Lead-free soldering of telecommunication network infrastructure products

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***Abstract*— Ericsson has successfully transferred to lead-free solder for its high volume telecom network infrastructure products. By implementing measures for lead-free soldering in all stages of the product development process, from design and component selection to the production process, reliable products are ensured.**

As the high volume consumer electronic products are driving the components market towards lead-free soldering, the availability of components and materials are better for lead-free than for leaded soldering. Components can be obtained from approved sources, which is the basis for quality assurance and reduces the potential problems with counterfeit components. Lead-free conversion has also reduced the number of Last Time Buy (LTB) cases affecting Ericsson.

***Index Terms*—Design for Environment, lead-free, soldering, telecommunication**

I. The EU RoHS Directive

The EU directive 2002/95/EC of the European parliament and of the council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS), includes a ban on lead. The directive came into force 1 July 2006, and since then, and in some cases earlier, consumer electronic products, like PCs and mobile phones, have been manufactured using lead-free solder. Due to the high reliability requirements and complexity of the designs, an exemption for “lead in solder for servers, storage and storage array systems, network infrastructure equipment for switching, signaling, transmission as well as network management for telecommunications”, was included in the RoHS directive. The exemptions are regularly being reviewed by the EU Commission, with the aim to withdraw the exemptions.

II. Market development

The exemption on lead in solder is only applicable to the more complex products like servers and network infrastructure equipment. Consumer electronic products like PCs and mobile phones can not use this exemption and have therefore since the RoHS directive came into force, and in some cases earlier, used lead-free solder. The volumes for consumer electronic products are much larger than for servers and network infrastructure products and are therefore driving the component market towards lead-free. Its getting more and more difficult to obtain components intended only for tin-lead soldering process. Most compliant lead and chip components have plating which is compatible with both soldering processes. Other components like BGA’s (Ball Grid Array) needs to be ordered with solder balls compatible with the used solder paste and soldering process. BGA’s with tin-lead balls are at high risk for being obsolete and this is one reason to transfer to lead-free soldering.

III. Legal situation

Several countries have followed the initiative of the EU RoHS directive and implemented restrictions on the same substances, e.g. California in USA, China and South Korea. The scopes of the products covered by the legislations are not exactly the same, but the same substances are restricted. Other countries are likely to follow.

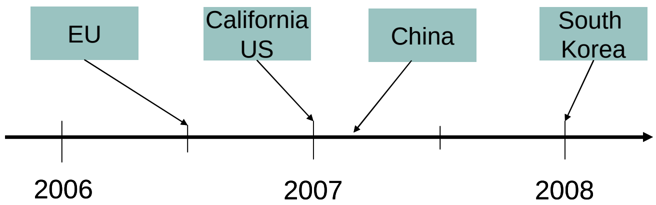

Fig.1. Regulations restricting lead have been implemented world wide.

IV. First Ericsson tests and evaluations

Already in the late 90´s, Ericsson started to evaluate lead-free solders and soldering methods. The initial ambition was to start converting new products in 2002, but due to lack of components for lead-free soldering and the down-turn in the telecom business in the beginning of the 21st century, the conversion was put on hold.

The main conclusions from these early investigations were:

- Tin-silver-copper (SAC) is the main candidate for lead-free solder paste
- The conversion to lead-free soldering process has to be aligned with the availability of component qualification standards and qualified components.
- It is important with stricter control of components and materials during the transition period to avoid

problems due to mixing of components for lead-free soldering in tin-lead process and vice versa.

- The design rules for printed board assembly (PBA) layout have to be updated
- The reliability requirements seem possible to reach.

The lack of standards for qualification of components and printed circuit boards (PCB) regarding resistance to the increased temperature for lead-free soldering was the main reason why it was considered too early to build complex lead-free PBAs. The lack of standards made suppliers reluctant to offer parts for lead-free soldering.

Even though it was difficult to find components for lead-free soldering Ericsson decided to make accelerated temperature cycling tests in the form of a designed experiment (DoE) to be able to vary several parameters at the same time. A ceramic filter of LCCC (Leadless Ceramic Chip Carrier) type and a plastic molded component, with similar sizes and designs, were used in the tests and the conclusion was that lead-free solder was at least as good as tin-lead solder for the 2 types of air to air thermal cycles used (–40 °C to +100°C and -55°C to +125°C, 30 minutes dwell time).

Based on the results from the accelerated test, 1000 radio base station transceiver units were produced with lead-free solder. The design and components used were identical to the standard tin-lead soldered units in order to be comparable. Since the PBAs did not include any BGA components, the mixing of alloys were not a major issue. The main problem was resistance to the increased soldering temperature. Aluminum electrolytic capacitors needed manual mounting to avoid being damaged and plastic components were baked to avoid pop corning. From a production point of view the lead-free process worked well and the yield was similar to the tin-lead soldered units. The lead-free soldered units were distributed to selected sites to cover different traffic and environmental situations and the return rates has since then been monitored and compared with the tin-lead soldered versions of the same product. See more information in chapter IX.

Ericsson participated in several industrial consortia's, e.g. CALCE at University of Maryland and the Area Array Consortium at Universal Instruments (now UNOVIS AREA), that made many of the material investigations that was needed. Ericsson also supported The Swedish Institute for Metals Research, regarding both solder and whiskers investigations. One of the main learning's from these early investigations was that a stricter control of components and other materials was needed to avoid problems related to mixing of technologies during the transition phase. It was also obvious that adopted design rules were needed, especially when it comes to PBA layout.

V. Ericsson RoHS program

To manage the implementation of the RoHS directive, Ericsson started an internal RoHS program in 2004. The program included all parts of the Ericsson organization, from design, production, sourcing and repair to market units. The program intensified the work on preparing for lead-free soldering, and a decision was taken to start the transfer. The main reasons were:

- Avoid costs for handling of parallel production processes.
- Avoid risks regarding component availability.
- Be prepared for removal of the RoHS directive exemption.
- Be prepared for introduction of similar legislation on other markets.

The program overall instructions for design were:

- Cost effective strategy and transition plans to be developed for all products.
- All new designs to be designed for lead-free soldering using the updated design rules and component specifications.
- All redesigns to be prepared for lead-free soldering.
- Clean up and phase out of products where feasible.

To manage and keep control of the transition, an exemption handling procedure were introduced, requiring an approved exemption if tin-lead solder was to be used.

The Ericsson training material in Design for Environment was updated regarding lead-free soldering and seminars were held in the design organizations.

The chapters VI to IX below, describes the program sub projects that was related to lead-free soldering.

VI. Design

The main actions introduced in design were:

- Updates of the product data management systems to handle new information for lead-free soldering and separate components for tin-lead and lead-free processes.
- Requests of new lead-free data from suppliers.
- Specification for qualification of components regarding soldering heat resistance and moisture sensitivity.
- Recommendations on component plating materials.
- Instructions on marking of components and PBAs.
- Update of the design rules for PCBs and PBAs.

A. *Management of new data*

The transfer to lead-free soldering meant that a lot of new data had to be managed. Lead was removed from component terminations. Materials were changed, especially for plastic components, to adopt to higher soldering temperatures. Components for tin-lead and lead-free processes had to be separated. To be able to manage the situation, Ericsson decided that the product data management systems had to be updated and populated with the necessary information with help from the suppliers. A questionnaire was sent to all component suppliers requesting information about intended soldering process and maximum allowed reflow soldering temperature. The information was used to set component status showing what soldering process the component could be used in and by that ensuring that components for lead-free soldering were not used in tin-lead process and vice versa. The approved soldering process and maximum temperature information is visible per component in the bill of material (BOM) for a PBA, making it possible to optimize each individual PBA BOM for lead-free soldering. The information is also used as reference when making PBA soldering profiles and for ensuring that the components will only be used in the soldering process that the component is designed and qualified for.

Even though Ericsson and other companies asked for a clear separation of materials for lead and lead-free (e.g. by change of manufacturer part designation number) many manufacturers avoided that due to cost reasons. However, in the most important cases where components were not backwards compatible, all suppliers agreed to separate lead-free and leaded parts. Internally Ericsson gave all non backwards compatible components (e.g. all CSP, BGA packages etc.) unique part numbers.

B. Qualification of components

At first there was a problem with the lack of an industrial standard for qualification of components to the temperature and Moisture Sensitivity Level (MSL) for lead-free soldering. Ericsson developed a specification on resistance to soldering heat, based on the drafts of Jedec-std-020B and extended it to be valid for all components, not only plastic packaged micro circuits. As soon as the Jedec specification became mature Ericsson adapted fully to that.

Most components could be qualified for lead-free soldering, but some exceptions became clear. Aluminum electrolytic capacitors for surface mounting did not fulfill the requirements for all sizes and also polymer tantalum capacitors needed special handling in production. Pin-in-paste connectors were a problem area as the plastic material in the housing did not manage the increased soldering heat. New plastic housings were developed and today connectors for lead-free pin-in-paste soldering are common.

C. Component and printed circuit board plating

The removal of tin-lead as plating option increased the risk for whiskers bridging on the PBAs. Ericsson decided to follow the mitigation principles developed by NEMI [3]. The use of pure tin plating is not forbidden but components with bright tin plating or other unsuitable plating is avoided. A specification with recommended surface treatments was developed and is referred to from the component quality specification. Components whisker testing shall be done according to JEDEC std JESD22A121. No whisker with a length >40 µm shall appear before, during or after the testing.

The PCB design rules recommend that immersion silver or tin should be avoided due to the risk of silver migration or tin whiskers. The PCBs used by Ericsson are mainly nickel-gold plated where whiskers will not appear.

D. Marking

Lead-free components and their outer and inner packaging material are marked for identification according to Jedec standard. At first this was a problem as no standard existed and when Jedec-std-097 on marking came, several suppliers did not follow it. Jedec-std-097 is now replaced by IPC/Jedec-std-609.

PBAs are marked with the lead-free category according to IPC/Jedec-std-609 to identify the used solder alloy.

E. Printed circuit board / printed board assembly design rules

Ericsson PCB and PBA design rules were updated to avoid large temperature differences (delta T) between the hottest component top and the coldest solder joint when soldering complex PBAs. The rules were also updated to avoid delamination due to the repetitive soldering heat cycles that occur because of double sided mounting of components and repair loops. Partly these methods have been developed together with other companies in the UNOVIS AREA consortia.

VII. Production and Repair

A special project was assigned to set up and document the processes for lead-free assembly, soldering and repair of PBAs. The activities included to evaluate and recommend necessary production equipment and solder material as well as develop training material for the staff at the Ericsson factories. A procedure for auditing of contract manufacturers was developed.

A. Management system

Each Ericsson factory is required to have a strict management system that separates material for lead-free and tin-lead production processes. This includes procedures for handling of solder paste and components so that the maximum floor life is not surpassed for moisture sensitive devices.

B. Soldering equipment

New convection reflow ovens suitable for lead-free production and also vapor phase reflow ovens were evaluated. With the best convection oven the temperature difference on the Ericsson high delta T PBAs was significantly reduced compared to the ovens used within Ericsson at that time. By doing redesign of some PBAs and investing in new convection ovens the use of the less common vapor phase process could generally be avoided.

Selective wave soldering equipment for production of lead-free PBAs was evaluated and the most suitable equipment when it comes to quality and flexibility was recommended.

C. Qualification of lead-free solder paste

Tin-silver-copper (SAC) solder pastes from different suppliers were evaluated regarding printability, slumping, tackiness, wettability, solder balling, flux residues and solder powder form. Solder paste from one manufacturer was recommended to be used in the Ericsson factories. New evaluations are made when new solder pastes enter the market.

D. Temperature profiling

Compared to soldering with tin-lead, tin-silver-copper solders require a higher reflow temperature and that reduces the process window. Reflow soldering requirements were therefore updated with new requirements regarding ramp rate, peak temperature and time above liquidus. The instruction for reflow soldering was also updated with information on how to verify that the maximum soldering heat resistance for each component was not surpassed.

E. Hand soldering and repair

The equipment for repair and manual soldering was evaluated. Based on the result, the process descriptions and work instructions for hand soldering, soldering pot machines and BGA-repair was updated. The updated information in the product data management systems and the PBA marking is important to identify the soldering process to be used for the repair.

F. Training material

Training material for education of operators and production engineers in lead-free soldering was developed and training seminars were held at the Ericsson production sites.

G. Audit specification

In order to ensure that Ericsson's quality requirements on a lead-free production process was followed at all manufacturing sites, including contract manufacturers, an audit procedure was developed.

VIII. SUPPLY CHAIN MANAGEMENT

One of the bases for reliable lead-free products is to have strict control of the component supply chain.

Problems related to availability of components for tin-lead soldering process might lead to that purchase of components have to be made on the spot market and by that increasing the uncertainty of a continuous supply, receiving counterfeit components, etc.

IX. RELIABILITY

When the Ericsson RoHS program started, a review of the potential reliability risks was done. Thanks to the preventive measures taken in design, component selection and production, the main risks were judged to be whiskers and PCB damage. Also solder joint reliability, pop-corning, component compatibility and PBA delta-T were areas that were judged to need further investigation.

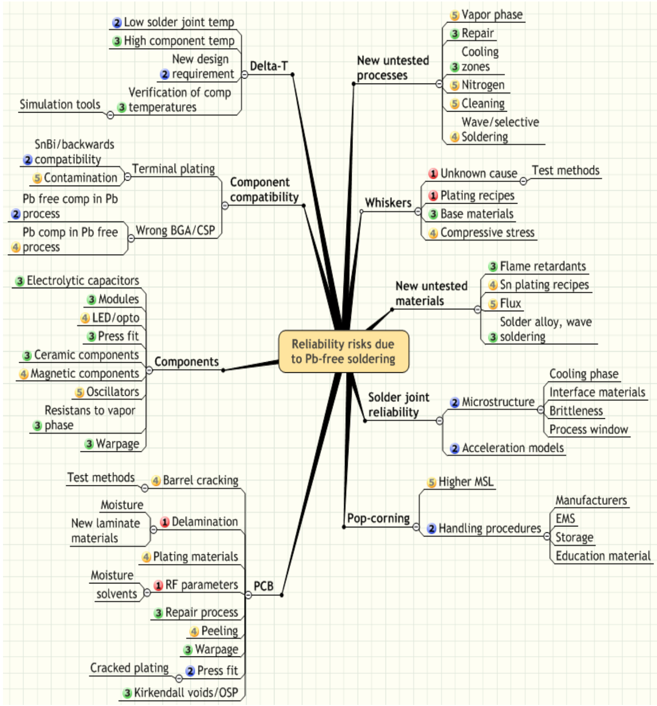

Fig.2. Potential reliability risk areas identified at an early stage of the Ericsson RoHS program.

A. Whiskers

The introduction of pure tin plating has increased the risk for whiskers growth regardless of the used soldering process and is still regarded as the largest reliability risk related to the conversion. The driving force for whiskers growth is stresses in the plating material. No acceleration tests exist that are proven to work for whiskers growth and therefore qualification tests are not giving the field life confidence normally expected. As a result, most work within the industry has been to mitigate the problem. This has been achieved by choosing the right plating and ensuring that standard tests are performed. The risk for an extensive fall out due to whiskers seems to be small based on the experience from the consumer electronics market and our own field repairs.

B. Printed circuit board damage

The issues related to PCBs turned out to be very design dependent and therefore difficult to handle on a general level. Ericsson made extensive testing on PCBs with different materials and complexity at different manufacturing sites. Some of the tested PCBs were designed for lead-free soldering and some not. The conclusion of the tests were a number of design rules and a requirement that PCBs should be specified and tested to handle 4x reflow at 260 °C for at least 20 s.

C. Solder joints

Solder joint fatigue was not regarded as a high risk due to three facts:

- Ericsson’s general restrictive use of large ceramic components.

- The relatively low stresses in our type of applications, i.e. mainly slow temperature cycling and very limited vibration and shock.
- The extensive amount of testing performed by CALCE and UNOVIS that indicates that the reliability difference between lead-free and tin-lead solder joints are relatively small for our type of applications.

Large mismatch in thermal expansion (CTE) between components and the PCB is the driver for solder joint fatigue in our type of applications. By avoiding large components with low CTE without compliant leads, the risk for fatigue failures is reduced.

Ericsson has used the modified Engelmaier model developed by CALCE [9] to predict the risk for future solder joint fatigue failures for different packages and application environments. The same model has successfully been used to predict cycles to failure in product stress testing and part level temperatur cycling for lead-free soldered joints.

D. Component compatibility

Problems related to compatibility between component and soldering process is a potential high risk but with the measures that Ericsson has implemented to separate materials in design, purchase and production, very few incidents have appeared. Component compatibility problems decrease when more PBAs become lead-free, as the main risk is related to lead-free BGA components that are not backward compatible with tin-lead soldering process.

There are still a number of components that can not be soldered according to the profiles in J-STD-020 and needs to be monitored during soldering profile generation and in worst case they must be mounted after the reflow process. Examples are some electrolytic capacitors.

A recent issue is the introduction of SAC105 or similar solder balls on BGAs. SAC105 have higher melting temperature than standard SAC305 which mean that the process window may be reduced to a level that good solder joints can not be achieved without introducing a risk to overheat other components. The component manufacturers have so far no special marking on SAC105 devices, which make it difficult to identify these parts for management of the risks.

E. Temperature difference on printed board assemblies

It is important to keep the highest temperature on the PBA below 260 °C to make sure the packages specified maximum temperatures are not surpassed and at the same time secure that all solder joints reach at least 235 °C. With a combination of better designs, thoroughly developed temperature profiles for each PBA and improved soldering ovens, this has been solved for Ericssons complex PBAs.

F. Pop-corning

The pop-corn risk is managed through design for low PBA delta T and by following the moisture sensitivity level (MSL) classification and handling system. The key to accomplish this is availability of component temperature data in the product data management system.

G. Field experience

Ericsson have lead-free soldered products deployed in field since 2002 and larger volumes from 2006.
Below is the result of a comparison between identical components packaged in BGAs with different solder balls and soldering processes. The use of identical BGAs limits the statistical selection but removes the impact from failures not related to the soldering process. The conclusion is that there are no difference between the failure rates of BGAs soldered in lead-free and tin-lead soldering processes.

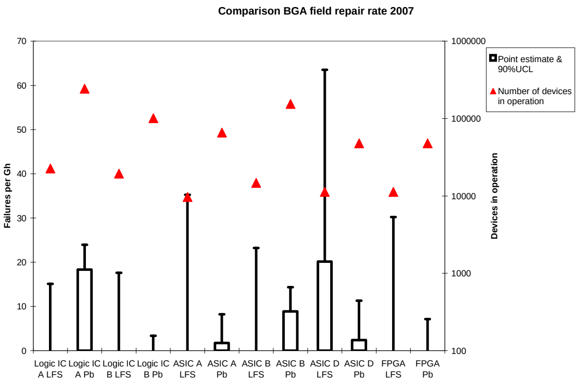

Fig.3. No statistically significant difference can be found between lead-free and tin-lead soldered parts. Very few BGA failures are reported but due to lower number of parts in field the 90% UCL failure rate value is often somewhat higher for the lead-free parts than for the tin-lead parts.

1000 lead-free soldered units were put into field during 2002 and 2003 and have been followed since then. The Weibull plot below is generated from repair actions (component replacements) and the lead-free soldered products are compared to two tin-lead soldered product revisions from the same time frame. The results show that the accumulated numbers of failures for the lead-free and tin-lead soldered units are similar.

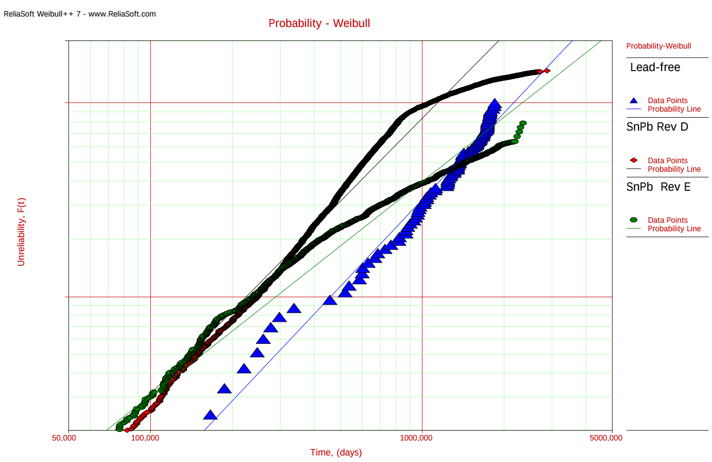

Fig.4. Failure distribution comparison of 1000 lead-free soldered units and 49000 tin-lead soldered units (SnPb Rev D and SnPb Rev E) put in operation during the same time frame.

Larger volumes of Ericsson lead-free soldered products have been in field for a few years, starting from 2006. By now, failures related to brittle solder joints due to PCB bending or similar should have turn up if existing. The comparison in Fig.5 for two WCDMA products shows that this is not the case. Return rates for the lead-free soldered units are the same or lower.

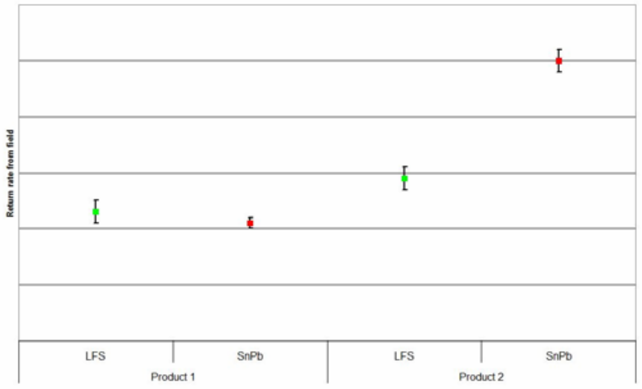

Fig.5. Comparison of return rate during 2007 for two WCDMA PBAs before (SnPb) and after switch to lead-free (LFS).

X. Lead-free series production

Ericsson started series production of lead-free soldered products in the beginning of 2006. Since the transition is made on PBA level and individual transition plans are made for each separate PBA, the end product, e.g. a radio base station, is gradually over time consisting of more and more lead-free soldered PBAs.

By the end of 2008 the majority of the PBAs for our high volume telecom network infrastructure products had been successfully transferred to lead-free solder.

Some large volume examples:

- By Q1 2009, more than 10 million lead-free soldered PBAs for radio base stations had been produced.
- From Q4 2007 more than 60000 MINI-LINK radio units have been produced with lead-free solder.
- The new Ericsson LTE radio base stations only include lead-free soldered PBAs.

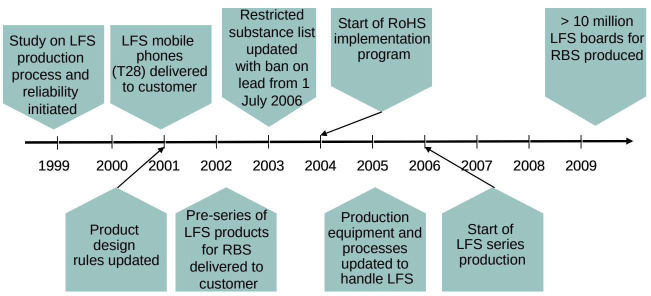

Fig.6. Ericsson has long experience of lead-free soldering.

XI. Conclusions

- Ericsson has over 10 years of experience of lead-free soldering.
- Risks have been identified and mitigation actions have been implemented.
- Reliable lead-free products are ensured through an update of the entire product development process.
- 7 years experience of lead-free products in field.
- The field reliability of lead-free PBAs is the same or better than tin-lead soldered PBAs.
- Series production of lead-free telecommunication network infrastructure products since 2006.
- By end of 2008 the majority of the PBAs for Ericsson high volume telecom network infrastructure products had been successfully transferred.
- By transferring to lead-free soldering risks related to availability of components for tin-lead soldering have been avoided.

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