

This application note describes the board assembly process used in surface-mount technology (SMT) and focuses on the SMT component-to-board reflow soldering process and rework soldering if you are removing or replacing individual components on already-assembled boards.



The information in this application note is for your reference only.

Conventional Tin-Lead and RoHS-Compliant Lead-Free Components

Altera® provides both the conventional tin-lead and restriction of hazardous substances (RoHS)-compliant lead-free packages. [Table 1](#) lists the second Level Connections of each package type.

Table 1. Second Level Connections

Package Type	Wire Bond (Eutectic)	Wire Bond (RoHS Compliant or Pb-Free)	Flip Chip	Flip Chip (RoHS Compliant or Pb-Free)
Lead frame	Sn85Pb15	Matte Sn	—	—
Ball-grid array (BGA)	Sn63Pb37 (Balls)	SAC305 (Balls)	Sn63Pb37 (Balls)	SAC305 (Balls)



While lead-frame and wire-bond packages can be provided as eutectic or lead-free, currently Altera flip-chip packages are RoHS compliant. We use Exemption #15 for the first Level Connections between the flip-chip die to the substrate (RoHS Exemption #15: Lead in solders to complete a viable electrical connection between the semiconductor die and the carrier within the integrated circuit flip-chip packages). For the remainder of this application note, the term *Pb-free* is used to refer to the BGA solutions provided with Pb-free package solder balls. This is considered the second Level Connections between the package and the PCBs.

The recent directives and legislations by nations around the world have mandated elimination of hazardous substances in the electronics industry. While elimination of many of these substances do not have significant impact on reflow soldering of the electronic component, there is one notable exception—lead. The elimination of lead from solders requires special consideration in soldering of the Pb-free components on to PCBs. This application note outlines the differences and recommends solutions to develop the reflow process for Pb-free and RoHS-compliant devices.

Altera has taken an industry leadership position and has adopted lead-free technologies to provide solutions that align with industry requirements. In semiconductors, lead is mainly used in packaging as a part of the eutectic solder used as the surface finish for leaded packages and as solder balls for BGA packages. Altera has proactively researched alternatives for lead compounds and has selected matte Sn lead finish for leaded packages and Sn-3-4%Ag-0.5%Cu solder balls for BGA packages. In addition, the thermal robustness of the packages has been improved by selecting appropriate materials and processes to allow for the higher reflow temperature compatibility required for assembling boards using lead-free solder pastes.

 For more information about Altera's Pb-free product offerings and solutions, refer to the [Packaging](#) page of the Altera website.

Surface-Mount Technologies—Pb-Free Soldering Versus Tin-Lead Soldering

This section outlines the differences between conventional tin-lead reflow soldering and Pb-free soldering.

The reflow soldering process for Pb-free components is very similar to the conventional eutectic (tin-lead) solder reflow process. Often, you can use the same equipment set and process steps used for eutectic soldering for Pb-free soldering.

However, some important differences must be taken into account for Pb-free soldering, as the material set used for Pb-free soldering is different and higher reflow temperatures are required. The important factors that must be considered for Pb-free soldering are described in the following sections.

PCB Considerations

The important PCB consideration is the surface finish. Several PCB surface finishes, such as Organic Solderability Preservatives (OSP) and metallic surface finishes (such as electrolytic NiAu and immersion silver), are available in the industry. You need to determine the PCB surface finish based on wetting, storage, planarity, and cost issues. In addition, you must ensure that board materials can withstand reflow temperatures without warpage or other damage. For most cases, FR-4 board material is acceptable, but high-density and high-complexity applications may require different board materials, such as high Tg FR-4 (above 170°C).

Solder Alloy and Flux Considerations

A wide range of solder paste alloys are available in the industry. The lead-free alloys typically have higher soldering temperatures than eutectic solder. The SnAgCu family of solder alloys is most commonly used for SMT manufacturing. The eutectic and Pb-free solder alloy selected must be nonhazardous, mechanically reliable, thermal fatigue resistant, have good wetting and relatively low melting temperature, and must be compatible with a variety of lead-bearing and lead-free surface coatings (1).

When selecting flux chemistries suitable for Sn-Pb and Pb-free processing, you must consider the flux activation temperature, activity level, compatibility with chosen lead-free alloy and reliability properties, such as surface insulation resistance (SIR) and electromigration.

Print Process Considerations

Sn-Pb and Pb-free pastes require special handling. You must take into consideration the development of the printing process and the specific aspects of the lead-free paste, as outlined in this section.

Solder Paste Handling

The shelf life and storage conditions of the lead-free pastes may be different from the eutectic solder pastes. To avoid issues related to paste handling, you must strictly follow the paste handling recommendations provided by the paste manufacturers.

Screen Printing

The printing process for lead-free pastes is identical to the process used for eutectic solder pastes. You must follow the guidelines recommended by the paste manufacturers to accommodate paste-specific requirements. In general, the lead-free paste characteristics yield similar performance in terms of stencil life, aperture release, print definition, and repeatability.

One important factor that you must consider in designing stencils is that lead-free pastes have higher surface tension and do not wet or spread on the surface of pads as easily as eutectic solder pastes. This higher surface tension can lead to exposed pad finish material after reflow soldering. You can rectify this problem by modifying the stencil aperture designs to increase the paste coverage on the pads.

Reflow Process Considerations

For Pb-free soldering, the most important factor to consider is the characterization and optimization of the reflow process. The reflow process window for conventional soldering is relatively wider than that of Pb-free soldering.

The melting point of eutectic solder is 183°C. The lower temperature limit for reflow is usually 200°C. The upper limit is approximately 235°C, which is the maximum temperature to which most components can be exposed ([Table 3 on page 5](#)). These high- and low-temperature limits provide a process window of over 35°C.

The lead-free alloy used for BGA solder balls has a melting point of 217°C. This alloy requires a minimum reflow temperature of 235°C to ensure good wetting. The maximum reflow temperature is in the 245°C to 260°C range, depending on the package size ([Table 4 on page 5](#)). This narrows the process window for lead-free soldering from 10°C to 20°C.

The increase in peak reflow temperature, in combination with the narrow process window, makes the development of an optimal reflow profile a critical factor for ensuring a successful lead-free assembly process. The major factors contributing to the development of an optimal thermal profile are the size and weight of the assembly, the density of the components, the mix of large and small components, and the paste chemistry you use.

To ensure that all components are heated to temperatures above the minimum reflow temperatures and that smaller components do not exceed the maximum temperature limits, you must perform reflow profiling by attaching calibrated thermocouples embedded in the spheres of the larger BGA parts as well as other critical locations on the boards (2). Because the components are subjected to higher reflow temperatures, select the appropriate moisture sensitivity level (MSL) for the components and component handling. You must strictly follow the storage recommendations.

Although nitrogen is not required, Altera recommends including nitrogen in the reflow process as its presence helps achieve better wettability and widen the process window. Nitrogen is especially beneficial when temperature differential across the board is large. Additionally, nitrogen improves the appearance of solder joints by inhibiting the effects of oxidation.

Manufacturing processes for each PCB are unique and may require unique solutions to ensure acceptable levels of quality, reliability, and manufacturing yield. Because of differences in equipment, materials, and PCB density and sizes, you will need your own unique process parameter development and validation.

To ensure that all packages are successfully and reliably assembled, the reflow profiles studied and recommended by Altera are based on the JEDEC/IPC standard J-STD-020 revision D.1 (3).

Figure 1 shows the range of temperature profiles compliant with the JEDEC/IPC standard J-STD-020 revision D.1 (3).

Figure 1. IR/Convection Reflow Profile (IPC/JEDEC J-STD-020D.1)

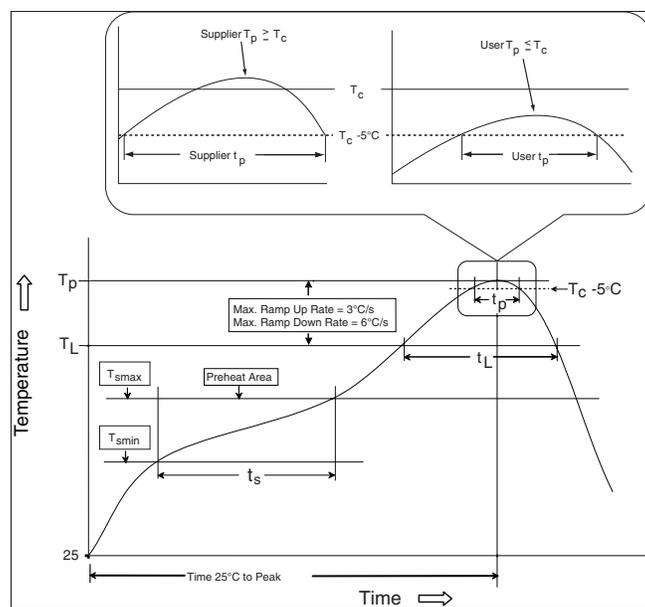


Table 2, Table 3, and Table 4 list the reflow parameters and peak temperatures as recommended by JEDEC (3). Industry studies have shown that the Ramp-to-Spike (RTS) process yields better results for the Pb-free assembly. This RTS profile type offers better wetting and less thermal exposure than the Ramp-Soak-Spike (RSS) profile typically used in eutectic soldering.

Table 2 lists the reflow profile recommendations.

Table 2. Reflow Profile Recommendations (JEDEC/IPC J-STD-020D.1) ⁽¹⁾

Profile Feature	Sn-Pb Eutectic Assembly	Pb-Free Assembly
Average ramp-up rate (T _S MAX to T _P)	3°C/ second maximum	3°C/ second maximum
Minimum preheat temperature (T _S MIN)	100°C	150°C
Maximum preheat temperature (T _S MAX)	150°C	200°C
Preheat time (T _S MIN to T _S MAX) (t _S)	60–120 seconds	60–120 seconds
Temperature (T _L)	183°C	217°C
Time above liquidous temperature T _L (t _L)	60–150 seconds	60–150 seconds
Peak temperature (T _P)	Refer to Table 3	Refer to Table 4
Time within 5°C of peak T _P	20 seconds ⁽²⁾	30 seconds ⁽²⁾
Average ramp-down rate (T _P to T _S MAX)	6°C/ second maximum	6°C/ second maximum
Time 25°C to T _P	6-minutes maximum	8-minutes maximum

Notes to Table 2:

- (1) All temperatures refer to the topside of the package, measured on the package body surface.
- (2) Tolerance for T_P is defined as a supplier's minimum and a user's maximum.

Table 3 lists the Sn-Pb eutectic process peak reflow temperature (T_P).

Table 3. Sn-Pb Eutectic Process—Peak Reflow Temperature (T_P) ⁽¹⁾, ⁽²⁾

Package Thickness	Volume mm ³ < 350	Volume mm ³ ≥ 350
< 2.5 mm	235°C	220°C
≥ 2.5 mm	220°C	220°C

Notes to Table 3:

- (1) The package volume excludes the external terminals such as balls, bumps, lands, and leads.
- (2) The tolerance of all classification temperatures is ±2°C.

Table 4 lists the Pb-free process peak reflow temperature (T_P).

Table 4. Pb-Free Process—Peak Reflow Temperature (T_P) ⁽¹⁾

Package Thickness	Volume mm ³ < 350	Volume mm ³ 350–2000	Volume mm ³ > 2000
< 1.6 mm	260°C	260°C	260°C
1.6 mm–2.5 mm	260°C	250°C	245°C
> 2.5 mm	250°C	245°C	245°C

Note to Table 4:

- (1) The package volume excludes the external terminals such as balls, bumps, lands, and leads.

Typical Reflow Oven Setting for Altera's Board-Level Reliability Studies

Altera uses a PCB board 40 cm long by 10 cm wide and 2.36 mm thick for board-level reliability studies. The following oven settings are based on an eight-zone production reflow oven.

Table 5 lists the Pb-free reflow oven settings.

Table 5. Pb-Free Reflow Oven Settings

Zones	1	2	3	4	5	6	7	8
Temperature setting	180°C	190°C	195°C	195°C	210°C	240°C	270°C	275°C
Belt Speed	32 inch/ minute							
Targeted peak temperature	205°C to 245°C							
Time above liquidus (217°C)	60 to 90 seconds (Approximately 70 seconds)							
Package Type	1517-Pin FineLine BGA (Flip Chip)							

Table 6 lists the eutectic reflow oven settings.

Table 6. Eutectic Reflow Oven Settings

Zones	1	2	3	4	5	6	7	8
Temperature setting	150°C	160°C	160°C	160°C	170°C	195°C	250°C	255°C
Belt Speed	32 inch/ minute							
Targeted peak temperature	205°C to 215°C							
Time above liquidus (217°C)	60 to 90 seconds (Approximately 60 seconds)							
Package Type	1517-Pin FineLine BGA (Flip Chip)							

Compatibility with Pb-Free Assembly Rework

Per the JEDEC standard J-STD-033, the Pb-free area array components (Table 4) must be capable of assembly rework at 260°C within eight hours of removal from dry storage or bake. This requirement is not applicable for the eutectic Sn-Pb area array components.

To reduce thermal stress on boards and components, you must control the peak temperatures below the recommended maximums (Table 4) and minimize the temperature gradients across the board. High temperatures can put significant stress on plated through-holes and barrels, which can lead to cracking. High first-pass temperatures on double-sided assemblies increase the amount of second-side oxidation, which can cause solderability problems on the second pass.

Altera has worked extensively with leading EMS companies and has successfully demonstrated that the Pb-free parts can be soldered in air atmosphere (5).

However, for high-density, two-sided assemblies, you can alleviate the problems related to a narrow process window by selecting modern reflow ovens with forced convection and more heating zones with tighter process controls on reflow parameters. Reflow ovens equipped with nitrogen reflow atmosphere have shown to improve wettability at lower peak temperatures and reduce temperature gradients across the board and have proven beneficial for double-sided assemblies (6).

Post-Reflow Inspection

Industry studies have shown that using automated x-ray inspection systems are effective for both the eutectic and lead-free solder joints. You may have to optimize the x-ray inspection systems to take into account the contrast differences of the lead-free solder and the differences in solder fillet shape and length.

You can also use Automated Optical Inspection (AOI) and visual inspection methods for inspecting solder joints other than BGA joints. Lead-free solder joints are not as shiny as eutectic solder joints. Therefore, inspectors must be trained to distinguish the lead-free solder joints from the eutectic solder joints. Optimize the AOI system parameters to account for changes in the solder fillet shape and the reflection characteristics of the solder joint surface (4).



For more information, refer to the latest IPC-A-610D Standard.

Manual Soldering and Rework

Because higher soldering temperatures are required for lead-free solders, set the solder tip temperature higher. The higher soldering temperature requires that you keep the soldering iron clean and coated with the solder alloy. Lead-free solders are more sensitive to the effects of a dirty soldering iron. If not cleaned and coated, the higher soldering temperatures can result in the soldering iron tip becoming oxidized. You can improve the soldering performance with more active solder flux and soldering in nitrogen atmosphere. In addition, the technicians performing the operation must be trained thoroughly in lead-free soldering operation.

BGA Rework

The rework process for Pb-free BGAs is similar to that used for eutectic BGAs. The BGA rework process typically consists of the following steps:

1. Thermal profiling
2. Removal of defective component
3. Site redressing
4. Solder replenishment or flux application
5. New component placement
6. Reflow soldering
7. Post reflow inspection

The rework machine must be capable of handling both eutectic and lead-free processing temperature. The equipment must be a preheat system equipped with a vision system that can accurately place fine-pitch components, hot gas airflow control, and have software capable of thermal profiling and editing rework sequences.

Site redressing is a crucial process in lead-free rework. There are two methods for site redressing—the soldering iron or wick method and the copper coupon redress method. The success of the redressing techniques depends on the technician's skill and training.

The components being reworked have been exposed to moisture, they must be baked before reflow. The baking parameters depend on the MSL of the package.

Thermal profiling is very important and you must measure the temperature at the solder joints. Thermal profiles must be developed for component removal and the component replacement process. In addition, board preheating has proven to be beneficial during reflow to reduce thermal gradient related stresses on adjacent components. Also, using nitrogen gas improves wettability and reduces manufacturing defects during the rework process (6).

Backward Compatibility

In this application note, backward compatibility refers to the soldering process. Both eutectic and Pb-free devices from Altera have the same form, fit, and function. If you switched from Altera's eutectic Sn-Pb products to Pb-free products, no board design changes would be required. However, the finish materials for PCBs, solder paste, and SMT reflow profiles will need adjustment. Altera does not recommend using the eutectic BGA packages in the Pb-free process.

Altera lead-frame packages (for example, plastic J-lead chip carriers [PLCC], plastic quad flat pack [PQFP], or power quad flat pack [RQFP]) are backward compatible. The components are soldered with Sn-Pb solder using the Sn-Pb soldering process. Altera lead-frame packages use matte Sn plating on the leads, which are compatible with both Pb-free and Sn-Pb soldering alloys.

However, Altera does not recommend soldering Pb-free BGA packages (for example, PBGA, super BGA™, FBGA, Lidless FBGA, Flip Chip FBGA, or FCmBGA) with Sn-Pb solder using the Sn-Pb soldering process. The eutectic Sn-Pb soldering process usually has a peak reflow temperature of 205°C to 220°C. At this temperature range, the SnAgCu BGA solder balls do not properly melt and wet to the soldering surfaces. As a result, reliability and assembly yields are compromised.

References

1. Lau, John and Liu, Katrina, "Global Trends in Lead-free Soldering—Part I and II," Advanced Packaging, January and February 2004.
2. Baldwin, Daniel and Kazmierowicz, Philip, "Taking the pain out of lead-free reflow," www.assemblymag.com, December 2003.
3. JEDEC/Electronic Industries Alliance, Inc, "Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices," March 2008.
4. Bath, Jasbir, "A Manufacturable Lead-Free Surface Mount Process," January 2003.
5. Bath, Jasbir; Chou, Chris; Lam, Samson; Wu, Roy; and Yoon, Sam, "Lead-Free BGA Assembly," July 1, 2004.
6. Åström, Anders, "The Effect of Nitrogen Reflow Soldering in a Lead-Free Process," September 2003.

Document Revision History

Table 7 lists the revision history for this application note.

Table 7. Document Revision History

Date	Version	Changes
October 2011	4.0	<ul style="list-style-type: none"> ■ Combined AN-353 with AN-81. ■ Minor text edits.
September 2010	3.0	<ul style="list-style-type: none"> ■ Changed title from “Reflow Soldering Guidelines for Pb-free Packages” to “Reflow Soldering Guidelines for Lead-Free and RoHS-Compliant Packages” ■ Updated Table 1. ■ Updated Figure 1. ■ Added note to page 1. ■ Added the “Compatibility with Pb-Free Assembly Rework” section. ■ Applied new template. ■ Minor text edits.
February 2009	2.0	Technical changes to Table 1.
July 2004	1.0	Initial release.

