Solder Joint Temperature and Package Peak Temperature Determine the Thermal Limits during Soldering

Processability of Integrated Circuits
JEDEC/IPC J-STD-020C (http://www.jedec.org) is a Joint Industry Standard of Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices. This document takes care to determine the package temperature and thermal mass dependent Moisture Sensitivity Level (**MSL**) of products in order to ensure reliable processing of moisture sensitive surface mount components. The detailed recommendations ought to be followed to maintain package integrity of components during any heat exposure of board soldering and de-soldering.

The relevant temperature is measured at the top of the parts and is defined as Package Peak Temperature (**PPT**). This package temperature is often also named Peak Reflow Temperature (PRT) which –because of the 'reflow' in the technical term– can be (and has been) misleading to take the temperature in the solderjoint where the material reflow happens. It is important to note that the **PPT** is the reference temperature for the parts' **MSL**. **The Package Peak Temperature (PPT) must not be confused with the Solder Joint Reflow Temperature, the MSL/PPT Classification Profile is not for component board soldering in production lines**.

MSL and **PPT** belong together and are product characterisitcs reflecting the robustness of semiconductor components for board soldering and tell how long the parts are allowed to be exposed to a controlled environment before it is necessary to dry-bake them again before any first or subsequent soldering step. Absorption of water has to be kept at a tolerable level so that no ‚pop-corn' effects compromise parts' reliable performance later on. **Table 1** is a partial list of the J-STD-020C MSL guidelines of processing rules for correct storage and handling prior to soldering. The standard is also important for double-sided reflow, i.e. for top- and bottom-side board assemblies where it is mandatory to prevent excess moisture take-up of the plastic components during storage before they will see a second exposure to soldering heat. This advice of best-practice is also applicable for any re-work, service and repair soldering step.

Moisture Sensitivity Level (MSL)	Dry-Packing Required	Floor Life	
		Time	Conditions
1	NO	unlimited	</= 30°C/85%RH
2	YES	1 year	</= 30°C/60%RH
2a	YES	4 weeks	</= 30°C/60%RH
3	YES	168 hours	</= 30°C/60%RH
4	YES	72 hours	</= 30°C/60%RH
5	YES	48 hours	</= 30°C/60%RH
5a	YES	24 hours	</= 30°C/60%RH
6	YES	Time on Label (TOL)	</= 30°C/60%RH

Table 1: Moisture Sensitivity Levels per J-STD-020C

As indicated above, the technical justification for the series of the J-STD-020 standard and its importance for the industry is based upon the inherent behaviour of components where plastics are used for encapsulation, glue, seal or underfill which all absorb more or less water at slower or faster speed. Existing voids and gaps fill with water, in addition or in consequence the material properties like thermal coefficient of expansion change and the adhesion at interfaces is weakened.

There is a conflict of interest between good solder joint formation of hot and fast soldering versus maintenance of good package integrity by keeping the package temperature low and also by using slow temperature gradients. This basic problem is getting into the foreground again with a **solder joint temperature** range of 235°C - 245°C for Pb-free SnAgCu solders which have liquidus between 217°C - 227°C. That is higher than the usual solder joint temperatures of nearly eutectic SnPb solders with 205°C - 220°C and the liquidus between 179°C - 183°C. The different temperature scenarios for conventional SnPb and "Pb-free" SnAgCu board soldering are outlined in **Table 2**.

Solder Paste Liquidus	SnPb based 179°C- 183°C		SnAgCu based 217°C-227°C	
	Maximum Package Peak Temperature	Minimum Solder Joint Temperature	Maximum Package Peak Temperature	Minimum Solder Joint Temperature
Large, thick Packages	225°C	205-220°C	245°C	235-245°C
Small, thin Packages	240°C	205-220°C	250-260°C	235-245°C

Table 2: Typical Minimum Solder Joint Temperature and Maximum Package Peak Temperature for SnPb and SnAgCu based board soldering and accounting for package sizes.

Now it is paramount to take note of the fact that board assemblies use a mix of package types of different materials and dimensions which results in a spread of thermal mass and heat conduction on the boards. Uneven heat distribution plus oven and process tolerances are reflected by a temperature difference (delta-T) on the various boards ranging in size, component dimensions, materials, arrangement and density. Detailed investigations were performed to characterize the thermal conditions at components during reflow soldering where the process window is narrowed for "Pb-free". **Figure 1** shows the relevant temperatures and where to measure them for a reliable board production.

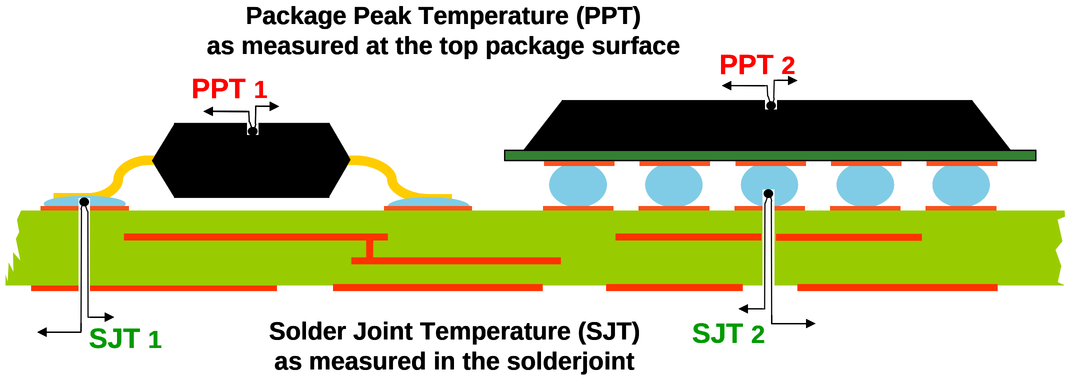

Figure 1: Solder Joint Temperature (SJT) and Package Peak Temperature (PPT) have to be determined for critical components on the boards.

In IR or convection processes the temperature can vary greatly across the PC board, depending on the furnace type and on the size and mass of components, and their location on the board. Profiles must be carefully tested to determine the coolest solder joint and the hottest package on the board. Oven settings have to ensure the minimum solder joint temperature is reached and long enough for good solder joint formation including self-registration of the component in the solder bed while at the same time the specified package peak temperature of any component on the board must not be exceeded. Thermocouples must be carefully attached with very small amounts of thermally conductive grease or epoxy to the package top for PPT, directly to the solder joint interface between the package leads and board for the SJT measurement.

Table 3 outlines the changed thermal stress scenario on the package bodies during the conventional SnPb process compared to Pb-free soldering. The shown temperature classes base upon J-STD-020C and depend on package volumes and thicknesses giving guidelines for product classification which, however, should be verified in the real board production environment to prevent excess package temperatures can affect parts' mechanical integrity.

SnPb Eutectic Process - Package Peak Temperature

Package Thickness	Volume mm³ <350	Volume mm³ ≥ 350
<2.5 mm	240 +0/-5 °C	225 +0/-5°C
≥ 2.5 mm	225 +0/-5°C	225 +0/-5°C

Pb-free Process - Package Peak Temperature

Package Thickness	Volume mm³ <350	Volume mm³ 350 - 2000	Volume mm³ >2000
<1.6 mm	260 +0 °C *	260 +0 °C *	260 +0 °C *
1.6 mm - 2.5 mm	260 +0 °C *	250 +0 °C *	245 +0 °C *
≥2.5 mm	250 +0 °C *	245 +0 °C *	245 +0 °C *

* Tolerance: The device manufacturer/supplier **shall** assure process compatibility up to and including the stated classification temperature (this means Peak reflow temperature +0 °C. For example 260 °C+0°C) at the rated MSL level.

Table 3: Package Peak Temperature (PPT) of surface mount devices.

MSL/PPT is a product characteristic. Freescale Semiconductor is determining the Moisture Sensitivity Level of the components using the Package Peak Temperature Profile (**Figure 2**) as measured with a thermo couple at the package top surface. This profile builds on J-STD-020C and reflects several customers' requirements and their production processes which were evaluated for standardization.

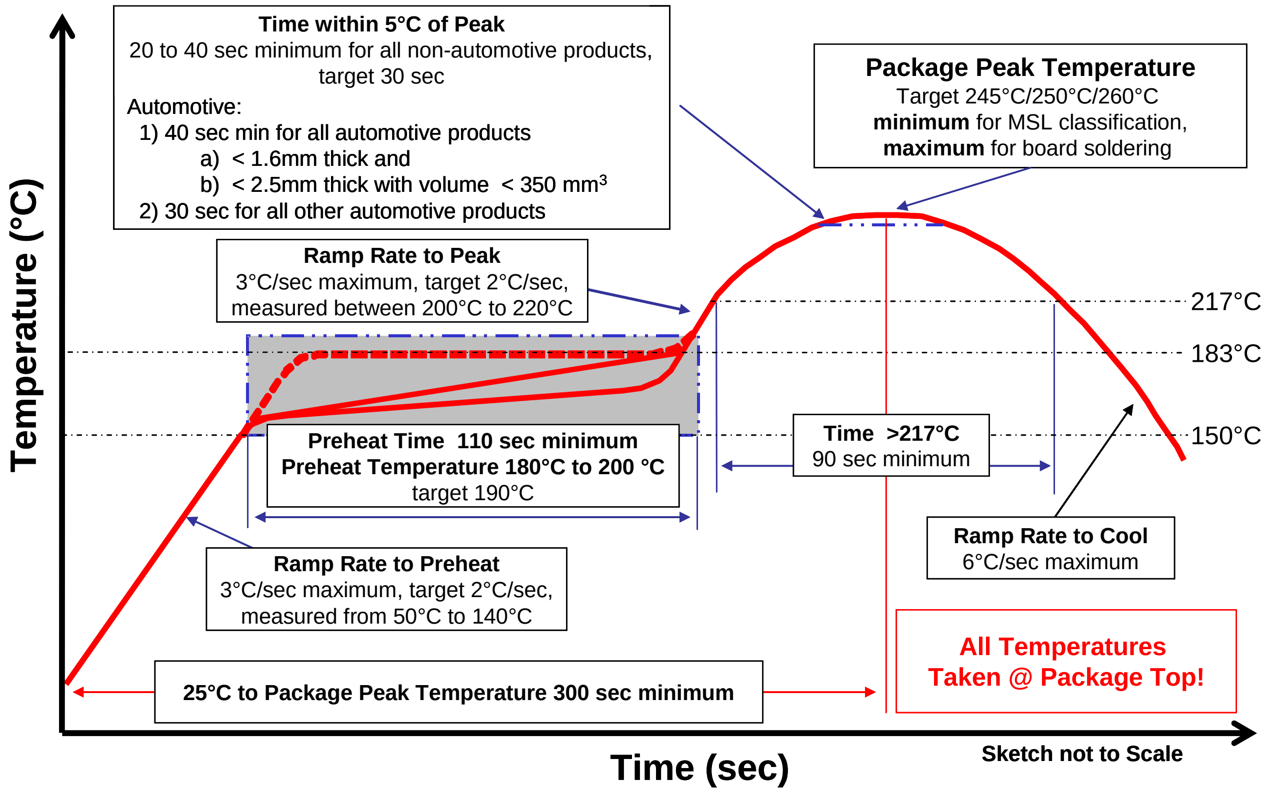

Figure 2: Package Peak Temperature (PPT) characterization for determination of components' Moisture Sensitivity Level (MSL) and the parts' processability per J-STD-020 and including customer board soldering requirements.
This is not a soldering profile showing the solder joint temperature!

Mixed Assemblies –

Board Soldering of "Pb-free" Terminated and Conventional Components

During the change-over from conventional SnPb to the coming "Pb-free" board soldering not all components will be available with the required solder finish. There will be conventional SnPb parts on "Pb-free" boards and already converted "Pb-free" components will land on printed circuit boards which are still run through traditional SnPb soldering processes. There is only a conditional OK to be given for "forward", i.e. SnPb into "Pb-free" respectively "backward compatibility", i.e. "Pb-free" into SnPb on the boards. Freescale offers a portfolio of Environmentally Preferred Products (EPP) which are RoHS compliant and also provide the necessary MSL/PPT for "Pb-free" board assemblies.

In case of mixed assembly attention is required when soldering conventional SnPb components under "Pb-free" conditions that the parts' MSL/PPT is adequate for the higher thermal stress and exposure during "Pb-free" soldering. Dry-baking prior to soldering might be necessary. SnPb solders melt and give good solder joints without problems in both air and nitrogen atmospheres solder ovens and at normal "Pb-free" process temperatures.

Freescale's EPP "Pb-free" leadframe parts can be put on boards with SnPb solders and no changes have to be done to the SnPb process with typical solder joint temperatures between 205°C and 220°C. The SnPb solder finish or paste on the board rule the solder system and are not influenced by the minute amount of "Pb-free" solder on the leads. Good solder joints form, the component reliability is unaffected as its MSL/PPT is superior to the SnPb process conditions and commonly established MSL/PPT rules were followed during the board soldering and related handling.

The situation is different when soldering EPP BGAs with their SnAgCu solderballs on to boards with SnPb solder paste. Care has to be taken for a complete melt and mix of both solder reservoirs of paste bumps and balls. Now the large volume of the solder balls determines the necessary temperatures and soldering kinetics. The paste volume disappears into the ball and both form the final joint. The process is well set when the "dual collapse" of the BGA towards the board can be observed, the BGA has to sink into the paste and further moves towards the board when the solder balls melt. Then enough time has to be given that the parts swim and center, the molten solders form a homogenous connection. Experience shows that solder joint temperatures of >225°C yield good and reliable solder joints between SnPb pastes and SnAgCu balls. That is higher than at the upper end of the normally established 205°C - 220°C in the joints of SnPb soldering. **Figure 3** shows the conditional forward and backward compatibility with the crucial areas for special attention.

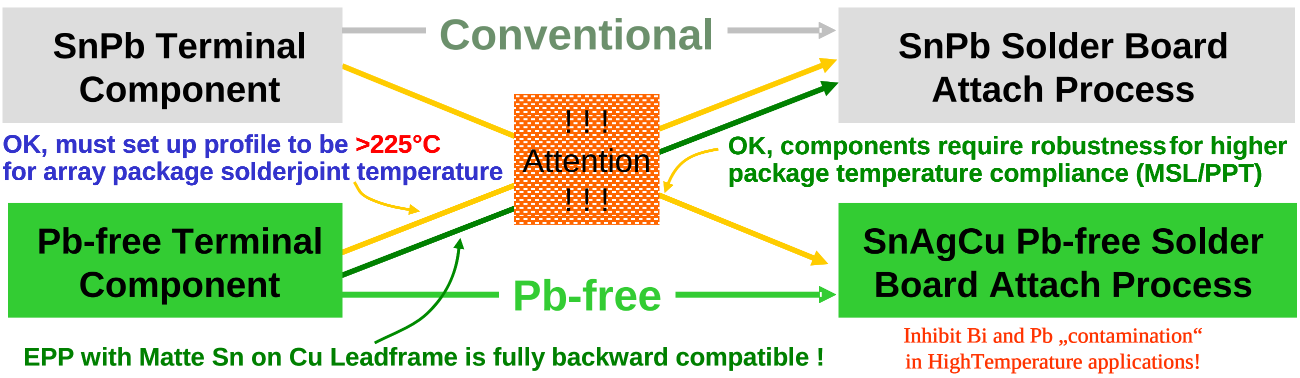

Figure 3: Conditional forward and backward compatiblity of SnPb into "Pb-free" and vice versa.

"Pb-free" board assemblies will typically require extensive changes to the board reflow soldering profile. SnAgCu based solders have a melt temperature that is approximately 40°C higher than eutectic SnPb based solders. Besides the above given recommedations and guidelines for the components' processability which is expressed by their Moisture Sensitivity Level and Package Peak Temperature (MSL/PPT) another material factor thus needs attention. It is preferrable that "Pb-free" parts be soldered with solder pastes employing fluxes formulated for the associated higher process temperatures.

Board assemblies have to run a temperature profile matching the solder paste flux requirement. Some flux needs a long dwell time below the temperature of 180°C while others will be burned up in a long dwell. Temperatures out of bounds of the solder paste flux recommendations, could result in poor solderability of all components on the board. The solder paste vendor should be able to provide an ideal reflow profile, which gives the best solderability.

Appendix A and Appendix B give recommendations for component soldering with SnPb pastes respectively with SnAgCu paste

Summary

During board assembly it is mandatory to control both the solder joint and the package temperature of components on the printed circuit board. The above geven general guidelines do not necessarily indicate the extremes that can safely be applied to surface mount packages. In most cases the package can withstand higher temperatures than the standard PC board. These guidelines are meant to represent good soldering practices that will yield high quality assemblies with minimum rework.

Solder flux technologies have improved dramatically in recent years, to the point that most of the industry is using "no clean" fluxes. Some of these fluxes require specific reflow profiles. These recommendations should always be followed precisely together with the solder joint and package temperature guidelines above.

When semiconductor products are subjected to process temperatures higher than those used for package process certification or product qualification, reliability issues like "pop-corn" can occur with said packages that suffered thermal stress and excursion beyond specified limits.

Appendix A

Component Soldering with SnPb solder paste

1. Preheat - Sufficient to raise temperature of leads/spheres to 100° C, over a period of no less than 50 seconds.
2. Infrared or convection reflow
   Products with SnPb or Matte Sn post-plated leadframes form good solderjoints under conventional SnPb board soldering conditions and should get SJT dwell time of less than three minutes above the eutectic tin/lead solder melting point of 183°C. Desirable dwell time above 183°C is greater than 50 seconds and less than 80 seconds. Solder joint temperatures are between 205°C and 220°C.

   Preferably BGAs with SnPbAg solder spheres are recommended for SnPb board soldering with solder joint temperatures again in the range of 205°C – 220°C.

   For BGAs with SnAgCu solder spheres a minimum Solder Joint Temperature (SJT) of 225°C is proposed so that the whole solder volume of SnPb paste and SnAgCu ball do melt in the solder zone while not exceeding any components' specified Package Peak Temperature at any time on the board during soldering.

Note: Prior to assembly it is important to verify that all components on the PCB can withstand Package Peak Temperatures (PPT) greater than 225°C if assembly is expected to use temperatures above 225°C which is above a standard SnPb board assembly process.

It is recommended to profile the PPT of critical components on the board.

Existing products that were qualified prior to the release of J-STD-020B in August of 2002 may have only been qualified for a maximum Package Peak Temperature of 225C.

Appendix B

Component Soldering with "Pb-Free" SnAgCu solder paste

Prevent to carry Bi or Pb into the "Pb-free" solder joint.

1. Preheat - Sufficient to raise temperature of leads/spheres to 100° C, over a period of no less than 50 seconds.
2. Infrared or convection reflow

Solder Joint Temperature (SJT) minimum to be reached is 235°C – 245°C while not exceeding the specified Package Peak Temperature (PPT, 240°C/250°C/260°C, see J-STD-020C) of any of the components on the board. SJT dwell time of less than three minutes above the solder melt temperature of 217°C. Desirable dwell time above 217°C is greater than 50 seconds and less than 80 seconds.

Note: Prior to assembly it is important to verify that all components on the PCB can withstand Package Peak Temperatures (PPT) of at least 245°C for "Pb-free" assemblies, see J-STD-020C.

It is recommended to profile the PPT of critical components on the board.

Existing products that were qualified prior to the release of J-STD-020B in August of 2002 may have only been qualified for a maximum Package Peak Temperature of 225C.