A Practical Guide to Achieving Lead-Free Electronics Assembly

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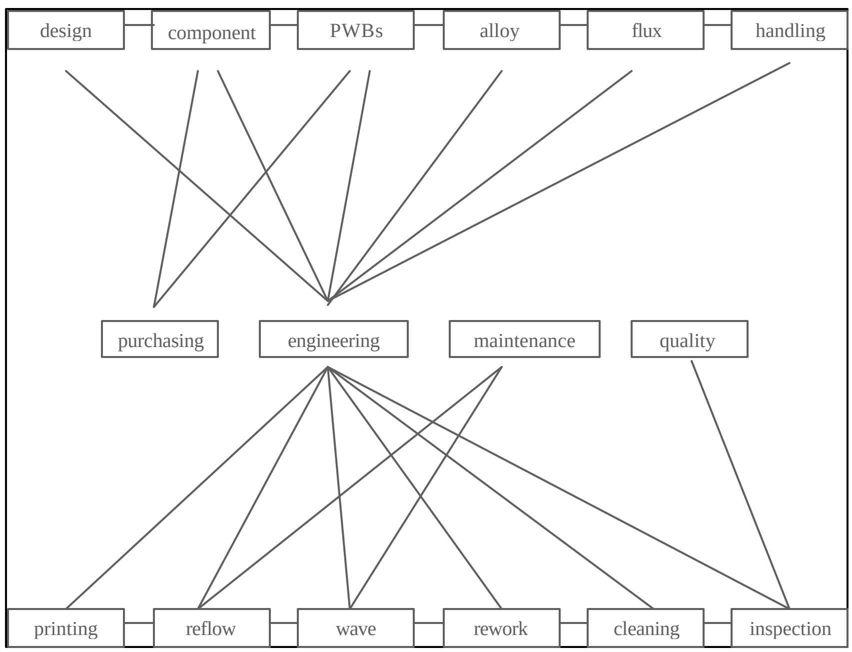
Abstract:
To successfully achieve lead-free electronics assembly, each participant in the manufacturing process, from purchasing to engineering to maintenance to Quality/Inspection, must have a solid understanding of the changes *required of them*. This pertains to considerations regarding design, components, PWBs, solder alloys, fluxes, printing, reflow, wave soldering, rework, cleaning, equipment wear & tear and inspection.

Introduction
With the WEEE and RoHS Directive in Europe (in its most recent revision) potentially outlawing lead from electronics produced and imported in the EU as early as 2006 and foreign competition driving the implementation of lead-free electronics assembly around the world, additional questions regarding how manufacturers can successfully transition to lead-free assembly continue to arise.

A great deal of consortia work and empirical data exists on lead-free soldering. What has been lacking, however, are studies directly related to real-world applications and advice on such topics as procurement, design, processes, maintenance, inspection, etc. This paper shall address each step of the manufacturing cycle and discuss the means to overcome the many challenges of lead-free assembly.

Paper Format
This paper will be approached as a chemistry experiment, with the goal being the successful achievement of lead-free soldering. The apparatus involved include Purchasing, Engineering, Maintenance and Inspection/Quality personnel. To the right is a visual outline of the considerations to be addressed and the personnel to which each consideration pertains. Because of the many topics to be discussed, each is given a brief, but thorough, overview.



Purchasing
Purchasing's main challenge is to requisition components and PWBs suitable for lead-free assembly and to balance the needs for parts with the myriad of lead finish, PWB surface finish and solder alloys currently available.

Although vendors are offering some components with lead-free lead finishes such tin, Pd/Ni, Au/Ni, and Pd/Au/Ni, purchasing will be far more restricted in terms of part availability than in the past. When attempting to purchase lead-free components, one may run into several obstacles: only a single-source for a part, a part that is not quite suitable, a change in lead-times, significantly more expensive, or no source at all. To overcome these obstacles, Purchasing needs to work in close conjunction with Engineering/Design and vendors to ensure that the lead-free parts needed are available and compatible with the manufacturing process.

As with components, there is some availability of lead-free PWB surface finishes. OSPs, Au/Ni, Immersion Sn, Ag, and Lead-Free HAL finish PWBs have been on the market for some time now. Again, Purchasing needs to work in close conjunction with Engineering/Design and vendors to ensure that the lead-free parts needed are available compatible with the manufacturing process.

Materials Management
The many component and PWB coatings, as well as several possible solder alloys results in a huge matrix of potential material intermix, and clearly can complicate materials management. More than ever, purchasing will need to be attuned to which parts go with which product. Once again, Purchasing must work in close conjunction with Engineering to ensure that ordering is streamlined and that the appropriate parts are available for particular jobs.

Engineering
The switch to lead-free assembly affects virtually all aspects of the Engineering function. Engineering personnel will have to pay close attention to design, components, PWBs, solder alloys, fluxes, and the printing, reflow, wave soldering, rework and cleaning processes and equipment.

Design
Established PCB-design rules may need to change during the transition to lead-free soldering. Currently, industry guidelines govern component lead-pad and land size, track width and spacing, via and through-hole dimensions, and similar factors to ensure manufacturability and reliability. However, the physical characteristics of any solder include subtle factors, such as its ductility and elasticity. In addition, the local heating of component leads and their pads causes some thermal expansion during operation, which tin-lead solder accommodates and matches.

In determining design solutions, Design should try to remain with as many standard parts as possible. This will reduce the unpredictability encountered with atypical parts. In addition, if the assembly is designed to have a long life, factor in the reduced moisture resistance of parts. Furthermore, Design must factor in the higher temperatures required for connectors.

Material Considerations
The first critical duty is to ensure that the parts to be used will be compatible and reliable *for their particular application*. Compatibility relates to components, PWBs, solder alloy and flux. Reliability relates to component concerns, which includes such factors as Moisture Sensitivity Level (MSL) Rating, wetting and tin whiskering.

Component Reliability Concerns
The higher melting temperatures of the lead-free solders that are coming into use mandate components that can withstand the increased temperature stresses of the soldering process. Life-test data for many components at these higher temperatures is less comprehensive than it is for tin/lead processes. To maximize reliability, Engineering should start looking now at all critical components, design rules, fabrication processes, component engineering, and reliability records.

A critical factor in the transition to lead-free assembly is the MSL rating of components. To date, industry testing has demonstrated that there is no generic solution for maintaining an IC's MSL with a higher reflow profile. However, it has been demonstrated that degradation of MSL may increase with increasing profile dwell above 200°C and that MSL typically degrades by one level for every 5 to 10°C increase of peak reflow temperature. Therefore, all ICs must be reclassified for lead-free applications and the impact to MSL. This could result in an increased need to pre-bake parts and more stringent storage methods.

As discussed above, several lead-free component lead finishes are available. It should be noted that these different materials have different wetting characteristics and that Engineering should consider wetting when specifying components. Engineering also needs to balance the fact that increased reflow temperatures can improve wetting, but worsen reliability. In addition, Design should be aware of reduced solderability on second-side reflow and through-hole processes.

Another hot topic of discussion is tin whiskering, which continues to be an oft-misunderstood and debated subject. Proponents of matte tin argue that whiskering is a result of the plating process, and not necessarily inherent to pure tin. They demonstrate that whiskering can also occur with Sn/Bi, etc. Others, however, suggest that a dopant is needed to offset the whiskering. Engineering should follow the on-going debate and studies regarding this topic, work closely with component vendors and participate in studies to determine the most suitable lead finish for their applications.

PWBs
Several PWB lead-free surface finish options exist. Many of these, such as OSPs and Au/Ni, have been available for years. Engineering should determine the finish of choice based upon wetting, storage, planarity and cost issues. In addition, it must be ensured that board materials can withstand reflow temperatures without warpage or other damage. For many cases, FR-4 will remain acceptable, but other applications may require a modification.

Solder Alloy and Flux
Unfortunately, despite a great deal of research, comprehensive and comparative data on lead-free alloys is lacking. The list of solder alloy requirements is lengthy and involved. In general, technical requirements include being non-"hazardous", mechanically reliable, thermal fatigue resistant, good wetting, relatively low melting temperature and compatible with a variety of lead-bearing and lead-free surface coatings. In addition, one must consider logistical issues such as alloy cost, availability and patent issues. While most of the world has settled on the tin-silver-family of alloys, a good deal of debate still exists as to which exact composition is ideal, and of course others will choose alloys from outside of this family. As with all other technical issues, although there has been much consortia work on alloy selection, the alloy of choice will come down to the specific requirements of each unique assembly. Your choice of alloy is dependent upon your application and should be proven out to your standards.

As with alloys, what is a suitable flux (paste, liquid flux and cored wire) for one manufacturer may not be for another. Select flux chemistries suitable for lead-free processing *and* your particular application. One should consider a flux's activation temperature, activity level, compatibility with chosen alloy and reliability properties such as SIR, electromigration.

Process Considerations
Once it is confirmed that the parts and materials to be used in lead-free assembly are available, suitable and reliable, it is time to get the processes optimized in order to achieve maximum throughput and reliability. To do so, Engineering must refocus attention to paste handling, printing, reflow, wave soldering, rework & repair and cleaning.

Paste Handling
Shelf-lives with lead-free pastes may be reduced as compared to tin/lead, and storage conditions may be slightly more stringent. However, in general, the same rules as with tin/lead apply. For example, prevent/minimize paste's exposure to heat and humidity, allow paste to come to room temperature before using and do not mix old and new paste in the same jar. If one follows proper paste handling procedures now and has good results from these, there should be very few issues when transitioning to lead-free paste use.

Printing
In general, no major changes to the printing process *should* be necessary. That is, lead-free pastes should exhibit similar features on the stencil and the same equipment set points should transition well. One can expect similar performance in terms of stencil life, aperture release, print definition, high-speed print capabilities, print repeatability, etc. However, this depends on the paste manufacturer and if they have density issues resolved. If one experiences a significant difference in printing a lead-free solder paste versus the equivalent tin/lead paste, it may be related to the metal loading or flux chemistry of the paste in

use. In this case, Engineering should work with the paste vendor, or try competitive pastes, in order to resolve these issues.

As tin/lead solder alloys tend to have better wetting than most lead-free alloys, some stencil design modifications may be needed to maximize spread of paste and counteract inferior wetting. Engineers should run tests with lead-free alloys on their current stencils to confirm adequate spread and wetting. If wetting is not sufficient and cannot be rectified by other means, stencil design modifications may be in order.

Reflow

This is the SMT process area that will be most affected by a switch to lead-free processing. Most lead-free alloys require higher reflow temperatures than the 210-220°C peak temperature of tin/lead; anywhere from 235-260°C is common. This higher reflow temperature dictates that one should minimize ?T and maximize wetting through the reflow profile (including cooling), and could possibly mandate reflow equipment changes.

Profile - Depending upon the oven utilized and the density of the assembly being processed, the Ramp-to-Spike process is generally recommended for lead-free assembly. This profile offers superior wetting and less thermal exposure than the traditional Ramp-Soak-Spike profile.

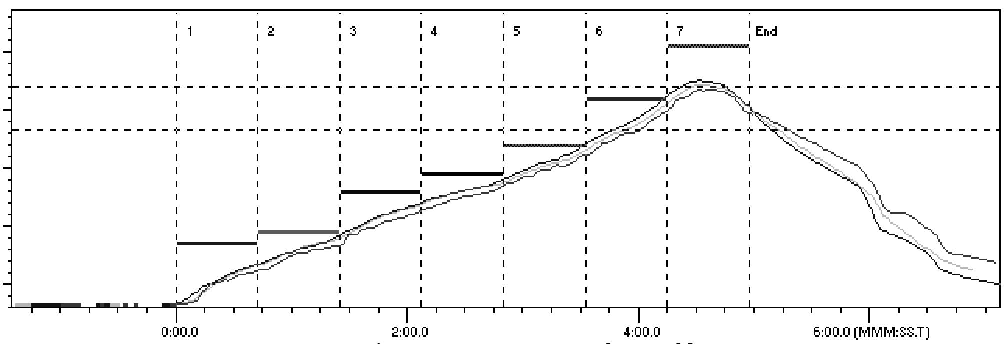


Figure 1: Ramp-to-Spike profile

Due to the higher reflow temperatures required, voiding tends to be more prevalent with lead-free alloys. To negate this, a low-voiding paste formula can be used. In addition, the reflow profile also can be adjusted to compensate for this and reduce voiding. The LSP profile pictured below has been proven effective in reducing voiding.

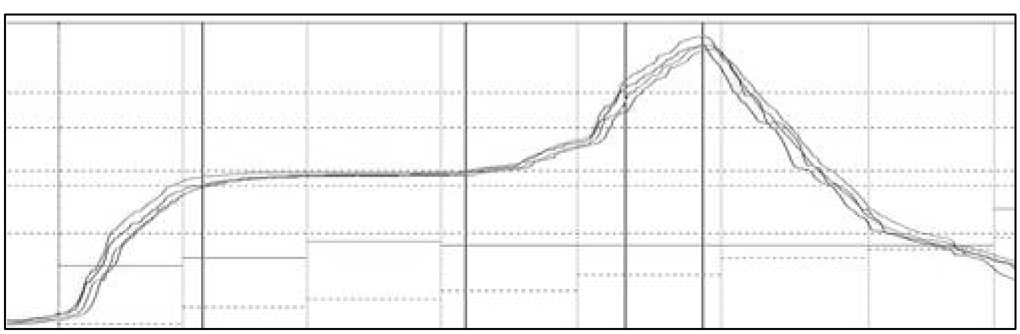


Figure 2: LSP profile used to reduce voiding

Ovens- Most modern reflow ovens in use today can provide the necessary heat (additional 20 to 40°C) for lead-free soldering. However, whether this equipment can also tightly control the reflow profile parameters (minimize ? T) should be investigated. This implies that pure IR equipment will probably not be suitable for lead-free processing. Rather than replacement, some oven may simply require retrofitting. For example, some convection ovens currently have the electronics too close to the process chamber, which can lead to overheating. Ovens may also need to be equipped with nitrogen to compensate for difficult-to-wet parts and poorer wetting solder alloys.

Wave Soldering
Depending upon the alloy selected, wave soldering will require a pot temperature of 260-275°C. This increase of temperature and the change in solder alloy will require some additional process changes.

Flux- May require a change in liquid fluxes to compensate for the poor wetting of some alloys and high thermal stresses of the wave process. If changing fluxes, particular attention should be paid to both to operating window it offers and the material's reliability characteristics.

Equipment- Most modern wave solder machines can provide the necessary heat (preheat and wave) for lead-free soldering. However, as shown in figures 3 and 4[1], the high-tin lead-free alloys rapidly dissolve the materials often used in wave solder equipment. Stainless steel pots, nozzles, impellers and other parts will need to be replaced with cast iron and other materials available from wave soldering equipment manufacturers or be covered with an appropriate paint that should protect the parts for 2-3 years. In addition, a nitrogen blanket may be required, depending upon the alloy and flux selected.

Figure 3: Dissolved solder pot

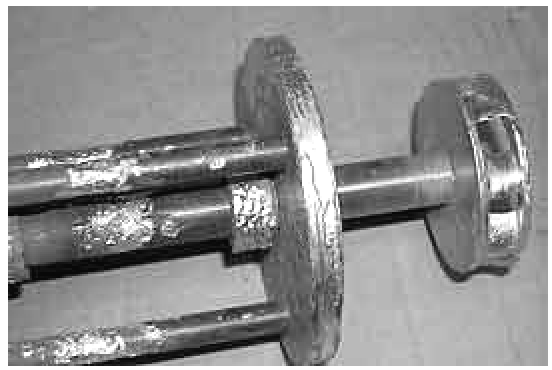


Figure 4: Dissolved impeller

Rework and Repair
Materials - Operators must be re-trained for lead-free rework, as the lead-free solders do not flow as well as tin/lead. This could also require stronger cored wire fluxes to be used. As with any change of flux chemistry, if changing wire solders, particular attention should be paid to both to operating window it offers and the material's reliability characteristics. Some wires often assumed to be safe to leave uncleaned are actually classified as rosin fully-activated and could cause field failures.

All rework should use the same lead-free solder alloy as originally used on the solder joint; different lead-free solder formulations should not be mixed on the same joint. If more than one alloy is in use in the production process (i.e., Sn/Ag/Cu for SMT and Sn/Cu for wave soldering), operators should be trained to use the correct wire for each part. For this reason alone, it is advisable to use a single solder alloy for all assembly operations.

Equipment- It is necessary to ensure that the desoldering and soldering stations are suitable for lead-free processing, i.e. can reach the necessary temperatures for lead-free soldering. It should be noted that lead-free soldering can wear out tips at a much higher rate than tin/lead.

Cleaning
In general, studies have demonstrated that post-process flux residues from lead-free applications are still cleanable. Water soluble chemistries may be cleaned in water, no-clean and RMA chemistries with a saponifier or cleaning solvent. However, it has been found that an increase in pressure, cleaning times and/or cleaner concentrations often is necessary. The efficiency of the cleaning equipment, strength of the cleaner, melting point of the alloy being used and thermal stability and propensity of the flux to "char" all affect the cleanability of an assembly.

[1] Pictures courtesy of TWI/UK

Maintenance

The main challenge for maintenance is the additional wear and tear that lead-free assembly puts on assembly equipment. This is especially true of reflow ovens and wave solder machines. This is the result of the higher melting temperatures at which the lead-free solders require the equipment to work and the tendency of the lead-free materials to wear out the materials they come in direct contact with.

Reflow Ovens

As a result of a greater strain being placed on reflow ovens, additional maintenance to oven components, heating elements, etc. will be required. It has been reported that ball bearings of motors without a cooling fan will breakdown far more frequently as a result of lubrication problems. In addition, the higher reflow temperatures and new flux chemistries could create the issue of flux management, which results in flux control units having to be cleaned more often. Furthermore, sealings in nitrogen equipment will need more frequent replacement.

Wave Soldering Equipment

As discussed above, high-tin alloys rapidly dissolve the materials often used in wave solder equipment. If stainless steel parts are not replaced or protected at the onset of lead-free processing, Maintenance can expect these parts to wear rapidly. As with reflow ovens, wave soldering equipment pushed to its limits by lead-free assembly may require additional maintenance to wave components, heating elements, and flux management systems.

Quality/Inspection

The main challenge for Quality Assurance /Inspection is to recognize the inherent different appearance of lead-free solder joints and flux residues that are not as easily pin probed.

Inspection

Due to inherent physical differences in their grain structures, lead-free solder joints look different than tin/lead solder joints. Whereas tin/lead joints often appear bright & shiny, lead-free joints are generally dull & grainy. In addition, wetting spread may not be as great as with tin/lead joints. However, this does *not* necessarily mean that lead-free joints are sub-standard or weaker than tin/lead joints. Inspection personnel must be trained on what to look for when inspecting lead-free solder joints. Figure 5 contains examples of lead-free solder joints.

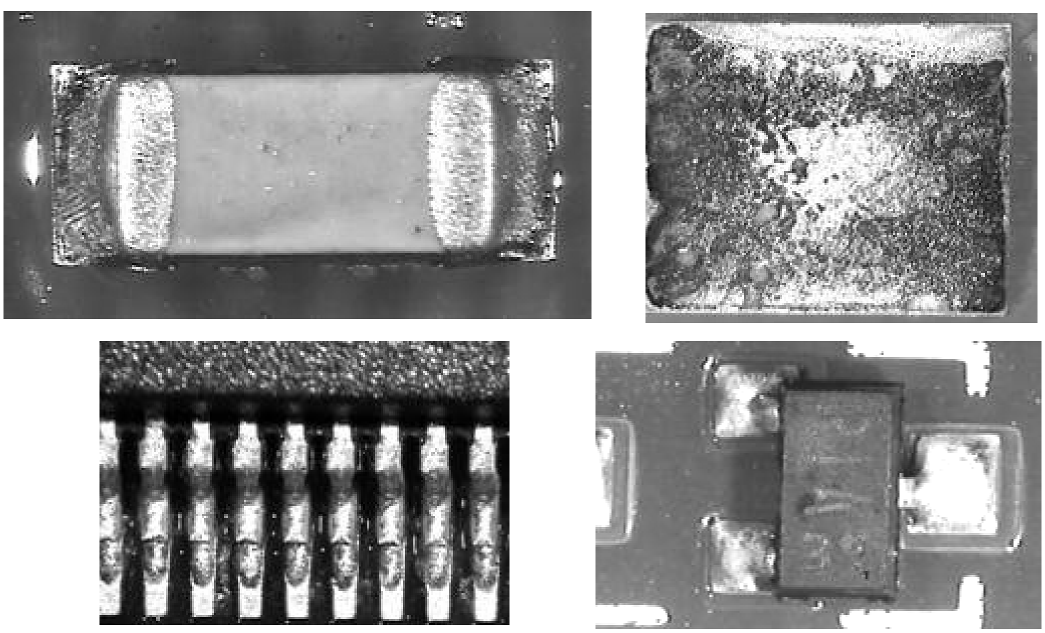


Figure 5: Lead-free solder joints

Pin Probe Testing
Current test fixture settings could possibly damage lead-free solder joints. In addition, the higher reflow temperatures may result in charring and make probing through “pin probeable” flux residues more difficult. This could warrant changing flux chemistries or even residue removal in some cases.

Conclusion
A great deal of empirical information has been presented in order to help organizations implement lead-free soldering per their own time-line. Lead-free electronics assembly is achievable, but it requires a strong understanding of the changes required of *each person* involved in the manufacturing process. This pertains to considerations regarding design, components, PWBs, solder alloys, fluxes, printing, reflow, wave soldering, rework, cleaning, equipment wear & tear and inspection.