RELIABILITY OF PRODUCTS FOR DEFENSE AND AEROSPACE APPLICATION IN THE ERA OF LEAD-FREE COMPONENTS

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Elta Systems
Israel Aircraft industry
background

• On the 27th of January 2003, two European directives (2002/95/EC and 2002/96/EC), have been published at the Official Journal.

• These two documents have, in particular, the objectives to preserve, protect and improve the quality of environment, protect human health and utilize natural resources prudently and rationally.

• The objective of the directive 2002/95/EC (called also RoHS) is to facilitate the dismantling and recycling of waste electrical and electronic equipment (as identified in 2002/96/EC called also WEEE) by restricting the use of hazardous substances.

• The materials banned are lead, mercury, cadmium, hexavalent Chromium, PBBs (Polybrominated biphenyls) and PBDEs (polybrominated diphenyl ethers).
Who Decided to Remove the Pb?

**EU RoHS**
Effective on 1 July 2006

**RoHS: Restriction of Use of Hazardous Substances**

**US RoHS**
Maine, California
Effective on 1 Jan 2007

**TX, RI, WA, VT: Similar legislation proposed**

**China RoHS**
Will be implemented on 1 January 2007

**Japanese**
Electronics manufacturers have created market differentiation based on “green” products

Also includes: Cadmium, Mercury, Hexavalent chromium, Polybrominated biphenyls (PBB) & Polybrominated diphenyl ethers (PBDE)
Where Is Pb Used in Electronics?

Internal to components:
- Die Bonding

Solder Ball Array

Lead Finish

PWB / Component Interconnect

Component Terminations

Plating of Hardware on and around Circuit Cards

PWB Surface Finish
Why Is Pb Currently Used in Electronics?

• Added to improve electronics reliability
  – Essentially eliminated the growth of tin whiskers that cause failures
  – Lower the solder melt temperature for improved component reliability
  – Stronger Solder Joints (Mechanical and Electrical Properties)
  – Improved Solderability
  – Inexpensive Solution

*Tin Whiskers Growing on a Pure Tin Component*

*Losing 50+ Years of Proven & Predictable Performance Using Tin-Pb Electronics*
Aren’t Military Products Exempt from the Environmental Legislation?

- Waste Electrical and Electronic Equipment (WEEE 2.3):
  - Equipment which is connected with the protection of the essential interests of the security of Member States, arms, munitions and war material shall be excluded from this Directive

However:
EU will review exemptions every 4 years.
China will review exemptions annually. Commercial electronic suppliers are not exempt and aren’t waiting.
Does “Exemption” Matter?

• Unable to purchase Pb components or prevent use of Pb-free components

2004 Electronics Market Share

- Telecomm., 41.4%
- Computers, 32.3%
- Consumer, 14.7%
- Automotive, 5.8%
- Industrial, 4.7%
- Mil/Space, 1.1%

• The commercial market is rapidly going Pb-free
  – 84% of manufacturers to be RoHS compliant by the end of 2006
  – 46% of manufacturers will communicate RoHS compliance by request only
What is the problem with Lead-Free?

• Tin Whisker
• Higher reflow temperature
• Solder joint reliability issues
• Non predictable solder joint reliability model
SnPb process window

Peak: 205 – 250°C

<table>
<thead>
<tr>
<th>Temp.</th>
<th>tc1 – small SMD</th>
<th>tc1 – medium SMD</th>
<th>tc3 – large SMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>250°C</td>
<td>205°C</td>
<td>50°C</td>
<td>50°C</td>
</tr>
<tr>
<td>205°C</td>
<td>205°C</td>
<td>50°C</td>
<td>50°C</td>
</tr>
</tbody>
</table>
Lead-Free (SAC alloy) process window

Peak: 230 – 250°C

Too Hot!

Too Cold!
Other effects influenced by the increasing of temperature

BGA Self aligning

Tombstoning
Solder Paste

- Today SnPb (or SnPbAg)
- Tomorrow (SAC – SnAgCu, SnCu, SnCuZn, …)

SAC 305  SAC 387  SAC105
SAC 396  SnBi  SnZn
SnCuNi  SAC-Bi

50 + years of experience and data had been collected for the SnPb solder joint reliability. The LF joint reliability issue has become more complex because of the multitude of alloys being used.

- Lack of reliability data & prediction models
- Impact on components from higher process temps
- Incompatibility of materials (PWB, solder, component)
  – 24 Solder Alloys x 6 PWB Finishes x 20 Component Finishes = 2080 Potential Combinations!
What Are the Pb-Free Electronics Concerns?

- **Pb-Free Tin Alloys Are Susceptible to Whisker Growth**
  - Pure tin and nearly all tin alloys are at risk
  - Current mitigation techniques are not infallible
  - Will cause random product failures
  - Also impacts plated hardware (nuts, bolts, covers, card guides, etc.)

- **Pb-Free Solders Have Significant Unknowns**
  - Lack of reliability data, especially in a military environment
  - Impact on component life from potentially higher process temperatures
    - Prevailing Pb-free solder replacement (SnAgCu) has ~35°C higher reflow temperature
    - May cause infant mortality/latent failures
  - Impact on manufacturing infrastructure (reflow temperature, yield, rework)
  - Some alloys are being patented, increasing component costs
  - Limited solderability shelf life of Pb-free components
  - Incompatibility of materials (PWB, solder, component)

**Impacts ALL Programs that Have Electronics**
What Are the Pb-Free Electronics Concerns? (Cont’d)

- **Solder Joint Reliability (Durability)**
  - Intermetallics between solder and lead/pad
  - Cross contamination of different alloys
  - Changed / unacceptable wetting characteristics
  - New qualification parameters
  - Thermal cycles to first failure
  - Sensitivity to shock and vibration

- **Manufacturing Nightmare**
  - Require new process development
  - Must maintain different processes for different materials
  - Extensive Documentation Requirements to Comply with RoHS

- **Configuration Control/Field Support/Depot Repair Logistical Nightmare**
  - Must prevent mix of incompatible alloys
  - Need to develop new rework processes
  - 24 Solder Alloys x 6 PWB Finishes x 20 Component Finishes = 2080 Potential Combinations!
  - Warranty & Contractor Logistical Support (CLS) risk from increased failures
What Are the Pb-Free Electronics Concerns? (Cont’d)

- **Configuration Control Nightmare**

- **Pb-Free Solder Alloys:**

<table>
<thead>
<tr>
<th>24 Variants</th>
<th>Sn</th>
<th>SnBi7.5Ag2.0</th>
<th>SnZn9</th>
<th>SnAg4.0Cu0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnAg2.5Bi1.0Cu0.5</td>
<td>SnAg3.4Bi4.8</td>
<td>SnZn8Bi3</td>
<td>SnAg3.9Cu0.6</td>
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<tr>
<td>SnAg2.5Cu0.8Sb0.5</td>
<td>SnIn8.0Ag3.5Bi0.5</td>
<td>SnBi57Ag1</td>
<td>SnAg3.0Cu0.5</td>
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<td>SnAg2.0Bi3.0Cu0.75</td>
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<td>SnBi58</td>
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<td>SnCu2.0Sb0.8Ag0.2</td>
<td>SnIn20Ag2.8</td>
<td>SnSb5</td>
<td>SnAg3.5Cu0.7</td>
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<tr>
<td>SnAg3.5</td>
<td>SnIn52</td>
<td>SnCu0.7</td>
<td>SnAg3.5Cu0.9</td>
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</table>

- **Pb-Free PWB Finishes:**

<table>
<thead>
<tr>
<th>6 Variants</th>
<th>Palladium</th>
<th>Tin (electroplated or immersion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Solderability Preservatives</td>
<td>Silver (electroplated or immersion)</td>
<td></td>
</tr>
<tr>
<td>Electroless Nickel / Gold</td>
<td>Immersion Bismuth</td>
<td></td>
</tr>
</tbody>
</table>

- **Pb-Free Component Finishes:**

<table>
<thead>
<tr>
<th>20 Variants</th>
<th>NiPd</th>
<th>Matte Sn over Ag</th>
<th>Hot-dipped SnAgCu</th>
<th>Reflowed Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiAu</td>
<td>AgPd</td>
<td>Ag</td>
<td>Annealed matte Sn</td>
<td></td>
</tr>
<tr>
<td>NiPdAu</td>
<td>Hot-dipped SnAg</td>
<td>Hot-dipped SnCu</td>
<td>Bright Sn</td>
<td></td>
</tr>
<tr>
<td>SnAg</td>
<td>Annealed matte SnCu</td>
<td>Sn over Ni</td>
<td>Matte Sn</td>
<td></td>
</tr>
<tr>
<td>SnCu</td>
<td>SnBiCu</td>
<td>SnBi</td>
<td>Hot-dipped Sn</td>
<td></td>
</tr>
</tbody>
</table>

24 Solder Alloys x 6 PWB Finishes x 20 Component Finishes = 2080 Combinations!
What Is a “Tin Whisker”? 

- **Tin whisker effects documented since the 1940’s**
- **Tin Whiskers**
  - Occur on nearly all tin alloys
  - Few microns to ½ inch +
  - Electrically conductive
- **Hardware**
  - Tin plated nuts, bolts, covers, card guides, etc. also at risk
- **Whisker Induced Failures:**
  - *Short Circuit*: Bridges two adjacent pins
  - *Metal vapor arc*: High voltage and specific atmosphere can result in plasma arc capable of catastrophic damage
  - *FOD*: Whisker breaks off and interferes with mechanical, optical, or MEMS component

*Photo Source: NASA Space Shuttle Program*

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**Raytheon Quote During Pb-Free Technical Paper Presentation at DMC 2005:**

“Based on our findings, any new electronics will be suspect after 2 years of life”
Matte Tin Plated 28 pin SOIC Stored at Ambient for 3 years
Connector Pins (Pure Tin-Plated)
~10 years old
Observed in 2000

Courtesy: NASA Electronic Parts and Packaging (NEPP) Program

Tin whiskers on chip resistor end-cap, tin-silver-copper solder dip finish. Whisker is ~5μm

Courtesy: Peter Bush, SUNY-Buffalo
Tin Whisker Short on Matte Tin

Whiskers from this component caused a FAILURE in the Electric Power Utility Industry > 20 YEARS!!! after fielding the system

Courtesy: NASA Electronic Parts and Packaging (NEPP) Program
Tin Whisker Failure on Oscillator

Thru hole oscillator.
Lead diameter 18 mils.
Bright tin finish leads and case.
Tin/lead solder dipped within 50 mils of glass seal and hand soldered to PWB.

Tin whisker growth noted from seal to about 20 mils from edge of solder coat. Electrical failure was traced to a 60 mil whisker that shorted lead to case.

Courtesy: NASA Electronic Parts and Packaging (NEPP) Program
Photos by Ron Foor
Tin Whisker Example

Tin Whisker “Forest” on test coupon in CALCE Tin Whisker Group’s collaborative test

Courtesy: Bill Rollins CALCE Tin Whisker Group
Have Tin Whiskers Caused Failures?

- NASA Goddard Space Flight Center Literature References
  - 48 Documented Occurrences (NASA/Industry/Academic Publications)
    - Nuclear Utilities
    - 7 Satellites ($100M Boeing Loss)
    - Patriot (PAC-2)
    - 6 Missile Programs
    - Heart Pacemaker
    - F-15 Radar
    - Military Airplane
    - Telecom. Equip.

- Weapon systems that were built between 1985 and 1992 have had documented tin whisker failures
  - Failure rates attributed to tin whiskers varied from 1% to 10%
- 7 Satellites were partial or complete losses 1998-2002:
  - Galaxy – 3
  - Solidaridad 1
  - Direct TV3
  - HS 601
## Categories of product occurrences/failures

<table>
<thead>
<tr>
<th>Product Description</th>
<th># Occurrences</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-electrical assemblies and components (floor tile and hardware)</td>
<td>20</td>
<td>Prohibit Pure Tin</td>
</tr>
<tr>
<td>Uncoated electronics assemblies and connectors (RF assemblies, connectors, etc.)</td>
<td>13</td>
<td>Prohibit Pure Tin</td>
</tr>
<tr>
<td>Cavity style electrical components w/ pure tin finish (hybrids, relays, etc.)</td>
<td>10</td>
<td>Prohibit Pure Tin</td>
</tr>
<tr>
<td>Uncoated components w/ pure tin terminations soldered or attached with conductive adhesive</td>
<td>5</td>
<td>Prohibit Pure Tin</td>
</tr>
<tr>
<td>Components with pure tin terminations soldered with Sn/Pb and conformal coated</td>
<td>0</td>
<td>Preferred Method</td>
</tr>
</tbody>
</table>
Dancing Whisker

~2.5 mm Long Tin Whisker
Inside Electromagnetic Relay

Motion of Whisker Produced
By Gentle Air Currents Only
The difference between good and bad Whisker
What Is the Military groups Doing about Pb-Free?

Air Force

“To date, no lead-free solders are known to have met the reliability requirements imposed upon military electronics. At the same time, many electronic items being acquired by the United States Air Force (USAF) and Department of Defense (DoD) may already contain lead-free solder due to electronics manufacturers’ use of solely lead-free solder.”

“Until such time that a suitable, reliable, lead-free solder replacement is identified, all program managers should ensure their electronic equipment suppliers continue to provide items which meet all performance, compatibility, and reliability requirements.”

Airworthiness Advisory  9 May 2005
DEPARTMENT OF THE AIR FORCE
Headquarters Aeronautical Systems Center
Engineering Directorate

The Customer Recognizes the Existing Vulnerability to Pb-free Products
What Is the Military groups Doing about Pb-Free? (Cont’d)

**NASA**
- Goddard: Collecting comprehensive tin whisker information
- Kennedy: Participating in Joint Council on Aging Aircraft (JCAA) / Joint Group on Pollution Prevention (JG-PP)

**Navy – Office of Naval Research (ONR)**
- Facilitating industry collaboration:
  - Best Manufacturing Practices Center of Excellence
  - Electronics Manufacturing Productivity Facility (EMPF)
- Limited research funding through EMPF MANTECH Projects

**DoD**
- Participation in joint consortiums with industry
  - Lead-free Electronics in Aerospace Project (LEAP) Working Group formed by the Aerospace Industry Association (AIA), Government Electronics and Information Association (GEIA), & Aviation Maintenance Congress (AMC)
  - Executive Lead Free Integrated Process Team (ELF IPT)
- DoD Lead Free Working Group (Being Chartered under AT&L)
  - Drafting Policy (Using GEIA Input) that will require a Pb-Free Management Plan for each DoD Program

**Government Is Looking to Industry for Development of Path Forward**
Aerospace & Defense Sector in the EU

• This sector has been closely following the evolution of the European Directive and many companies have been participating in Lead Free Initiatives in the US, under the JGPP program, in the UK, under the NPL MPP programs and in the EU, under ELFNET where BAE SYSTEMS chairs the Defense and Aerospace Industry Network.

• The Sector position is:
  – Electrical and electronic equipment for aerospace, military and similar purposes, are required to have high reliability and long operational life under harsh conditions.
  – Military and aerospace sector customers are concerned about the reliability of lead-free electrical and electronic equipment. We share these concerns and until such time as effective alternatives are available, will continue to use lead-based solder in its products as permitted by the legislation. We will continue to support the move towards lead-free solder for electrical and electronic equipment. We will continue to participate in joint industry activities in order to identify and validate alternative solders and processes for military and aerospace sector applications. Having agreed this strategy for dealing with the issue of Lead Free Soldering the difficult phase of implementation followed.
## Links to Lead free programs

<table>
<thead>
<tr>
<th>Joint R&amp;D program of...</th>
<th>Substitution of... Companies</th>
<th>participating to these programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Group on Pollution Prevention (JG-PP) in the US, co-funded by Nasa and the DoD</td>
<td>Lead, Cr VI, Cd</td>
<td>BAE Systems, Honeywell Aerospace, Rockwell Collins, Raytheon systems Limited, Bendix/King Avionics, **...</td>
</tr>
<tr>
<td>National Physical Laboratory in the UK</td>
<td>Lead</td>
<td>BAE Systems Avionics, Raytheon systems Ltd, Honeywell Aerospace, **...</td>
</tr>
<tr>
<td>LEADFREE</td>
<td>Lead</td>
<td>Siemens, **...</td>
</tr>
<tr>
<td>iNEMI High reliability Task Force (International, but groups a lot of non-European countries and is aimed at components)</td>
<td>Lead</td>
<td>Alcatel, **...</td>
</tr>
<tr>
<td>NEMI Tin whisker accelerated test projects (National)</td>
<td>Lead</td>
<td>Honeywell Aerospace, Raytheon Systems Limited, **...</td>
</tr>
<tr>
<td>ASTRAL (adaptive solder technology for reliability and environment compatibility of electronic assemblies)</td>
<td>Lead</td>
<td>Thales Systèmes Aéroportés SA, **...</td>
</tr>
<tr>
<td>NONE (NO lead in Nordic Electronics)</td>
<td>Lead</td>
<td>Saab AB, Alcatel, **...</td>
</tr>
</tbody>
</table>
Lead-free Aerospace Electronics Working Group (LAEWG)

- Joint activity of Aerospace Industries Association (AIA), Aeronautical Radio, Inc. (ARINC), and Government Engineering and Information Technology Association (GEIA)
- Addresses issues that are—Unique to aerospace—Within aerospace control
- Documents will be published through International Electro technical Commission (IEC) Technical Committee 107 (TC 107), Process Management for Avionics
  - Participating Members: China, Czech Republic, France, Japan, Korea, Germany, UK, USA
  - Observer Members: Belgium, Denmark, Finland, Greece, Israel, Italy, Netherlands, Norway, Spain, Sweden, Switzerland,
What are They Going to Do?

External Resources

Science Projects:
JEITA, JG-PP, NEMI, NCMS, Part mfrs., PWB Assemblers, automotive mfrs., etc.

Industry specifications:
IPC, IEC, ANSI, JEDEC, etc.

LAEWG Deliverables

DDDD-Program Manager’s Handbook (when applicable)

AAAA - Performance Standard

CCCC-Pure Tin Standard

BBBBB-Technical Guidelines

Aerospace Industry

Customers

Suppliers
Alternative Finishes for Components and/or Boards

- **Component Termination Finishes**
  - Unless otherwise required by the part specification, part number, or purchase order, the following requirements apply to component leads or other solderable component surfaces.
  - All component or component package labels shall be marked with the finish code as defined in IPC-1066 or JESD97.
  - For area-array components such as ball grid arrays (BGA’s) or ceramic column grid arrays (CCGA’s), balls or terminations **shall be tin/lead (SnPb) alloy**.
  - For other components, **tin/lead finish is preferred**. Electroplated tin/lead finishes **shall be fused and shall** conform to SAE-AMS-P-81728. For hot solder dipping, solder **shall comply with J-STD-006 type Sn60A, Pb36B, or Sn63A**.
  - Alloys containing **bismuth are not allowed**.
  - “**Matte tin**” plating and **Nickel/Palladium/Gold is permissible**, as are alloys composed of tin, silver, and copper (“**SAC**” alloys), and **tin/copper**.
  - “**Bright tin**” plate or **tin/nickel alloys are not allowed**.
  - **Silver-plated or gold-plated surfaces to be soldered shall be hot solder dipped using alloys Sn60A, Pb36B, or Sn63A per J-STD-006. Gold removal shall** be in accordance with J-STD-001D Paragraph 3.9.3. Solder cups and connector eyelet-style terminations are exempt from this requirement.
Component finish buying restriction at IAI

<table>
<thead>
<tr>
<th>Solderable Finish</th>
<th>Whisker formation risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnPb</td>
<td>1</td>
</tr>
<tr>
<td>NiPdAu</td>
<td>1</td>
</tr>
<tr>
<td>NiPd</td>
<td>1</td>
</tr>
<tr>
<td>NiAu</td>
<td>1</td>
</tr>
<tr>
<td>Matte Sn w/ Nickel underplate</td>
<td>2</td>
</tr>
<tr>
<td>Reflowed Sn</td>
<td>2</td>
</tr>
<tr>
<td>Hot Dipped SnAgCu</td>
<td>2</td>
</tr>
<tr>
<td>Matte Sn w/Silver underplate</td>
<td>2</td>
</tr>
<tr>
<td>Hot Dipped SnAg</td>
<td>2</td>
</tr>
<tr>
<td>Hot Dipped Sn</td>
<td>2</td>
</tr>
<tr>
<td>Hot Dipped SnCu</td>
<td>3</td>
</tr>
<tr>
<td>SnAg (1.5-4%)Ag</td>
<td>3</td>
</tr>
<tr>
<td>Matte Sn –150 deg C anneal</td>
<td>3</td>
</tr>
<tr>
<td>Matte SnCu – 150 deg C anneal</td>
<td>3</td>
</tr>
<tr>
<td>SnBi – (2-4%)Bi</td>
<td>3</td>
</tr>
<tr>
<td>Matte Sn</td>
<td>4</td>
</tr>
<tr>
<td>SnCu</td>
<td>5</td>
</tr>
<tr>
<td>Bright Tin w/Nickel underplate</td>
<td>5</td>
</tr>
<tr>
<td>Bright Tin</td>
<td>5</td>
</tr>
<tr>
<td>Ag over Ni</td>
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<tr>
<td>AgPd over Ni</td>
<td>5</td>
</tr>
<tr>
<td>Ag</td>
<td>5</td>
</tr>
</tbody>
</table>
JCAA/JG-PP Lead-Free Solder Testing for High-Reliability Applications

• International collaborative effort
  – Project begun under the auspices of the U.S. DoD’s Joint Group on Pollution Prevention (JG-PP), then turned over to the DoD’s Joint Council on Aging Aircraft (JCAA) (concerned about numerous lead-free solder logistical and repair issues)
  – DoD, NASA, U.S. and European defense and space OEMs, and component & solder suppliers

• The objective: to compare relative reliability of lead-free (Pb-free) and tin-lead (SnPb) solder joints under different environmental testing conditions.
Test Vehicle

Solder past: 95.5Sn3.9Ag0.6Cu (SAC) • 92.3Sn3.4Ag1.0Cu3.3Bi (SACB) • 99.3Sn0.7Cu, Ni-stabilized (SnCu)

<table>
<thead>
<tr>
<th>Component Type</th>
<th>Component Finish</th>
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<tbody>
<tr>
<td>CLCC-20</td>
<td>SnPb</td>
</tr>
<tr>
<td></td>
<td>SAC</td>
</tr>
<tr>
<td>PLCC-20</td>
<td>SAC</td>
</tr>
<tr>
<td>TSOP-50</td>
<td>SnPb</td>
</tr>
<tr>
<td>TQFP-144</td>
<td>SnCu</td>
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<tr>
<td>TQFP-208</td>
<td>SnPb</td>
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<tr>
<td>BGA-225</td>
<td>SnPb</td>
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<tr>
<td>PDIP-20</td>
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</tr>
<tr>
<td></td>
<td>NiPdAu</td>
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<td>0402 Capacitors</td>
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<td>0805 Capacitors</td>
<td>Sn</td>
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<td>1206 Capacitors</td>
<td>Sn</td>
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<tr>
<td>1206 Resistor</td>
<td>Sn</td>
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<tr>
<td>Hybrids</td>
<td>SnPb</td>
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<tr>
<td></td>
<td>SAC</td>
</tr>
<tr>
<td></td>
<td>SACB</td>
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<tr>
<td>CSPs</td>
<td>SnPb</td>
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# Environmental Exposure Tests

<table>
<thead>
<tr>
<th>Project Activity</th>
<th>Performer</th>
<th>No. of Test Vehicles</th>
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<tbody>
<tr>
<td><strong>Testing Prep</strong></td>
<td></td>
<td></td>
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<tr>
<td>PWA Assy. &amp; Rework</td>
<td><strong>BAE SYSTEMS</strong></td>
<td>119 86 42</td>
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<tr>
<td>Component Characterization</td>
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<td>--  --  --</td>
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<td><strong>Testing</strong></td>
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<tr>
<td>Vibration</td>
<td><strong>PHANTOM WORKS</strong></td>
<td>15 15 --</td>
<td>MIL-STD-810F</td>
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<tr>
<td>Thermal Shock</td>
<td><strong>PHANTOM WORKS</strong></td>
<td>15 15 --</td>
<td>MIL-STD-810F</td>
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<td>Thermal Cycling: -20°C to +80°C</td>
<td><strong>PHANTOM WORKS</strong></td>
<td>15 -- --</td>
<td>IPC-SM-785</td>
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<td>Thermal Cycling: -55°C to +125°C</td>
<td><strong>Rockwell Collins</strong></td>
<td>15 15 15</td>
<td>IPC-SM-785</td>
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<tr>
<td>Combined Environments Testing</td>
<td><strong>Raytheon</strong></td>
<td>15 15 15</td>
<td>MIL-STD-810F</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td><strong>aci</strong></td>
<td>13 13 --</td>
<td>MIL-STD-810F</td>
</tr>
<tr>
<td>Salt Fog</td>
<td><strong>aci</strong></td>
<td>9 -- --</td>
<td>IPC-TM-650</td>
</tr>
<tr>
<td>Humidity</td>
<td><strong>aci</strong></td>
<td>9 -- --</td>
<td>IPC-TM-650</td>
</tr>
<tr>
<td>Surface Insulation Resistance</td>
<td><strong>Boeing</strong></td>
<td>45 IPC-B-24 boards</td>
<td>MIL-STD-810F</td>
</tr>
<tr>
<td>Electrochemical Migration</td>
<td><strong>Boeing</strong></td>
<td>45 IPC-B-25A boards</td>
<td>MIL-STD-810F</td>
</tr>
</tbody>
</table>
# Vibration Test

| Parameters                        | 1 hour per axis  
|                                 | Start at 9.9 g<sub>rms</sub> in all three axes, then step up in 2 g<sub>rms</sub> increments in the Z axis |
| Number and Type of Specimens     | 5 PWAs per solder alloy |
| Trials per Specimen              | 1 |
| Acceptance Criteria              | Electrical reliability better than or equal to tin/lead controls |

**Lead-free/Tin-Lead Alloy Solder Test Levels**

![PSD Chart](chart.png)

- **Level 1**
- **Level 2**
- **Level 3**
- **Level 4**
- **Level 5**
- **Level 6**
Results for Vibration Testing

• the Pb-free solders under test sometimes performed as well or better than the eutectic SnPb control. For example, SACB was as reliable as SnPb with the CLCC-20s and SnCu was the most reliable solder with the PDIP-20s (with both NiPdAu and matte tin component finishes).

• In contrast, SnPb solder outperformed the Pb-free solders with the PLCCs. Only PLCC U15 exhibited failures, however, demonstrating that PLCCs are comparatively resistant to high vibration environments.

• With the BGA-225s, the combination of eutectic SnPb solder/SnPb balls always outperformed the combination of Pb-free solder with Sn4.0Ag0.5Cu balls.

• Contamination of the Pb-free solders with Pb gave mixed results. For example, SACB was still the best performer with the CLCC-20s even when contaminated with large amounts of lead (approximately 17% Pb). With the BGA-225s, the combination of eutectic SnPb solder/SnPb balls outperformed the combinations of Pb-free solder/SnPb balls and SnPb solder/SAC balls.

• SnPb generally outperformed the Pb–free solders on those components that were reworked.
Combined Environments Test

- The Combined Environments Test (CET) was based on a modified Highly Accelerated Life Test (HALT).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>-55°C to +125°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cycles ≥ 500</td>
</tr>
<tr>
<td></td>
<td>20°C/minute ramp</td>
</tr>
<tr>
<td></td>
<td>15 minute soak</td>
</tr>
<tr>
<td></td>
<td>Vibration last 10 minutes of soak period</td>
</tr>
<tr>
<td></td>
<td>10 Grms, initial</td>
</tr>
<tr>
<td></td>
<td>Increase 5 Grms after every 50 cycles</td>
</tr>
<tr>
<td></td>
<td>55 Grms, maximum</td>
</tr>
</tbody>
</table>

| Number and Type of Specimens                 | 5 PWAs per solder alloy |
Results for Combined Environments Test

- **SACB** solder had the fewest number of solder joints fail (59 % of the Components Registering as a Failure (CRF)).
- **SnPb** solder were second best (63 % of the CRF).
- **SAC** solder had the worst performance (73 % of the CRF).
- The “Rework” test vehicles
  - **SnPb** solder had the best performance with 74 % of the reworked CRF.
  - **SAC** had the next best performance with 86 % of the reworked CRF.
Thermal Cycle -55°C to +125°C Test

- This temperature range was one of two selected because it is a representative thermal cycle temperature range for both aerospace and defense products.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>-55°C to +125°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cycles: Until 63% failures or greater</td>
</tr>
<tr>
<td></td>
<td>5 to 10°C/minute ramp</td>
</tr>
<tr>
<td></td>
<td>30 minute high temperature dwell</td>
</tr>
<tr>
<td></td>
<td>10 minute low temperature dwell</td>
</tr>
</tbody>
</table>
Results for Thermal Cycle -55°C to +125°C Testing

• BGA-225 component total population had failed. On the “Manufactured” test vehicles (170°C Tg), both the SACB and SAC solder alloys had better performance that the SnPb solder alloy.
• TQFP-144 components assembled with SACB solder paste had ~40% better reliability than the SnPb components.
• The components assembled with SAC had a similar characteristic life (N63) to those with the other solderpaste, but a significantly lower Weibull slope.
• This result again suggests that the SAC solder joints were less consistent than those assembled with either SnPb or SACB.
• Contamination of Pb-free solder joints with small amounts of lead (3%) resulted in a large decrease in the reliability of SACB but only a small decrease in the reliability of SAC.
Reliability Conclusions

• Component type has the greatest effect on solder joint reliability performance (greater than does solder alloy) for thermal cycling and combined environments.
• Overall, the component type had the greatest effect on solder joint reliability performance.
• The plated-through-hole components proved to be more reliable than the surface mount technology components.
Relative Reliability of Components for Tin-Lead Solder
Reliability Conclusions

• Component type has the greatest effect on solder joint reliability performance (greater than does solder alloy) for thermal cycling and combined environments.

• The results of this study suggest that for some component types and environments, Pb-free solders are as reliable as the currently used eutectic SnPb solder. Unfortunately, this study also demonstrates that with other component types and environments, the Pb-free solders fail before the SnPb control.
Reliability Conclusions

• Component type has the greatest effect on solder joint reliability performance (greater than does solder alloy) for thermal cycling and combined environments.

• The results of this study suggest that for some component types and environments, Pb-free solders are as reliable as the currently used eutectic SnPb solder. Unfortunately, this study also demonstrates that with other component types and environments, the Pb-free solders fail before the SnPb control.

• For many components SACB solder joints were at least as reliable as the SnPb controls during the combined environments and thermal cycling tests. (Exceptions were when SACB was contaminated with SnPb.)

• Under high-stress conditions, SnPb generally outperforms Pb-free. For low stress conditions, Pb-free generally outperforms SnPb.

• The lower reliability of the Pb-free solder joints shown in some tests does not necessarily rule out the use of Pb-free solder alloy on aerospace and defense electronics. However, models for calculating the actual field lifetime of Pb-free solder joints must be developed and validated. These models can then be used to verify that electronics made with Pb-free solders will survive for the required lifetime in their use environments.
Reliability of LeadFree Passive components assemble with SnPb solder
MBT Division work

• The objective: to compare relative reliability of tin-lead (SnPb) solder joints when LeadFree and SnPb passive component finish where assemble, under different reflow profile and different environmental testing conditions.
### Test parameters

#### Reflow profile

<table>
<thead>
<tr>
<th>Lead finish</th>
<th>Reflow profile peak temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn, NiPdAu, SnPb</td>
<td>218 ° ÷ 220 °</td>
</tr>
<tr>
<td>Sn, NiPdAu, SnPb</td>
<td>225 ° ÷ 227 °</td>
</tr>
<tr>
<td>Sn, NiPdAu, SnPb</td>
<td>232 ° ÷ 234 °</td>
</tr>
</tbody>
</table>

Note: Time above reflow (183 °) will be between 40 to 80 sec

#### Components type and amount

<table>
<thead>
<tr>
<th>Component type</th>
<th>Lead finish</th>
<th>quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitors</td>
<td>Sn</td>
<td>126</td>
</tr>
<tr>
<td>Capacitors</td>
<td>SnPb</td>
<td>126</td>
</tr>
<tr>
<td>IC</td>
<td>NiPdAu</td>
<td>42</td>
</tr>
<tr>
<td>IC</td>
<td>SnPb</td>
<td>42</td>
</tr>
</tbody>
</table>
Environmental Exposure Tests

- Visual inspection according to IPC 610D
- Thermal cycling -55° - 125°
- Thermal shock -55° - 125°
- X-Ray Analysis
- Shear Test
- Metallurgic cross section
Results

• Shear test results show no different between LF and SnPb in various reflow profile.
• Visual, X-ray and cross section show no differences between the components and Lead finish.
• Both components show micro-cracks at the solder top area after 500 thermal cycling. These cracks did not affect the shear test results.
Israel Aircraft Industries (IAI) Work

- IAI Ltd., a participating member on the JCAA/JGPP Lead-Free Solder study, has initiated a Pb-free study building off of the work completed by the JCAA/JGPP consortia.
- The work being done by IAI Ltd. will expand on the work completed by the JCAA/JGPP and will fill in some of the remaining data gaps associated with Pb-free electronics.
- Will use a two sided test vehicle where components will be soldered to the top side and bottom side of the circuit board.
- Study will include test vehicles made of polyimide board laminates in addition to test vehicles made of high temperature (Tg~170°C) FR4 board laminate.
- The study will rework lead-free assemblies using lead-free components and solder alloys.
- The work will assemble Lead-free BGA components with SnPb solder at higher temperature (~230 °C)
What we are doing

• Staying with SnPb solder (for the moment)
• Applying restrictions for components finish
• BGA
  – Only SnPb
  – If needed -> reballing
Thanks

• This work is done by most of the Groups and Subsidiary of the Israel Aircraft Industries. These groups include Elta Systems Ltd., System Missiles and space group (MBT space division, MLM Division, TAMAM Division) and others.

• Special thanks to Pinhas Lazar, Zaritzky Jorge, Halperin Yosi, Fridlander Dan, Avi Klein, Naim Shalom, and more…
Questions?