPF is a U.S. Navy-sponsored National Electronics Manufacturing Center of Excellence focused on the development, application, and transfer of new electronics manufacturing technology by partnering with industry, academia, and government centers and laboratories in the U.S.

EMPF Director
Michael D. Frederickson
mfrederickson@aciusa.org

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GEIA Program Manager's Handbook

The RoHS regulation, adopted by the European Union, restricts the use of Lead (Pb) along with five other materials and chemicals from electronic products, and the electronics industry has until July 2006 to become compliant. While there are exemptions for the defense and perhaps aerospace markets, the greatest challenge to these sectors comes from their suppliers. Major electronic component manufacturers and sub-system producers are already using or in the process of integrating lead-free materials. Lead-free technology has proliferated across all electronics products and is effecting product manufacturing, reliability, rework and the sustainment of aerospace and defense programs. Thus, the question looms - How does the introduction of lead-free materials affect aerospace and DoD programs requiring high-performance and highly reliable electronic products?

Lead is a key ingredient of electronic solders and electronic component terminations. The elimination of this element is causing a significant shift in the way electronics have been manufactured, repaired and utilized over the past 50 years. This shift has caused major concerns in the program management and acquisition community, particularly the DoD and aerospace sectors. At the PM level there has been a great need for information, guidelines and criteria on how to address the effects of lead-free technology.

With a number of industry groups and technical bodies coming up with standards and handbooks to address the various technical issues arising from lead-free materials, processes and products, an Aerospace / DoD-wide approach to the transition was deemed to be highly valuable.

The Aerospace Industries Association (AIA), the Avionics Maintenance Conference (AMC), and Government Electronics and Information Technology Association (GEIA) formed a joint working group, LEAP (Lead-Free in Aerospace Project), with the express purpose of generating a series of international industry standards for the use and handling of lead-free solder and components in military and aerospace applications.

These documents are specifically targeted towards Performance Standards (GEIA-STD-0005-1), Technical Guidelines (GEIA-HB-0005-2), Risk Mitigation for Tin Whiskers (GEIA-STD-0005-2) and Program Management and Systems Engineering Guidelines (GEIA-HB-0005-1). The conceptual organization and scope of these documents is as illustrated in Figure 1-1.

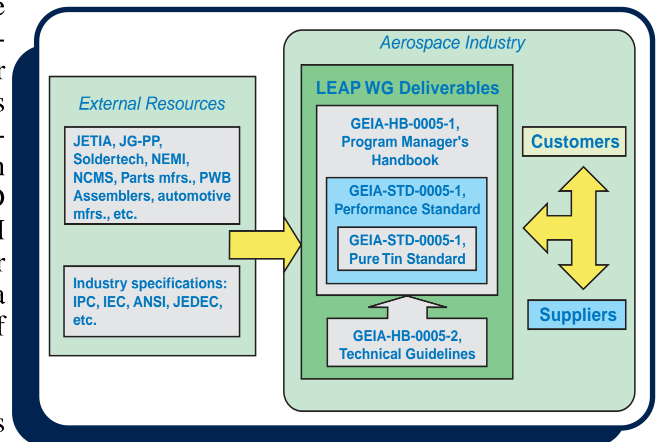

Figure 1-1 – LEAP Organization Concept

The Program Management/Systems Engineering Management Guidelines for

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NAVY MANTECH
manufacturing technology program

GEIA Program Manager's Handbook

(continued from page 1)

Managing the Transition to Lead-Free Electronics, GEIA-HB-0005-1, (The Handbook) is intended to educate program managers and system engineers in the Aerospace industries and in the Defense Acquisition Community on the issues and concerns associated with the transition from tin-lead to lead-free solder processes.

The Handbook Organization

The handbook is organized into sections, which include the discussion of major topics and programmatic issues associated with the introduction of lead-free technology in new and existing programs. This document provides a high-level framework for bringing together lead-free issues and allows one to take a stepwise approach to evaluating the impact of lead-free technology. The following major sections are included in this document:

General Discussion of Program Management Concerns

This includes a brief discussion of several concerns raised by the implementation of lead-free technology. The technical concerns are: reliability, configuration control, risk management, effects of tin whiskers, repair, rework and maintenance. The programmatic concerns are: cost, parts obsolescence, quality, contractual language and existing program constraints. A matrix of reliability concerns at the program level is described in Appendix A.

Requirements Definition

To assess the impact of the lead-free transition, the handbook recommends re-evaluation of program requirements with respect to customer requirements, WEEE/RoHS Directives, prime contractor requirements and elements required for contractual authorization.

Environmental Consideration

The handbook recommends that Program Managers evaluate the use environment, storage and transport conditions, and the definition of criticality to assess performance of lead-free solders in these conditions and to understand the possible differences in solder behavior.

Decision Criteria

The recommendation of several decision steps and criteria are provided as guidance to Program Managers. These include checklists to assess supplier's compliance to GEIA Performance Standard (Appendices C and D) along with obtaining and evaluating lead-free performance plans (LFSPP) from the supplier.

Re-qualification Test/Plan

A recommendation to evaluate the product to determine if the transitioning product should be re-qualified, delta qualified or accepted by similarity.

Rework/Repair and Maintenance

The document recommends obtaining rework/repair procedures from the supplier along with maintenance and training documentation.

Risk Management

The document recommends that the Program Managers identify, analyze and mitigate program level risk associated with transition to lead-free processes.

Cost

Recommends that the Program Manager should conduct a program cost impact analysis with respect to lead-free transition, including risk management, delta qualification impact, rework/repair/maintenance impact, warranties and schedule impact.

This handbook presents a good starting point for program managers and provides a framework to bring together all high-level program related aspects of lead-free. It highlights technical and programmatic areas for review and generates a discussion of program life-cycle phases among program team members. Checklists provided in the Appendices C and D are very useful and offer a detailed view of how current and future programs will be affected.

The handbook provides a schematic approach to assess the impact of lead-free technology with the topics described in an advisory fashion rather than as a rulebook. Tasks are presented from a high-level programmatic point of view and do not provide too many details at the practice level. Translation of high level tasks into practice level tasks can be better accomplished in a training format, which may be beyond the scope of this document. Lead-free technology is still in its infancy with regards to large-scale usage and the technical information required to implement many programmatic aspects is not yet complete. As a result, a specific action plan regarding risk matrix parameters is not yet available. Every program has a different scope and diverse needs, which need to be taken into account to further solidify actions at a practice level.

The EMPF is actively involved in assessing lead-free technology and its impact on DoD hardware, as well as taking an active role in designing and developing technical and program related courses and seminars to keep the DoD and industry personnel abreast of changes occurring in electronics manufacturing. In this transitional period, the Program Manager’s Handbook should be treated as a living document that will be updated as substantiated information and data become available.

Author of article: Rajan Deshmukh – Rajan is the R&D Manager at ACI. Comments or questions pertaining to this article can be sent to rdeshmukh@aciusa.org.

Custom Training

The pace of change in the electronics manufacturing industry requires the continuous acquisition of new knowledge and skills to remain competitive and cost effective. Companies seeking a competitive advantage through a trained workforce may find that generic off-the-shelf certification training is not enough to clearly differentiate themselves or it may simply not meet the current and future training needs of the organization. The development of a custom training curriculum at the EMPF Training Center will address the specific training objectives and work environment needs of a particular organization and deliver a high value, relevant, professional product implemented at either the client's site or at the EMPF's state of the art facility.

The EMPF utilizes a systematic approach to the development of a custom training program. The EMPF's team of instructional designers and subject matter experts work closely with clients in order to ensure that the program is successful starting with the assessment phase, through the design, development, implementation, and evaluation of the training program.

The following steps are used when developing a custom training program:

Define the Deficiency

The EMPF's team will first meet with key members of the client organization in order to help determine needs, establish goals, and make an assessment of the performance environment, student potential, and the training site. This assessment is important in that it ensures that the training that will be developed will be 100% applicable to the client's needs.

Establishing Training Objectives

Objectives should be S.M.A.R.T - Specific, Measurable, Attainable, Realistic, and Timely. The program objectives should be specific to the goals of the organization. If training needs are synchronized with organizational goals and can establish S.M.A.R.T. training objectives, then the successful evaluation of the program's results is assured. The EMPF's team will develop performance objectives that will address the client's needs, requirements, and ultimate project goals. Upon approval of the performance objectives by the client, the team will proceed with the development of assessment instruments that will determine whether the students have met those objectives. Assessment instruments will include written or oral tests as well as hands-on exercises.

Identifying Training Requirements

A training plan will be developed by a team composed of management, supervisors, workers and training providers. Input from all levels of a company will provide a forum for defining the purpose of the program. The team begins with a discussion to identify problems occurring in operations. This "needs assessment" identifies the difference between the desired employee performance and the actual performance. Assessment tools will include surveys, audits, job shadowing, focus groups, skills assessment tests, and self-assessment by workers. Needs assessment tools provide accurate quantitative and qualitative information while being sensitive to both company time and cost restraints.

Development of Training Methods

Once assessment instruments have been finalized, the instructional design team will begin the development of instructional materials and an appropriate instructional strategy, whether it be instructor-led, activity-based, computer-based, or a combination. The instructional strategy will be identified as one that will effectively maximize the transfer of skills and knowledge from the classroom to the client's work environment. Delivery methods must take into account the audience, the course content, and the training objectives. For example, there is little point in watching video tapes or listening to lectures if the objective is to demonstrate soldering skills or proficiency in a specific method of rework. Complex subjects can be simplified with demonstrations and directed activities. The use of examples and hands-on laboratory experience will help students make the transition from intellectual understanding to real-world application. The EMPF's unique combination of its demonstration factory, technical instructors, and laboratory facilities provide a hands-on approach well suited to the transfer of technology.

Designing and Implementing the Program

Information gathered in the previous steps is combined with the experience of the program designers and the tools at their disposal to create the unique course content designed specifically for the individual organization. The instructional design team will be involved in the implementation of the training, and the evaluation of the instructional materials. Follow-up evaluation will verify whether the goals of the project were met and have satisfied the company's training needs.

For more information, please call the EMPF registrar at (610) 362-1295, or via email at registrar@empf.org.

Author of article: Chuck Wagner – Chuck is a Technician / Instructor at ACI. Comments or questions pertaining to this article can be sent to cwagner@aciusa.org

Lead-free Conversion: Surface Finishes

When converting to lead-free solders questions arise regarding the selection and use of lead-free surface finishes. Whether the board assembler contributes to the surface finish selection process or the surface finish is pre-selected, most producers and manufacturers have been affected by the conversion to environmentally friendly materials and processes. The conversion to lead-free materials has resulted in changes in surface finishes for both the component manufacturers and the bare board suppliers.

While the majority of the lead-free surface finishes themselves are not new, the problems of materials compatibility and supply chain management are re-introduced to manufacturers who have neglected these areas in the past. The reality is that large manufacturers with extensive R&D budgets have been using alternative surface finishes for decades. Lucent and Texas Instruments, for example, had performed reliability testing on gold and palladium finishes well before the WEEE and ROHs directives were introduced. Pure tin finishes have been in use by the low, mid, and upper level manufacturers without consequence for years. However, today, surface finishes are getting as much if not more attention in the lead-free conversion process as the actual solder alloy.

Manufacturing and product engineers have recognized the effect that surface finishes have on the producability and performance of the hardware. The surface finish selection process can have significant impact on four main areas:

- Solderability
- Reliability
- Compliancy
- Cost

These areas influence the performance of both the component and the bare circuit board. The components and circuit boards share many of the same performance concerns, however, some problem areas have a more significant affect on components while other problem areas have considerable impact on the performance of bare boards.

Components

There are a variety of surface finishes available for lead-free components including:

- Tin (Sn)
- Tin Copper (SnCu)
- Nickel Palladium (NiPd)
- Palladium (Pd)
- Tin Bismuth (SnBi)
- Tin Silver (SnAg)
- Tin Silver Copper (SnAgCu)

For now, market demands will determine the alternative finish of choice. However, the change in surface finish materials from SnPb to alternative finishes has brought the component supply chain under increased scrutiny. Despite having clear guidelines for labeling components (IPC-1066 / JEDEC-97 Labeling Standard), suppliers have not demonstrated consistency in identifying component finishes. In many cases the component manufacturer or supplier cannot provide accurate information about the component surface finish. The unknown surface finish issue is of particular concern for discrete components like chip resistors and chip capacitors where part tracking can be more difficult. In one case, the technical support service line was contacted for information regarding the surface finish on a single lot of chip resistors. Not only did the technical service representative fail to provide accurate information regarding the surface finish, he could not provide a list of available surface finishes for that particular product. This example is unfortunatly not as atypical as one might think.

The negative effects of surface finish uncertainty can be catastrophic. Materials interactions can significantly reduce reliability. For example, a low temperature alloys is created when bismuth interacts with SnPb, which can negatively affect product reliability. Additionally, some surface finishes are sensitive to atmospheric conditions and require controlled environments for both short and long term storage. These are some of the main reasons that part tracking and inventory control have become secondary challenges associated with lead-free conversions. However, whisker related risk is greater in high reliability electronics that are used in harsh environments.

A recent EMPF study showed that most manufacturers are producing lead-free components with a matte tin finish despite industry concerns of tin whisker formation. Component manufacturers cite the low cost of converting existing equipment, compatibility with the current group of popular lead-free solders, and low risk of whisker related failure in consumer products as the main reasons for producing tin finished components.

The problem of tin whiskers on component leads has been well documented. While there is limited information on the exact growth mechanism, there are a number of mitigation strategies available. These strategies range from simple processes such as annealing the tin finish, to more complex processes such as plating underneath the tin finish with a stress reducing under-plating. One common option for high-reliability applications that are exempt from the European legislation is the refinishing of pure tin-plated components with a SnPb finish (3 weight % Pb or greater). A well performed lead tinning process can provide a consistent, even

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Ask the EMPF Helpline!

The EMPF helpline received a call regarding the trace amounts of lead (Pb) allowable under the European Union RoHS directive. The EMPF was asked how the cumulative effect of lead leaching may affect the lead-free solder manufacturing processes and how lead-free electronics assemblies may become contaminated by the trace amounts of lead.

The European Union RoHS directive allows for materials to include trace amounts of lead (1000 ppm or 0.1% Pb). Lead contamination is one of the major lead-free soldering concerns. The three main pathways that lead may be introduced to the lead-free manufacturing process are component finishes, board finishes, and poor discipline within the manufacturing infrastructure.

Tin lead (SnPb) finished components and boards may be introduced via mistakes made by the design engineer, purchasing agent, and/or the distributor. On the parts list, the design engineers may not have called for lead-free finished components and boards. Purchasing may not be aware of lead-free purchasing issues. The distributor may not be disciplined enough to distinguish between SnPb and lead-free finished parts with the same part numbers.

During this period of transition to lead-free, several electronics manufacturers reported to the EMPF that they ordered lead-free components and instead received SnPb finished components. This mix-up is understandable because some component manufacturers are reluctant to issue new part numbers for components with lead-free finishes. Instead some component manufacturers track the lead-free parts by lot number, by package labels, and/or by adding a suffix to a pre-existing part number (PN). The suffix indicates that the part is lead-free or RoHS compliant.

Some component manufacturers reported to the EMPF their plans to stop using the PN suffix after converting all their production lines to lead-free. JEDEC-97 and IPC-1066 standards provide methodology to identify finishes by labels, but these standards are not being consistently followed by component manufacturers. A Certification of Compliance from a component manufacturer will not prevent an undisciplined distributor from mixing SnPb and lead-free finished parts with the same part numbers. If the design engineer, purchasing agent, or the distributor fails to call for and properly track lead-free parts, the likelihood increases of SnPb finished components inadvertently being introduced to a lead-free manufacturing process.

Poor discipline in maintaining equipment is another way in which lead may be introduced to lead free manufacturing. In hand soldering, a solder iron tip used for SnPb soldering may be used for lead free soldering. Cleaning the tip after SnPb hand soldering and before lead free hand soldering will not prevent lead contamination of the lead free solder joint. The EMPF recommends that solder iron tips used for lead-free soldering be kept separate from tips used in SnPb soldering.

For wave soldering, an operator may mistakenly put a SnPb solder bar into a lead-free solder pot. Two SnPb solder bars are enough to raise the lead content of an 800 pound lead-free solder pot over the 0.1% RoHS directive limit. Some solder manufacturers are voluntarily changing the shape of their lead-free bar stock, but its implementation is not universal. Visually, it is difficult to tell the differences between lead-free and SnPb bar stock, as per Figure 2-1. The most important strategy is to identify and control the inventory of SnPb and lead-free bar stock solder to prevent accidental solder pot lead contamination.

Figure 2-1 - From left to right the alloys are:
SnCu, SnCuNi, SnAgCuSb and SnPb

Wave solder pot maintenance becomes critical if a lead-free solder pot shares the wave solder system with a SnPb solder pot. Scrapping SnPb solder splash and fingers into the lead-free solder pot is another source of lead contamination if the solder pot was switched out between SnPb and lead-free runs.

Lead from SnPb finishes can leach into the lead-free solder pot during wave soldering. Over time, enough lead may leach to raise lead content in the solder pot over the 0.1% allowable by the RoHS directive. X-ray Fluorescence (XRF) analysis is a quick test method to confirm components have lead-free finishes.

To gain control of lead contamination in wave soldering, the EMPF recommends performing solder alloy analysis on a weekly basis to determine the rate at which the solder pot becomes contaminated. After 2 - 3 months of gathering data, the solder pot analysis may be reduced to once a month, depending on usage and the rate at which the solder pot is contaminated.

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coating of SnPb solder to all leads on a component. Solder tinning is a long standing process outlined in MIL-PRF-38535 that provides a finish in compliance with the IPC J-STD-001/J-STD-002. Leads are re-tinned in Sn63 solder in most cases. Components are de-taped, treated, and re-taped to ensure a minimal loss in productivity. A good tinning shop will utilize ESD precautions and have no trouble refinishing any leaded SMT component, regardless of size or configuration. Lead-free tinning services have not yet emerged in the mainstream market, limiting the mitigation options for those forced to comply with the EU directives.

Bare boards

There are four major choices for bare board lead-free surface finishes:

- ♦ Immersion Silver (ImAg)
- ♦ Immersion Tin (ImSn)
- ♦ Organic Solder Preservative (OSP)
- ♦ Electroless Nickel Immersion Gold (ENIG)

Each finish has benefits and liabilities that would impact the selection process. Immersion tin finishes have proven to be one of the most logical and economical bare board finishes. The immersion tin finishes have also shown to provide excellent reliability. However, solderability concerns from oxidized tin and the fear of tin whisker formation at unsoldered areas prevent immersion tin finishes from gaining a higher degree of acceptance among electronic manufacturing engineers. Good co-planarity characteristics and favorable intermetallics are some of the benefits of immersion silver surface finishes. ImAg finishes are costly and require controlled storage conditions to prevent tarnish that can severely reduce solderability. Organic solder preservative finishes have gained popularity as a robust surface finish. Changes have been made to improve solderability, particularly after multiple reflows or long term storage.

Hot Air Solder Level (HASL) finishes using lead-free solder alloys are being developed and are currently available from select suppliers. These surface finishes present the same challenges of SnPb HASL such as co-planarity. They also present new challenges unique to lead-free such as compatibility of the surface and solder compositions. Table 3-1 shows a comparison of the surface finish properties, including the quoted cost for preparing an EMPF-009 board.

ENIG finishes can be susceptible to high phosphorous levels in the nickel layers that create a weak connection between the solder joint and pad (Black pad). However, the excellent wetting characteristics and good reliability of ENIG finishes have made ENIG boards one of the most popular lead-free replacements. Additionally, ENIG finishes have an excellent track record with SnPb solder joints.

When surveyed, the majority of organizations that attend the EMPF's lead-free soldering course select ENIG as the finish of choice when converting to lead-free finishes. Those new

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Board Finish	Positives	Negatives
Electroless Nickel Immersion Gold (ENIG)	Good corrosion resistence for on-board Contact Pads Suitable for wire bonding pads Good co-planarity features Used in high reliability applications	Cost Gold embrittlement possible with gold finished components Black pad caused by too much phosphorous in plating baths
Immersion Tin (SN)	Good co-planarity features Used in high reliability applications Least expensive lead-free finish	Tin thickness control Tin whiskers potential on unsoldered tin plated pads Board Oxidation
Immersion Silver (Ag)	Good coplanarity features No AgCu reaction Used in high reliability applications	Cost Environmental storage requirements Board tarnishing
Organic Solderability Preservative (OSP	High volume, low cost alternative Good co-planarity features	Solderability degrades after multiple reflows Solderability questionable with lead-free solders 'HALO' effect around solder joints from OSP finished pads Board finish may interfere with incircuit test points *Incircuit test plan may need to be re-evaluated
Hot Air Soldered Level (HASL)	Shows potential for specific applications	Difficult to control finishing process Co-planarity a major problem for fine pitch applications Lead-free HASL finish availability?

Table 3-1 – Comparison of surface finish properties

Lead-free Conversion: Surface Finishes

(continued from page 6)

to alternative finishes have based their decisions on the wetting performance and reliability results published in papers and presented at conferences and courses. However, many of the attendees underestimate the impact that improperly processed ENIG boards can have. The problems associated with oxidized nickel and black pad can be undetectable until the board is in service, requiring a recall of product in the field. Figure 3-1 shows the solder joint from a recalled black pad board. The manufacturer must be aware of the latent failure risk of ENIG boards. The recommendation is to require quality data for each lot of incoming boards. Despite these concerns, the reliability risks do not seem to be an impedance to ENIG as one of the most popular Sn-Pb replacement finishes.

Figure 3- 1 – Solder joint separation caused by black pad on an ENIG board.

Components and bare boards quite often do not share the same concerns with regards to surface finishes. For components, surface finish identification and tin whiskers are two main concerns for the assemblers and contract manufacturers. For bare boards, solderability and latent defects are areas of significant importance. The bottom line is that converting to lead-free components and bare boards require significantly more input and resources for the purchaser to ensure that proper quality surface finishes are being used.

Author of article: Blaine Partee – Blaine is an Engineer at ACI. Comments or questions pertaining to this article can be sent to bpartee@aciusa.org.

Ask the EMPF Helpline!

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Lead contamination above the 0.1% RoHS limit is more a regulatory problem than a reliability problem. Reliability problems come into play when the lead contamination is significantly beyond the RoHS limit. Significant lead contamination depresses the melting point of the lead-free solder and there is a possibility that the lead may concentrate in the wrong area of the solder joint when the joint cools. This is especially a concern with SnPb components used on a lead free surface mount manufacturing line, especially with BGAs. SnPb BGA balls soldered with lead-free solders have an interconnection that is compromised, but the literature says this is a manufacturing issue, not a reliability issue. The reverse situation is worrisome for surface mount lines that have not converted to lead-free. When tin silver copper (SAC) BGA is soldered with SnPb and a SnPb profile, the SAC balls do not melt and collapse. The lead does not properly defuse into the SAC solder balls which causes embrittlement at the bottom of the solder balls near the pads on the boards.

Unless there is total control of the manufacturing processes and assurance that the lead is distributed evenly in the solder joint, mixing of lead and lead-free solders may result in an unreliable solder joint.

The EMPF offers Lead Free Manufacturing Training and analytical services geared towards resolving lead-free manufacturing issues. If you have any questions about Lead Free services available from the EMPF, or would like to inquire about our Lead Free Manufacturing training course, please call the Helpline at (610) 362-1320, or email us at helpline@empf.org.

Author of article: Rebecca Morris – Rebecca is an Engineer at ACI. Comments or questions pertaining to this article can be sent to rmorris@aciusa.org

GEIA Tin Whisker Industry Standard

For the past several years, the electronics industry has scrambled to move its component products to RoHS (Restrictions on Hazardous Substances) compliance. RoHS will ban five toxic materials, one being lead, in electronics for any products offered for sale within the European Union. China, California, and other jurisdictions are following suit. Companies are now concerned with becoming compliant by the RoHS legislation deadline of July 1, 2006. The defense industry, while technically exempt from RoHS requirements, is feeling the pinch as commercial component makers work to meet the deadline. The defense industry must often use electronic components built by these non-exempt suppliers for the commercial world. Even electronic hardware that has dual commercial as well as military use, as in COTS (Commercial Off The Shelf) hardware, is specifically NOT exempt from the lead-free RoHS legislation.

The GEIA Industry Standard for Mitigating the effects of Tin Whiskers in Aerospace and High Performance Electronics Systems is expected to be issued in 2006 as one of four standards and guidelines that are designed to provide assistance to the defense and avionics industries who are trying to deal with and accommodate the lead-free electronics mandate for high performance and military markets. Having been in development for over 12 months, the document is currently in draft form, and undergoing final approvals by the members of the GEIA (Government Electronics and Information Technology Association) LEAP (Lead-free Electronic Products) committee chartered with its development. The standard will be issued jointly by ANSI (American National Standards Institute) and GEIA and is expected to be adopted by the military and commercial aerospace industry.

The GEIA-STD-0005-2 tin whisker mitigation standard first documents the background and scope by citing the European Union legislation known as RoHS. The imminent banning of SnPb solders, which have been used routinely in electronics for some 60 years, requires electronic manufacturers to switch to lead-free solders and lead-free component finishes.

This restriction of lead use has started the transition of many piece part and board suppliers from tin-lead to lead-free finishes such as pure electroplated tin. However, the pure tin finishes being applied to electrical component contacts and circuit boards are susceptible to the spontaneous growth of single crystal, electrically conductive "tin whiskers," (see Fig. 4-1.) which can cause electrical failures by shorting between the closely spaced components and other tin plated parts in lead-free electronic assemblies.

Tin whisker growth is a particularly difficult failure mechanism which has become a prime source of risk with the switch to pure tin plating for lead-free component leads and circuit boards. There are two factor of tin surface finish that pose a much more severe risk for the high-reliability DoD applications than for the commercial electronics world.

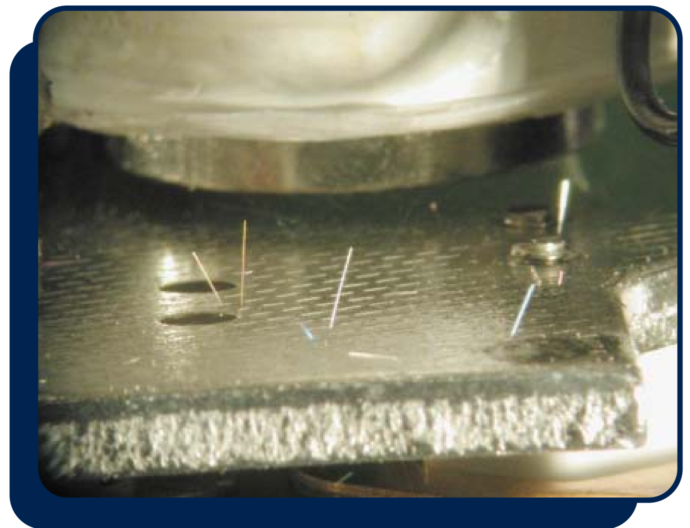

Figure 4-1 - Tin whiskers on a tin plated relay component
Courtesy of NASA

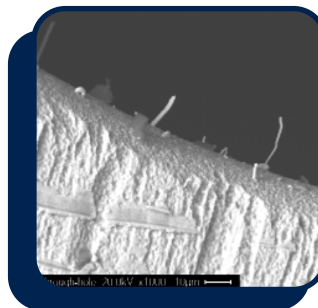

Figure 4-2 - Tin whiskers on an immersion tin plated circuit board, 3 months after plating

Figure 4-3 - Tin whiskers on an immersion tin plated circuit board, 30 months after plating

The first factor is the tendency of tin whiskers to grow for extremely long periods of time, long past the obsolescence timeframe (and replacement) of commercial electronics. Figure 4-2 is an electron microscopic picture of a circuit board surface having immersion tin plating after 3 months of room temperature storage onsite at the EMPF. Note the small, 10 to 20 micron tin whiskers that are present. These whiskers are too small to be a serious risk, even to fine pitch circuitry. Figure 4-3 shows the same sample after 30 months of storage (perhaps a long time for a commercial application, but a short time for a DoD application) showing some tin whiskers that have grown to over 100 microns, long enough to electrically short closely spaced modern electronic circuits.

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GEIA Tin Whisker Industry Standard

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The second factor is the growth rate of these whiskers. Their growth rate, and artificial methods that could be used to accelerate this rate, are unpredictable. Therefore, the only way to assure whiskers do not grow to excessive length is to observe the whiskers for that length of time. While for commercial applications, this might be practical, for military applications this would be unacceptable.

Finding ways to deal with these issues prior to the manufacture of specialized military assemblies is going to be the best way to prevent sustainment issues in the future.

The GEIA-STD-005-2 Tin Whisker Mitigation document specifies the steps that need to be taken to assure that the correct whisker risk level is applied to a given program, and once applied, actions taken to mitigate the risks pertaining to the assigned level. The whisker risk levels are defined in the document as follows:

Level I. No restrictions on tin finish use.

Level II. Tin finish is allowed under some circumstances.

> *Level IIA*. Use of tin finish without explicit controls is acceptable under most circumstances but the likelihood of whiskers and methods used to estimate their impact and mitigation strategies will be documented. Tin finish may be prohibited in some specific circumstances called out in contractual documents.
>
> *Level IIB*. Tin finishes may be used but only with customer approved and specified control measures. These tin finish approvals may be blanket approvals for multiple components and applications within the system. Tin finish may be prohibited in some specific circumstances called out in contractual documents.
>
> *Level IIC*. Restricted use of tin finish. Tin finish is prohibited unless an exception is made. Specific instruction on use of tin finish and required control measures to be provided and reviewed on a case-by-case basis.

Level III. Use of tin finish is prohibited and measures must be taken to verify compliance.

The document continues delineating the whisker risk mitigation techniques that correspond to each level that can be assigned to a program.

More details on the state of research and the difficulties of currently providing specific, quantitative assessments are provided in the appendices. Appendix A provides guidance on selecting control levels and performing risk assessments. Appendix B describes mechanisms of formation, properties, and potential deleterious effects of tin whiskers. Appendix C provides some background on various tin whisker mitigation methods.

This standard, when issued, will be available for reference in proposals, requests for proposals, work statements, contracts, and other documents. It may be used as a stand-alone standard or as part of compliance with GEIA-STD-0005-1, "Performance Standard for High-Reliability Electronic Systems Containing Pb-free Solder." In combination with the other three GEIA documents cited, a complete guide to the DoD and other high performance electronics program accommodation of the worldwide commercial lead-free movement is anticipated.

The EMPF has been working with the DoD and members of the electronics manufacturing industry for the past few years in an attempt to mitigate the problems surrounding tin whiskers. Because tin whiskers present a latent threat in terms of reliability to military and avionics hardware, the EMPF will continue to direct its efforts toward preventative measures with the idea of improving long-term reliability of these crucial types of electronics.

For more information on the EMPF's work in the field of lead-free electronics, visit the EMPF website at www.empf.org.

Author of article: Fred Verdi – Fred is a Lead Engineer at ACI. Comments or questions pertaining to this article can be sent to fverdi@aciusa.org.

Manufacturer's Corner
Niton XRF Analyzer

Implementation of lead-free soldering materials into electronic manufacturing requires inspection of components, manufacturing processes and finished goods, to validate compliance with respect to current global mandates.

X-ray fluorescence (XRF) analyzers are widely accepted by the electronics manufacturing industry as an accurate, repeatable non-destructive process to test for the presence of lead without delaying production schedules. Many analyzers provide qualitative simultaneous identification of elements and replacement materials.

By combining portability and ease of use, hand-held analyzers provide a unique technology resource to support incoming inspection in the stockroom, monitor production floor operations during product assembly and when required, support offsite inspection to validate compliance. The EMPF currently employs the Niton XLt 800 handheld XRF Analyzer (Figure 5-1) to inspect, identify and validate materials used in electronic manufacturing for lead-free compliance.

How does XRF work?

XRF analyzers determine the chemistry of a sample by measuring the spectrum of the characteristic x-rays emitted by the different elements in the sample when it is illuminated by high-energy photons (x-rays or gamma rays). A fluorescent x-ray is created when a photon of sufficient energy strikes an atom in the sample, dislodging an electron from one of the atom's inner orbital shells (lower quantum energy states). The atom regains stability, filling the vacancy left in the inner orbital shell with an electron from one of the atom's higher quantum energy orbital shells. The electron drops to the lower energy state by releasing a fluorescent x-ray, and the energy of this fluorescent x-ray (typically measured in electron volts, eV) is equal to the specific difference in energy between two quantum states of the dropping electron.

Because the quantum states of each electron orbital shell in each different type of atom (each of the atomic elements) are different, the energies of the fluorescent x-rays produced by different elements are also different. When a sample is measured via XRF, each element present in the sample emits its own unique fluorescent x-ray energy spectrum. By inducing and measuring a wide spectrum of the range of different characteristic fluorescent x-rays emitted by the different elements in the sample, Niton's hand-held XRF analyzers can rapidly determine the elements present in the sample and their relative concentrations, in other words, the elemental chemistry of the sample. For samples with known ranges of chemical composition, such as common grades of metal alloys, Niton analyzers can also identify many sample types by name.

Figure 5-1 – Niton XLt 800 handheld XRF Analyzer

Niton XRF analyzers quantify elements ranging from sulfur (element number 16 in the periodic table) through uranium (element number 92) to the heaviest transuranic elements, measuring fluorescent x-ray energies from two thousand electron volts (2 keV) up to 100 keV. Up to 30 or more elements may be quantified simultaneously by measuring the characteristic fluorescence x-rays emitted by a sample.

Features

The XLt 800 has a range of functions that make it a valuable tool in either the factory, the warehouse, or the analytical lab. The 800 series, like other models from Niton, has PC connectivity via a bluetooth interface for quick off loading of data collected from samples. There is also a built in barcode reader to catagorize samples. Additionally, the 800 series comes with 2 rechargable 6-8 hour Li-ion batteries, and an internal storage capacity of up to 3,000 samples, which allows for near continuous operation.

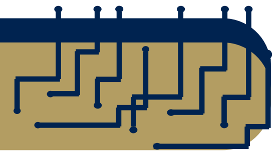
Verification of materials to be used in a manufacturing process will not only help one to achieve compliance with new environmental standards, but will also help to prevent problems that might stem from mixing materials that lead to possible maintenance and reliability issues.

For more information on the Niton XRF Analyzer, or to arrange for a demonstration, Please contact Robert Berta at (610)362-1200 x253, or via email at rberta@aciusa.org.

Technical Point of Contact: Blaine Partee – Blaine is an Engineer at ACI. Comments or questions pertaining to this article can be sent to bpartee@aciusa.org.

Tech Tips...

BGA Repair for Mixed Assemblies



Just as the industry was becoming familiar with BGA assembly technology, another challenge in the form of lead-free solders has presented itself. As companies are phasing-in lead-free technologies at different times and using different metallurgies, the electronics industry will have to learn to work with mixed solder technologies. BGA devices are especially sensitive to mixed solders in the rework process.

Studies of BGAs assembled with mixed solder technologies report both some successes, but also some areas of concerns. The biggest problem arises when attaching a BGA device with lead-free interconnect balls using SnPb solder paste at reflow temperatures below 217ºC. [1] Solder interconnects solidify in zones, and uneven stresses tend to develop in the SnPb rich areas. Early cracking has also been reported in PWB interconnects in SnPb rich areas.

Successful interconnects can be made with lead-free BGA interconnects using SnPb paste, but only if complete mixing of the BGA solder interconnect and the SnPb paste occurs. Industry studies indicate that full mixing is required to prevent yield and reliability reduction. [2] [3] Reflow profiles should be above the lead-free solder alloy melting point to assure full mixing of the metallurgy. As industry continues to work with lead-free materials and more data is collected, the best approach is not to mix solder technologies when possible.

Before starting the rework process, it is necessary to understand the BGA component solder ball composition and the PWB finish. Material certifications may be requested from the component and PWB manufacturers. Ensure that they identify the construction materials used in their products (solder alloy, coatings, etc.) If the BGA interconnect ball is the same as the PWB solder, then proceed using a solder paste with the same alloy composition. If certifications are not available prior to reworking the device, several techniques can be used to identify the solder alloy.

PWB solder joints may be easily analyzed with X-Ray Fluorescence Spectroscopy (XRF). Other methods such as Optical Emission Spectroscopy (OES), Energy-Dispersive X-ray Spectroscopy (EDS), X-ray Photoelectron Spectroscopy (XPS), and Auger Electron Spectroscopy (AES) can also aid in identifying solder compositions. Time and budgetary contraints might be concerns with analytical tools like these.

A simple technique is to place solder shavings on a controlled hot plate set to 195ºC, verified with a calibrated thermometer, to see if it reflows. If the solder reflows, there is a good chance that the solder is SnPb eutectic and can be reworked with standard SnPb eutectic solder using a new device with SnPb solder interconnects. This method may be used for other solders by identifying the melting range (See Table 6-1) and setting the hot plate to the melting point. However, this is more difficult for lead-free solders as the melting temperatures are close together and have overlapping ranges.

After identifying the solder compositions, rework the BGA using a solder paste alloy identical to the BGA interconnects ball and PWB coating.

Solder Type	Composition	Melting Range (ºC)
Sn-Ag Eutectic	Sn-3.5Ag	221ºC
	Sn-2Ag	221º-226º
Sn-Cu Eutectic	Sn-0.7Cu	227º
Sn-Ag-Bi	Sn-3.5Ag-3Bi	206º-213º
	Sn-7.5Bi-2Ag	207º-212º
Sn-Ag-Cu Eutectic	Sn-3.8Ag-0.7Cu	217º

Table 6-1 – Lead-free solder comparison [4]

In a case where time and access to equipment are limiting factors, it is best to carefully rework the device. Ensure that the old solder is removed as thoroughly as possible from the PWB before proceeding with the reattach process. Match your solder paste with the BGA device interconnects solder alloy and proceed with the rework. SnPb solders contaminated with lead-free solders of <1%, reflowed at >225ºC, should not create any reliability concerns.

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[4.] Dr. Ningcheng Lee, iNEMI, "The Relationship of Components, Alloys and Fluxes"

Author of article: *Jeff Gilbert* – Jeff is a Lead Engineer at ACI. Comments or questions pertaining to this article can be sent to jgilbert@aciusa.org.

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WEBSITE: www.empf.org
HELPLINE: (610) 362-1320
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