



# Reflow Soldering Guidelines

## for Surface-Mount Devices

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Application Note 81

## Introduction

Altera's surface-mount packages include quad flat pack (QFP), plastic J-lead chip carriers (PLCC), and ball-grid array (BGA), including FineLine BGA™ packages. Several soldering methods exist for these devices, but a combination of forced-air convection and infrared reflow soldering is the most common way to secure surface-mount technology (SMT) devices to printed circuit boards (PCBs). The reflow process consists of applying a eutectic solder paste to a circuit board, placing devices onto the paste, and then conveying the board through an oven with successive heating elements of varying temperatures. In the oven, each board typically goes through the following stages:

- Gradual preheating
- Brief duration at high soldering temperature
- Controlled cooling process

The maximum temperature, the rate of heating, the time a device spends at each temperature, controlled heating, and controlled cooling are critical parameters for effective soldering.

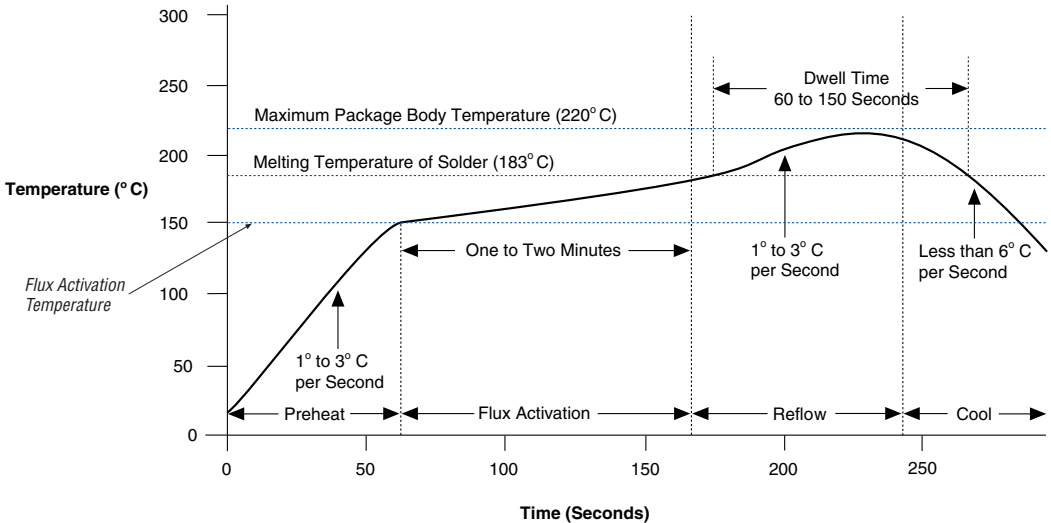
Customers' experiences have shown that Altera® surface-mount products can be mounted successfully on boards over a wide range of temperatures. However, an inappropriate reflow process can damage plastic packages. Although Altera does not perform board assembly, guidelines for reflow processes have been developed. These guidelines are based on Joint Electron Device Engineering Council (JEDEC) Standards (see "[References](#)" on page 10 for more information). Altera subjects devices to a controlled introduction of moisture and simulation of convection reflow as required in the JEDEC standards, followed by temperature cycling stress to validate component reliability. Altera also subjects devices to a complete board-level reflow to the JEDEC guidelines at an outside contract manufacturer, followed by board-level temperature cycling for board-level reliability validation. Each board design has an individual optimal reflow temperature profile that is dependent on application, available equipment, and solder paste. However, the recommendations in this application note provide guidelines and limits to ensure that devices are not unduly stressed and that the customer reflow process is properly characterized to successfully attach Altera devices. An example profile used by Altera's contract manufacturer is also included.

# Temperature Profiles

Because different board designs use different number and types of devices, solder pastes, reflow ovens, and circuit boards, no single temperature profile works for all possible combinations. However, you can successfully mount your packages to the PCB by following the proper guidelines and PCB-specific characterization. Altera runs both component-level verification using in-house Heller reflow chambers and board-level assembly with a third-party manufacturer. The results of this testing are verified through post-reflow reliability testing. Profiles used at Altera are based on JEDEC standards to ensure that all packages can be successfully and reliably surface mounted. Figure 1 shows a sample temperature profile compliant to JEDEC standards. You can use this example as a generic target to set up your reflow process. You should adhere to the JEDEC profile limits as well as specifications and recommendations from the solder paste manufacturer to avoid damaging the device and create a reliable solder joint. Guidelines on profiling PCB boards and characterizing new PCB designs are provided in “Reflow Tips” on page 3. You should properly and fully characterize any new PCB design to achieve good reflow results. The graph in Figure 1 illustrates the four basic stages of a reflow oven:

- Preheat
- Flux Activation
- Reflow
- Cool

Figure 1. Temperature Profile for Infrared or Convection Reflow



## Reflow Stages

In the preheat stage, the solder paste dries while its more volatile ingredients evaporate. After preheating, the leads should be kept at about 150° C for one to two minutes so the flux in the paste can clean the bonding surfaces properly. During the flux activation stage, the solder on all areas of the board should be roughly the same temperature. The devices enter the reflow stage when the temperature increases at a rate of 1° to 3° C per second. To prevent warping, bridging, and cold solder joints, keep the package body above the solder's melting point (183° C) for at least 60 seconds. The device body temperature—which may vary from the temperature of the leads by as much as 15° C—should not exceed 220° C. The package should be within 5° C of the actual peak temperature for 10 to 30 seconds. Small devices with a volume of less than 350 mm<sup>3</sup> will heat up more than larger packages. These devices have a maximum temperature rating of 240° C.

## Post-Reflow Cooling

The reflow stage is complete when the molten solder connections cool and solidify to form strong solder joint fillets. A fast cooling rate reduces the grain size of the intermetallic compounds and strengthens the solder joints. However, controlled cooling is important to reduce stress on the component body and minimize warping; this can sometimes best be achieved by a slow cooling rate depending on oven capabilities (air velocity, placement of heating elements, belt width, etc.).

## Post-Reflow Cleaning

After the soldering process, a simple wash with de-ionized water sufficiently removes most residues from the board. Most board-assembly manufacturers use either water-soluble fluxes with a tap water wash, or "no-clean" fluxes that do not require cleaning after reflow.

## Reflow Tips

New PCBs should always be characterized to a specific reflow profile using production ovens. Belt width, thermal mass of the board, air velocity and placement of heater elements can influence successful reflow. You should follow body temperature restrictions described in [Figure 1](#) to avoid moisture-related damage. You should thermal-probe larger components, particularly BGA and FineLine BGA packages, at several locations to verify the temperature is consistent across the component and that all key profile attributes are maintained.

The following tips provide information on how to optimize the reflow process:

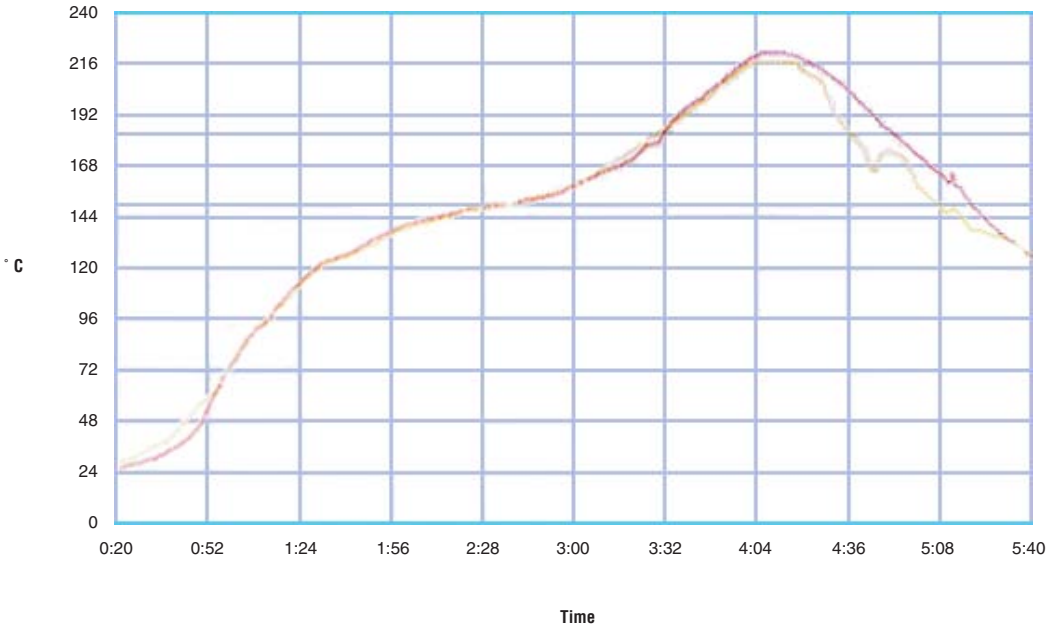
- For more uniform heating, use ovens that utilize a combination of full convection and IR heating. In general, ovens providing more heating/cooling zones are better because they provide greater control and shaping of the temperature profile.
- Use an oven with more heating elements on both its floor and ceiling to minimize temperature variations, deliver precise temperature, and provide the necessary heat to board areas that might be shielded.
- Variation can exist across the width of an oven belt - it's best to characterize and run a board in the same relative position (across the width of the oven belt) in the oven. Pay attention to temperature variations particularly at the edges of the PCB.
- Place thermocouples on the PCB adjacent to the leads/balls and on the bodies of the devices. You should also place thermocouples at the center ball location of BGA devices by drilling through the underside of the PCB board. This should be the coolest location on the device. Monitor the lead/ball temperatures to ensure good solder joints, and monitor the device body temperatures to protect the devices. The difference between the lead/ball and device body temperatures can be as high as 15° C. Therefore, it is risky to rely on temperature measurements at only one location. Thermocouples should not be applied to heat sinks, but to alternative surfaces such as the package substrate or the PCB board immediately adjacent the package.
- Adjust the reflow duration to create good solder joints without raising the device body temperature beyond the allowed maximum of 220° C (240° C for packages smaller than 350 mm<sup>2</sup>).
- Validate the reflow process by thermal profiling and evaluating the solder joints. You can evaluate the solder joints electrically, visually (with BGA packages, only on the outer row), and, if possible, by cross-section analysis. You can also evaluate the solder joints on BGA packages by x-ray. Analyzing the solder joints may reveal specific ways to improve the reflow profile/process.

### Reflow Process Example

Altera performs board-level reliability evaluations by first reflowing BGA components onto reliability stress boards at a local contract manufacturer. The contract manufacturer uses a Conceptronics eight-zone oven, along with Qualitex 778 water-soluble solder paste. Altera reliability stress boards are between four to eight layers, 63 to 93 mils thick, 13 inches × 4.5 inches, use SnPb HASL pads, and are made of standard FR4 board material. Altera performs board-level temperature cycling to check solder connections on all reflow experiments and reliability (see the *Altera Reliability Report* posted at <http://www.altera.com>).

A typical reflow profile from Altera’s contract manufacturer is shown in Figure 2. This is an example profile measured on an Altera FineLine BGA device. Different package types have different profiles due to individual device characteristics, especially thermal mass and construction. Tables 3 and 4 provide parameters to the reflow profile in Figure 2.

Figure 2. Reflow Profile



Probe	Location	Time Above 150° C (Seconds)	Time Above 185° C (Seconds)	Peak Temperature (° C)
Probe 1	Next to solder point	160	81	220
Probe 2	Top of package	149	68	217

<i>Table 4. Oven Setting</i>	
Oven Setting	Temperature (° C) (1)
1	150
2	150
3	160
4	160
5	160
6	190
7	230
8	230

*Note to Table 4:*

(1) This temperature is for both the top and bottom of the device.

## Device Moisture- Sensitivity

Semiconductor moisture sensitivity becomes an important issue as board assemblers switch to hotter and faster reflow processes. Any non-hermetic package can absorb moisture. Like popcorn, the moisture in some plastic packages can vaporize and expand rapidly due to high temperatures causing cracks or delamination (a separation of the plastic from the die or leadframe inside a device). Delamination sometimes, but not always, degrades devices.

Altera is dedicated to improving package materials to reduce the risk of moisture-induced damage. Nevertheless, as a precaution, Altera currently bakes and dry-packs devices in the following package families (these are plastic surface mount packages that may require dry-pack, depending on the number of leads and the device):

- Thin quad flat pack (TQFP)
- Power quad flat pack (PQFP)
- Plastic quad flat pack (PQFP)
- Plastic J-lead chip carrier (PLCC)
- Ball-grid array (BGA), including FineLine BGA packages

Based on the sensitivity of each device to moisture, Altera has specified the floor life of each package, which is the maximum recommended time between removing devices from a dry pack and soldering them onto a PCB. To determine the floor life for each moisture-sensitive device, Altera forced moisture into sample packages, then subjected them to typical reflow temperatures and temperature cycling. The devices were subsequently tested electrically and analyzed physically with x-ray and acoustic microscopy to gauge their sensitivity to moisture. Altera performs moisture sensitivity tests according to *Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices* (J-STD-020A). Reliability and solder tests demonstrate that 220° C is both a satisfactory and safe maximum body temperature for Altera devices during reflow. The MSL is indicated on the dry-pack label. The dry-pack label also provides the recommended bake conditions for devices out of dry pack for longer than the recommended time.

Altera provides a broad range of packages, pin counts, and device sizes. While this variety provides convenient options for designers, it precludes Altera's ability to specify one level of sensitivity per package type. For instance, QFP packages with a larger die or pin count tend to be more sensitive to moisture than QFP packages with smaller die or pin count. Therefore, Altera tests the sensitivity of packages by using representative devices with a variety of die sizes, die shapes, and pin count. (Although similar packages tend to have similar sensitivity, all devices in a particular package rarely have the same floor life.) Based on the tests of the representative devices, Altera specifies the sensitivity of each device and package combination. However, designers should refer to the dry-pack labels, which have the most current and reliable information about a device's sensitivity to moisture. When transferring devices to new dry-pack bags, operators should carefully copy the floor life and expiration date onto the new dry-pack labels.

## Reflow of Moisture-Sensitive Devices

Once the moisture-sensitive devices are removed from their dry-pack bags or other controlled environments, the devices should be soldered onto a PCB within the floor life specified on the dry-pack label. Devices can be stored indefinitely in a desiccant cabinet, which is a controlled environment kept at less than 30° C and 10% relative humidity. If a device is stored in an uncontrolled environment, bake it for 12 hours at 125° C to dry it, then mount the device within the specified floor life.



For more information about storing and handling moisture-sensitive devices, see *AN 71: Guidelines for Handling J-Lead, QFP & BGA Devices* and *Standard for Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices* (IPC/JEDEC J-STD-033).

## Guidelines for Removing SMT Devices

During reflow, the device's temperature should be kept below 225° C (240° C for packages smaller than 350 mm<sup>3</sup>), and the rate of temperature increase should be kept between 1° to 3° C per second. Based on testing done by Altera, the devices can operate safely at any humidity level after reflow.

When the soldering process is complete, you may need to rework or remove SMT devices from PCBs. Although Altera devices are designed for ease-of-use, you should be careful when separating them from PCBs. Careless heating or removal of a plastic package can cause thermal and lead damage. These degradations may render a device useless, impeding any failure analysis and preventing the reuse of the device. Therefore, it is important to observe the thermal and lead damage precautions outlined in this section.

### Preventing Thermal Damage

Removing SMT devices requires guidelines similar to those for soldering parts. The temperature, rate of heating, and time a device spends at each temperature are the most critical parameters for effective soldering. These thermal guidelines are also important when removing devices from PCBs—whether you use an oven, heat gun, or soldering iron. Most importantly, you should ensure that the temperature of the plastic packages does not exceed 220° C (235° C for packages smaller than 350 mm<sup>3</sup>). By adjusting the duration of heating, you can safely remove devices in almost all cases without raising the temperature of the package body beyond 220° C (235° C for packages smaller than 350 mm<sup>3</sup>).

To prevent thermal damage, follow these guidelines:

- Place thermocouples on the PCB adjacent to the leads/balls and on the body of a device. You should monitor the leads' temperature to ensure clean removal of solder and the package body temperature to protect the device. The difference between the lead and device body temperatures can be up to 15° C. Therefore, it is risky to rely on temperature measurements at only one location. Thermocouples should not be applied to heat sinks, but to alternative surfaces such as the package substrate or the PCB board immediately adjacent to the package.



- When heated, some plastic devices are especially sensitive to moisture, which can quickly expand and irrevocably destroy devices. After reflow, based on Altera's testing, even these devices can operate safely in any level of humidity. If a device's exposure to moisture exceeds the JEDEC-rated moisture sensitivity level (MSL), bake it for 12 hours at 125° C to dehydrate it, and then remove it from the board within the recommended floor life duration. The JEDEC-rated MSL is characterized by Altera and can be found on the dry-pack moisture label. If all moisture-sensitive devices on the board are within the original specified floor-life times, baking is unnecessary.

### Preventing Lead Damage

Although Altera uses industry-standard materials and assembly processes for QFP, SOIC, and J-lead packages, you should handle SMT devices carefully to prevent lead damage, which can cause solder-related problems. In addition, extreme temperatures can damage the solder plating (i.e., by oxidation), and solder from the PCB may remain on leads and cause shorts by bridging. To prevent these types of lead damage, you should ensure that the leads are heated for the right amount of time at a uniform temperature before removing a device. The actual temperatures and durations depend on the heating tools and methods, which require some experimentation.

To prevent lead damage, follow these guidelines:

- Place thermocouples on the leads and bodies of the devices. You should monitor the leads'/balls' temperature to ensure clean removal of solder and the package body's temperature to protect the parts. The difference between the lead/ball and device body temperatures can be as high as 15° C. Therefore, it is risky to rely on temperature measurements at only one location.
- Once the solder on the PCB is sufficiently heated, use a vacuum pen to lift a device straight up off a PCB. Avoid twisting or rotating the device while removing it. Also, do not touch or cut leads if the device will be reused or returned to Altera for failure analysis.
- Soon after removing a device from a PCB, wash it with de-ionized water to remove excess solder and residues.
- Using a vacuum pen, immediately transfer removed devices to an Altera-approved tray. Ensure that each device sits in the tray correctly.



For more information on Altera-approved trays, see *AN 71: Guidelines for Handling J-Lead, QFP & BGA Devices*.

## References

Institute for Interconnecting and Packaging Electronic Circuits, Inc. *Component Packaging and Interconnecting with Emphasis on Surface Mounting* (ANSI/IPC-SM-780). New York: Institute for Interconnecting and Packaging Electronic Circuits, Inc., 1988.

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