Leaded Solder, No Lead and Low Lead

Shuttle Environmental Assurance Team Activities and Experience

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BACKGROUND

- RoHS regulations and similar environmental legislation in Japan and China are driving a worldwide movement to eliminate lead from EEE parts and assemblies
  - Many US manufacturers have eliminated lead in some or all of their products to avoid duplication of facilities and products
  - A significant percentage of suppliers have announced that they will not change part numbers for components now made with lead free solders

Shuttle Environmental Assurance Initiative

- SEA provides an integrated approach promoting environmental excellence, proactively managing material obsolescence and optimizing resources
- SEA's primary objectives are to improve the safety and reliability of the Shuttle system and to identify and resolve obsolescence concerns

SEA ACTIVITIES

- SEA has established a lead-free team to evaluate the risks to the SSP and to formulate a mitigation strategy
- Team Members
  - Orbiter – Boeing, Huntington Beach
  - Space Shuttle Main Engine (SSME) - Rocketdyne, P&W
  - Extravehicular Mobility Unit (EMU) – Hamilton Sundstrand
  - Reusable Solid Rocket Motor (RSRM) – ATK-Thiokol
  - Solid Rocket Booster (SRB) – United Space Alliance
  - Ground Operations – United Space Alliance
  - Logistics – United Space Alliance
  - Acquisition Pollution Prevention (AP2) - ITB
  - NASA JSC, KSC and MSFC Materials and Avionics

SEA ACTIVITIES (cont)

SEA leverages the lead-free solder mitigation efforts of the individual SSP Elements by collaboration with each other and non-SSP groups and agencies

- MSFC Avionics
- Department of Defense (DOD)
- NASA Electronic Parts and Packaging (NEPP)
- Joint Council on Aging Aircraft/Joint Group on Pollution prevention (JCAA/JGPP)
- Computer Aided Life Cycle Engineering Center (CALCE)
- National Electronic Manufacturing Initiative (NEMI)

SEA ACTIVITIES (cont)

- SSP specifications require the use of leaded solder for EEE parts
- The world-wide switch from leaded solder to lead-free greatly reduces the availability of parts that meet SSP requirements
- > 40% of suppliers have stated that they do not intend to change part identification when switching from leaded solder to lead-free

SEA ACTIVITIES (cont)

To avoid the inadvertent use of lead-free solder on EEE parts, the SEA lead-free team has proposed the following mitigation strategies:

- Notification letters to all suppliers reminding them of their contractual obligation to supply leaded parts to the SSP
- Identify Criticality 1/1 hardware (single point failure leading to loss of life or vehicle)
  - Obtain Certificates of Compliance
  - Identify suppliers of mixed (leaded and lead-free) product lines for special attention
- Receiving Inspection
  - X-Ray Fluorescence (XRF) spectroscopy and Scanning Electron Microscopy (SEM) inspection of parts
  - 100% inspection is the only way to verify leaded solder; single “lots” have been found to contain mixed leaded and lead-free parts

LEADED SOLDER

The Space Shuttle Program (SSP) requires high reliability electronic parts and assemblies

- MIL-Spec requirements, contractual obligations and the experience database dictate the use of leaded solders for most applications
- Pure tin solders and plating have known issues with the growth of “tin whiskers” that can cause short circuits
- Newer, lead-free solders are not yet standardized, do not have long term reliability data and may be incompatible with leaded solders and each other
- Aerospace electronic solders account for ~0.0005% of all solders used worldwide*, making the SSP increasingly dependent on commercial off-the-shelf (COTS) EEE parts

*Design News, July 19, 2004

IMPACTS TO SSP ELEMENTS

Element	Risk and Mitigation
Orbiter	Problem: Could be found on various flight control systems such as RJDA, ATVC and ASA. Loss of this system may result in a loss of control in jet firing. This could become especially problematic when docked to Space Station. Due to the recent discovery of tin whiskers, even non-EEE parts coated in pure tin may be an area of concern Mitigation: Detailed assessment of criticality 1/1 and 1R2 hardware design and operational controls
SSME	Problem: Lead free solder usage in the Spark Igniter Exciter Box could result in a failure to start the SSME. Lead free solder usage in the controller could result in loss of an SSME. However the controller has two independent channels, which reduces the likelihood of failure. Mitigation: Monitor industry activity. Lead free solder coating is used on terminal lugs on controllers supplied by Honeywell. The controller components are inspected and reflowed as required when returned to Honeywell for periodic inspection.
EMU	Problem: Lead-free usage could result in a short in the electrical system; EVA would be terminated and the secondary oxygen pack would be used in purge mode to provide life support for ~ 30 minutes Mitigation: Failure due to a lead-free component would not cause catastrophic failure. XRF available for Receiving Inspection.

IMPACTS TO SSP ELEMENTS

Element	Risk and Mitigation
RSRM	Problem: Solder is used in components such as severance cables, Safe and Arm device, and heat sensor cables (preflight). A loss of functionality in these areas would not result in a critical failure. There is one use of lead on circuits supporting pressure transducers where a faulty system would result in sensor loss prior to flight. Mitigation: Maintaining frequent contact with suppliers for these components. They forecast no lack of leaded solder in the foreseeable future. Program has stockpiles and/or long-term supplies of required lead should it not be available elsewhere. Failure in the RSRM components due to lead-free usage could not result in catastrophic failure.
SRB	Problem: Lead-free usage could result in pyrotechnics failing to initiate (such as separation bolts or hold down bolts), loss of navigation and TVC control. These worst case-scenarios could result in loss of vehicle, loss of crew. Mitigation: The solder in use is verified to meet the engineering requirements during process audits.
Ground Ops	Problem: The use of lead-free solder may affect the ability of overhead crane controllers to properly function. A malfunction in the controller system may lead to the crane unexpectedly dropping the load thus resulting in a loss of life or damage to the Orbiter. Mitigation: Each GSE system is evaluated for the likelihood and consequences of having tin whiskers within the hardware. Clearing a LRU through analysis is preferred.

IMPACTS TO SSP

How We are Affected?

- Problem with tin in a lead based system
  - COTS parts can be switched to lead-free solder without notice or identification changes
  - MIL-Spec EEE parts have been found with lead-free tinning in violation of their Certificate of Compliance (CoC)
  - Commercial sector is the driving force
  - Ability to buy leaded components is diminishing
- Evidence of the existing problem:
  - GIDEP issued in 2005 stated that the lead content on surface mount semiconductor device terminations did not meet the 3% minimum
  - At Boeing Satellite Systems (BSS) 1% of parts received from 1998 -2003 that had Sn-Pb callouts were found to have pure tin finishes

NO LEAD

Tin Whiskers

Tin Whiskers have caused shorts in electronics, affecting the overall reliability of avionics and other electronic based systems

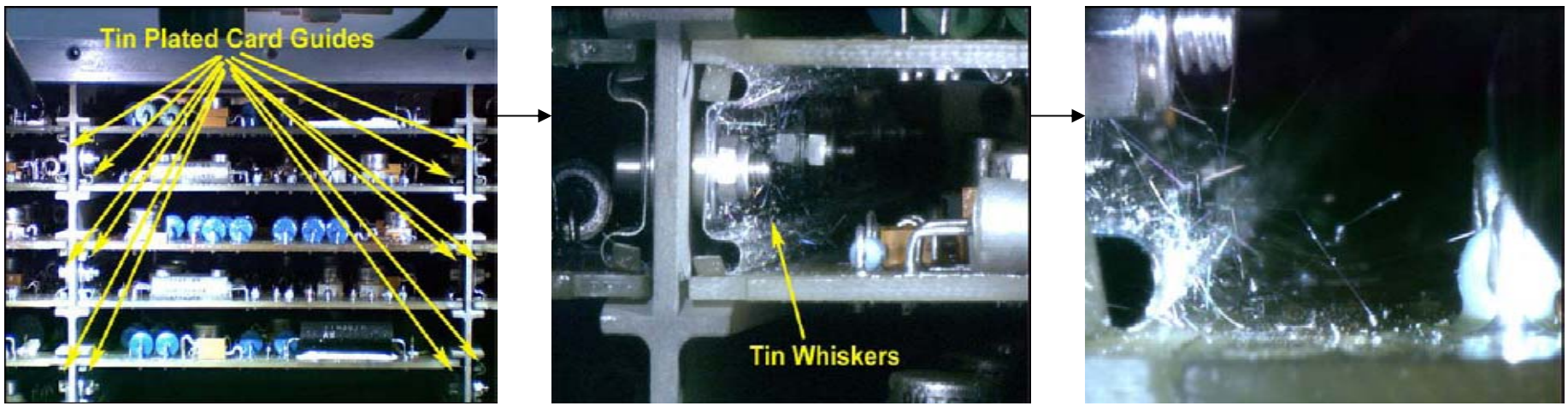
- •GALAXY IIIR [PanAmSat] Complete loss of commercial satellite (1° & 2º SCP)
- •Boeing BSS 601 DirecTV 3 - Partial Loss (primary spacecraft control processor)
- •Military Airplane - failed relay resulting in system malfunction
- •Patriot Missile - Suspected tin whisker related problems

Failed Relay

ORBITER TIN WHISKERS

- Tin whiskers observed in Orbiter Flight Control System (FCS) Line Replaceable Units (LRUs)

Orbiter Ascent Thrust Vector Controller (ATVC) Internal View Showing Progressively Finer Detail



Note: Whiskers were found on non-EEE hardware. Pure tin was specified in the design.

ORBITER TIN WHISKERS

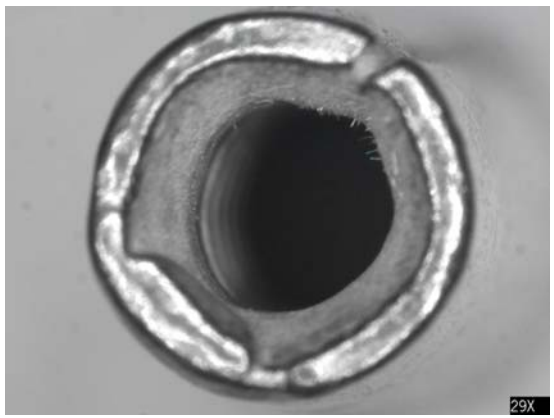
Result of Tin Whiskers on Hardware:

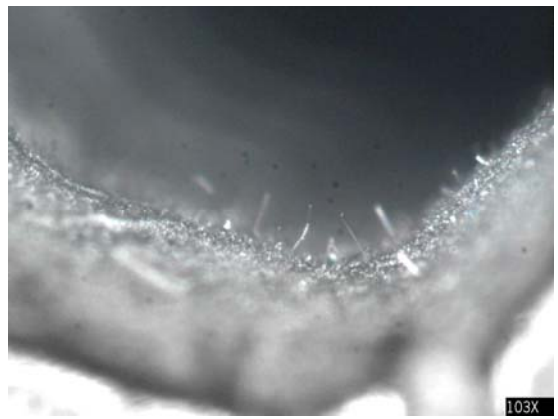
- Investigation team formed to assess the impacts of tin whiskers in FCS and Non-FCS hardware
- After EXTENSIVE review of criticality 1/1 and 1R2 components, acceptable mitigation against tin whiskers was determined for each component
- Concluded that a criticality 1/1 whisker-induced failure is remote

EMU TIN WHISKERS

Tin whiskers found on wire splice connectors used on the ExtraVehicular Mobility Unit (EMU)

- Whiskers ~ 0.005 inch long
- Part is normally overwrapped with shrink tubing
  - Low risk for contributing to short circuit
- In stores since 1988





EMU TIN WHISKERS

- 102 components identified in EMU requiring pure tin plate
  - Application and potential for causing shorts reviewed
  - Rationale generated for risk mitigation
    - Reflowed tin (stress relief)
    - Distance > 1” to conductive item at different potential
    - Potting or conformal coating
      - Tin whiskers can grow out through and under conformal coat.
      - Evidence to date is that they do not grow into conformal coat
    - Current > 50 mA and voltage < 12V (short will vaporize whisker without creating a plasma)

LOW LEAD

- Risk from plating that has less than required lead content
  - Nov. 2005 GIDEP Alert
    - SMT semiconductor components reported to contain < minimum 3% lead in plating
    - Leads were plated at outside supplier
    - MIL-Spec permits testing the solder bath vs the plated part
    - 3% lead in tin is not eutectic mixture, non-homogeneous
    - Discovered by testing inventoried components with XRF equipment
- Are there other suppliers/components producing out-of-spec parts while meeting MIL-Spec testing requirements?

WHAT'S BEING DONE

- Continue to use leaded solder whenever possible
- Exchange of technical methods and techniques for risk mitigation through SEA Lead-Free Team
- Apply the most appropriate mitigation strategy based on hardware
- Continue to monitor industry for information on lead-free solder reliability and compatibility

FUTURE WORK

- Implementing screens to assure leaded solder where the need is critical
- Evaluating lead-free electronics used in specific hardware configurations
- Consider lead-free alternative testing for future space exploration missions

SUMMARY

- Leaded Solder
  - SSP requires the use of leaded solders and EEE parts
  - No reported inadvertent use of lead-free solder at this time but there is an increasing risk to SSP hardware
- No Lead
  - Tin Whiskers found on Critical Hardware
  - Consumer sector will continue to drive the electronics market
- Low Lead
  - A 3% minimum lead requirement may not be met on more components than we had previously believed

<u>Conclusion</u>: Methods must be in place to ensure leaded solders and components in critical applications

QUESTIONS?