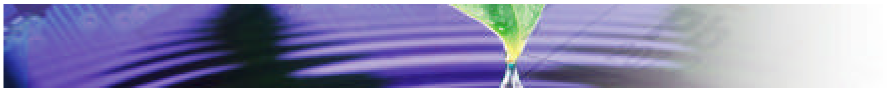
Guide to Changing from Tin/Lead to Lead-Free Soldered Products

PREPARED BY ERA TECHNOLOGY ON BEHALF
OF ARROW ELECTRONICS, INC.



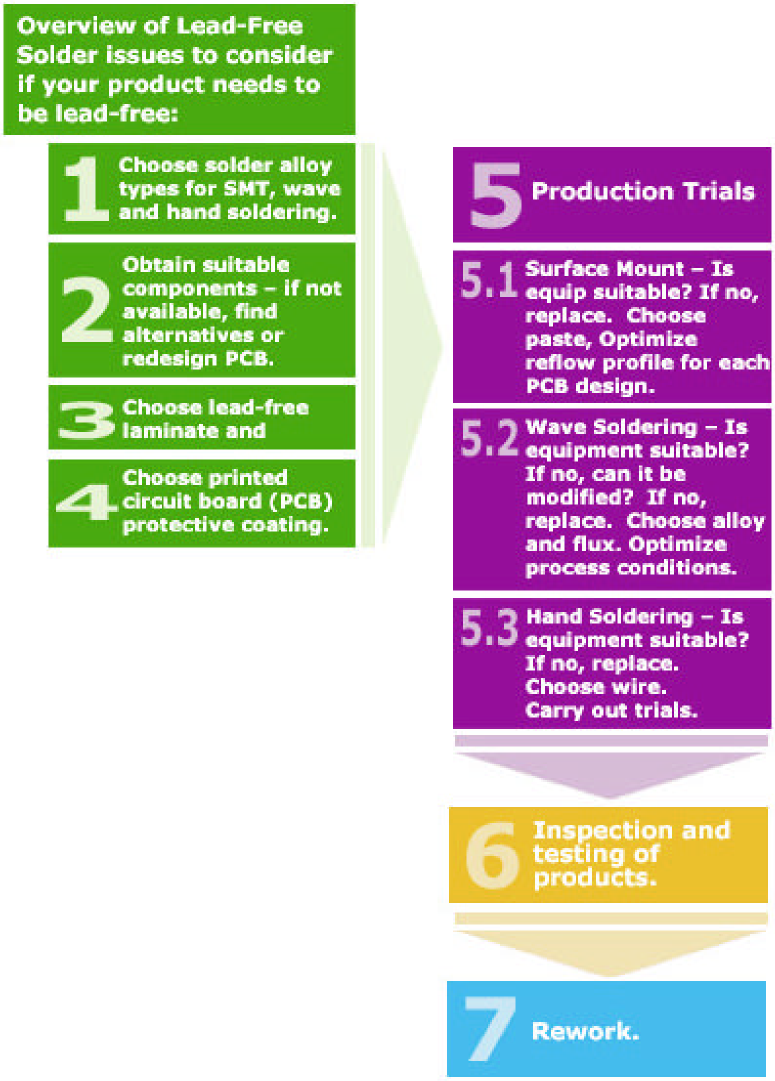
Guide to Changing from Tin/Lead to Lead-Free Soldered Products

To help our customers meet the challenge of manufacturing with lead-free solder for RoHS compliance, Arrow recently commissioned a study by ERA Technology. ERA is an international leader in technology consulting based in the UK.

Our Guide to Changing from Tin/Lead to Lead-Free Soldered Products was prepared by Paul Goodman of ERA, a recognized expert in the field. It is designed to highlight key considerations and steps for your company to use in preparing for your transition.

Arrow collects complex information such as manufacturing characteristics and material composition as it becomes available. Please contact your local Arrow sales office to learn more about the availability of data in our tools and services.

We hope you find this guide informative and useful.



Overview of Lead-Free Solder issues to consider if your product needs to be lead-free:

1 Choose solder alloy types for SMT, wave and hand soldering.

2 Obtain suitable components – if not available, find alternatives or redesign PCB.

3 Choose lead-free laminate and

4 Choose printed circuit board (PCB) protective coating.

5 Production Trials

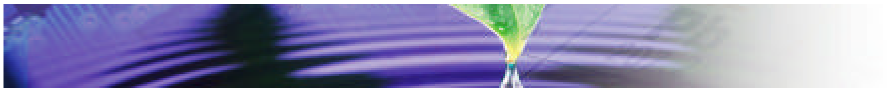
5.1 Surface Mount – Is equip suitable? If no, replace. Choose paste, Optimize reflow profile for each PCB design.

5.2 Wave Soldering – Is equipment suitable? If no, can it be modified? If no, replace. Choose alloy and flux. Optimize process conditions.

5.3 Hand Soldering – Is equipment suitable? If no, replace. Choose wire. Carry out trials.

6 Inspection and testing of products.

7 Rework.



Overview of Lead-Free Solder Issues

In order to comply with the upcoming legislation of the Restriction of Hazardous Substances (RoHS) Directive in the EU, equipment manufacturers will need to produce reliable electrical equipment using lead-free solders. In fact, there are already many lead-free products, mainly consumer goods, available on the market today.

Unfortunately, despite extensive research there is no lead-free alloy which is a drop-in replacement for tin/lead. All of the alternatives are different. Production of reliable product is possible as long as the differences are understood and appropriate lead-free process conditions are developed. Most manufacturers who have developed lead-free processes find that the process window with lead-free is much smaller than was the case with tin/lead and so much better process control is essential.

This article lists the steps required to change over to lead-free technology: choosing solder, components, printed circuit board laminates and coatings, production trials, inspection and training.

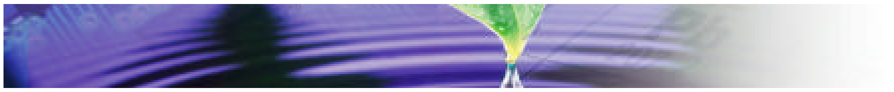
1 - Choose Lead-free Solders

The main types of lead-free solders which are commercially available are:

Alloy composition	**M.pt. °C**	**Comments**
Sn0.7Cu	227	Recommended for wave soldering applications (known as 99C)
Sn3.5Ag	221	Wetting inferior to SnAgCu but used where higher melting point is required
Sn3.5Ag0.7Cu (and variations on this)	217	Most widely used lead-free alloy. Various percentages of silver and copper are used. Recommended by NEMI for surface mount
SnAgBi alloys (some with Cu)	~ 210 - 215	Better wetting properties than SnAgCu but must not be used with lead. Mainly used as solder paste but has been used for wave soldering, mainly in Japan. Wire not available so rework difficult
Sn9Zn	198	Zinc-containing alloys are difficult to use, need special fluxes and are susceptible to corrosion but new solder pastes with reasonable soldering performance have recently been developed
Sn8Zn3Bi	~ 191	Used by several Japanese manufacturers where heat sensitive components are used. Includes NEC and Matsushita. Paste made by Senju. Difficult to use, needs nitrogen for SMT
58Bi42Sn	138	Low melting point, hard, brittle alloy but performed well in reliability trials

The main difference between tin/lead and the most commonly used lead-free solders is melting point. The melting point of SnAgCu is 34°C higher than that of eutectic SnPb. Increased temperature can damage components and laminate and so it is important to:

- use as low a temperature as possible
- avoid heat sensitive components – damage includes plastics melting, delamination of ICs, cracking of brittle ceramic devices, loss of fluid from electrolytic capacitors, and



- consider using high T g laminate for thicker PCBs with many layers and large high thermal mass components – laminate damage can include warping, delamination, and cracks in plated through holes.

2 - Obtain RoHS Compatible (lead-free) Components

The termination coatings of components are being changed from tin/lead to lead-free alternatives. The most common alternative is tin but tin alloys, nickel/palladium/gold and other materials are also used. Details of manufacturer and component availability are at www.arrow.com/green and from your Arrow representative.

Component Issues

Components need to be chosen to ensure that they are RoHS compatible and so do not contain restricted substances. Some components will not be available in RoHS compatible versions and so in these cases redesign of the product will be required.

Many components are heat sensitive and can be damaged by high reflow temperatures. The maximum reflow temperature will be specified by the manufacturer and typical quoted values include:

Component	Max. temperature
Aluminium electrolytic capacitor – maximum temperature depends on size	240 - 250°C
Tantalum capacitor – various types	220 - 260°C
MLCC (ramp rate more important)	240 - 260°C
Film capacitor (depends on plastic film type)	230 - 300°C
SMT relay (plastic deformation)	226 - 245°C
Crystal oscillator (plastic deformation)	235 - 245°C
Connectors – depends on type of plastic used	220 - 245°C
LED – may function but light output affected	240 - 280°C
ICs	245 - 260°C

It is also important to note that the moisture sensitivity levels (MSL) of ICs will probably change so that shorter storage times after removal from packaging can be tolerated.

The implications are that when lead-free PCB production is planned components which are likely to be damaged by the higher temperature should be replaced if possible. In some cases redesign will be needed. This potential need for redesign is one of the main reasons why manufacturers should begin the development of RoHS compliant products now, as this can be very time consuming.

3 - Choice of Laminate

For many applications, standard laminates can be used but if the PCB laminate is relatively thick, has many layers, or there are large heat capacity components, a high Tg laminate may be required.

4 – Choice of Printed Circuit Board Coating

Tin/lead hot air solder level (HASL) cannot be used on PCBs for RoHS compliant equipment. However, there are several suitable alternatives on the market. The most popular are electroless nickel / immersion gold (ENIG), immersion silver, immersion tin and organic solderability preservatives (OSPs).

PCB coating	Advantages	Disadvantages
Organic solderability preservatives (OSP)	Lowest cost lead-free option. Very thin and electrical contact can be made.	Fragile and easily damaged by handling. Protection during storage for shortest of all alternatives, at best 6 months but less if stored in hot humid conditions. Incompatible with some fluxes.
Immersion silver	Thin flat coating with good solder wetting. More robust that OSP and less than half cost of ENIG.	Solder wetting deteriorates if stored in atmosphere with sulphides. Protection during storage for ~ 6 months but can be less.
Immersion tin	Thin flat coating with good solder wetting. More robust that OSP and lower cost than ENIG.	Solder wetting deteriorates during storage, particularly at high humidity. Protection during storage for ~ 6 months but can be less.
Electroless nickel / immersion gold (ENIG)	Best protection of all immersion coatings, up to ~ 1 year in storage. Gold has very good solder wetting.	Most expensive option. Sometimes used to make electrical contacts but these can deteriorate.
Lead-free HASL (SnCu solder)	Good corrosion resistance, flat surface, good solder wetting.	Needs new equipment. High temperature can damage PCB, very good process control needed, boards usually need to be pre-baked.
SnPb HASL (for comparison)	Well understood, good protection, excellent solder wetting and corrosion resistance.	Thermal damage to PCB, surfaces tend to be uneven so not suitable for some large low profile components.

5.1 - Surface mount technology

Most solder suppliers now offer a wide range of solder pastes with lead-free solder alloys. These vary in their performance and some trials to evaluate alternatives using realistic PCBs and components will be required to identify the most suitable product.

Lead-free processes require good temperature control, ideally with forced air convection ovens and a minimum of 7 zones. Throughput will be slightly reduced and there is likely to be a small increase in energy use. Some manufacturers are finding that their ovens originally used for tin/lead are suitable for lead-free but this will depend on the type of PCB, the presence of heat sensitive components, and the performance of the oven.

Solder paste suppliers will provide suggested reflow profiles for their products. The shape is different to lead-free profiles. These should be regarded as a guide for trials and optimisation of profiles will be needed. Many manufacturers are finding that where they could use one profile for most of their tin/lead PCB designs, many different profiles are needed for lead-free and, in some cases, a different profile for each design.

5.2 - Wave soldering

Lead-free solders are more aggressive to steels and can damage internal parts of ovens, particularly if solders containing silver are used. Some, but not all wave soldering machines can be “converted” to operate with lead-free solders and manufacturers should consult their machine vendors to determine if they can be modified to use lead-free solders.

A suitable “lead-free” flux will be required as fluxes designed for tin/lead are usually very poor. Fluxes designed for tin/lead wave soldering function at the temperature at which tin/lead processes are carried out. Lead-free processes are at higher temperatures and so fluxes designed for tin/lead will be consumed and thus much less effective at the higher temperature at which lead-free solder wetting occurs.

As with surface mount, the temperature profile will need to be optimised for each PCB design. It is advisable to regularly analyse the solder until it is clear that no significant undesirable changes will occur. The use of tin/lead terminated components will contaminate the solder and can quickly increase the lead content to above 0.1%.

5.3 - Hand soldering

Lead-free solder wetting time is longer than, and flow inferior to, tin/lead solder. This will reduce throughput in production lines. Lead-free solders and their fluxes are more aggressive than tin/lead and so will reduce tip life, especially if soldering temperature is increased.

To overcome hand soldering problems with lead-free alloys, soldering iron manufacturers have introduced new products which have much better temperature control. These enable faster wetting, allow lower temperatures to be used increasing tip life, and allow wetting of difficult surfaces without the need to use more corrosive fluxes.

6 - Inspection

Most lead-free solder joints will appear dull and have a matte surface unlike tin/lead solder. This is normal but training will be needed to identify good and bad solder joints. IPC have published standard IPC-A-610D for assessment of lead-free solder joints.

X-ray inspection and automated optical inspection are possible with existing equipment although modifications may be required.

7 - Re-work

The same tools can be used as for tin/lead but bear in mind the comments made under hand soldering. Re-worked surfaces are likely to have poor wetting properties so that more aggressive fluxes are required. This can lead to surface insulation resistance (SIR) or electromigration issues; if these are a concern then cleaning to remove these residues may be required.

Other issues

Mixing solder alloys

It is not recommended that alloys are mixed as combinations of metals will be created that could potentially affect long term reliability. Research has shown that some combinations can severely shorten the life of a product. The combination of tin/lead with bismuth solders has been found to create solder joints which are particularly unreliable and so this should be avoided.

Backward compatibility

Manufacturers should be aware that there are a few issues with the use of new “lead-free” components and continued use of tin/lead solders.

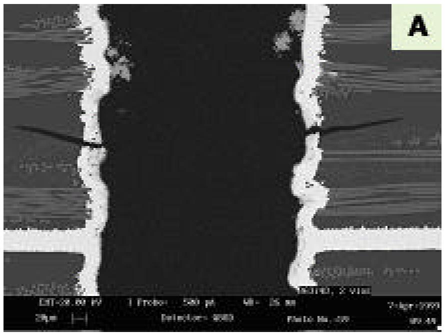
The wetting properties of tin plated termination coatings will be different to tin/lead coatings. As a result, reflow profiles and wave soldering conditions may need to be modified. Hand soldering should not present difficulties although wetting times may be slightly longer.

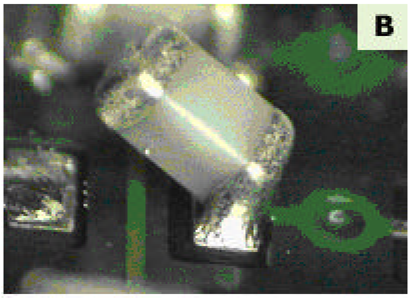
Lead-free ball-grid arrays can be successfully attached to PCBs with tin/lead solder paste but unless the reflow temperature is increased, the balls will not fully melt and this can affect long term reliability.

Defects

All of the defects that can occur with tin/lead also occur with lead-free solders but many will be more likely to occur including:

- Poor wetting
- PCB warping
- Cracks in plated through holes (Figure A)
- Conductive anodic filaments
- Tomb-stoning (Figure B)





The higher temperature can also cause delamination of multilayer PCBs and damage components.

Trials will identify whether any of these is likely to occur and determine what corrective action will be required.

Solder Industry Links

To learn more about Arrow Component Information Services enhancements that include component-level data elements such as lead-free and RoHS compliance status and environmental manufacturability parameters, please visit our Component Information Services page at www.arrow.com/cis.

Additional information on the issues associated with lead-free manufacturing / soldering is available on many industry websites including:

Soldertec: Tin Technology - www.tintechnology.biz/soldertec/soldertec.aspx

Inemi: International Electronics Manufacturing Initiative - www.inemi.org/cms

ERA Technology Lead-Free & RoHS Directive Compliance Services -
www.era.co.uk/Services/RoHS.asp

IPC Lead-Free Soldering Site - www.leadfree.org