Process Development with Temperature Sensitive Components in Server Applications

L. G. Pymento[1], W. T. Davis[1], Matthew Kelly[2], Marie Cole[3], Jim Wilcox[4],
Paul Krystek[3] and Curtis Grosskopf[3]
[1] Raleigh, NC, [2] Toronto, Canada, [3] Hopewell Junction, NY, [4] Endicott, NY
IBM Corporation

Abstract

As the electronics industry prepares for the possibility of Pb-free Printed Circuit Board Assembly (PCBA) processing without the EU RoHS server Pb solder exemption, many studies continue to focus on attributes of assembly material chemistries, board finishes and processing techniques. These efforts generally target critical components such as ball grid array packages (BGAs) to ensure reliable solder joints that meet operational requirements at time zero and lifetime reliability targets. For consumer products, this approach may address the known failure mechanisms of the subject card, components, and assembly.

For high reliability products, there could be failure mechanisms in Temperature Sensitive Components that extend beyond critical components in BGA packages. These components include SMT aluminum capacitors, tantalum ceramic capacitors, crystals, oscillators, fuses and other components which have temperature limitations on the package body that restrict the peak reflow temperature and the time duration above 217^{o}C. Exceeding these temperature and time limitations may not induce time zero fails, but may reduce the long term reliability of the component. These components have all been classified and specified for Pb-free processing by their suppliers. Users, including designers and assemblers, may consider these components as non-risk components capable of withstanding the Pb-free evaluation peak temperatures of up to 260 ^{o}C as set forth for ICs in J-STD-020. Additionally, as part of temperature profiling efforts, most assemblers do not attach thermocouples to these components resulting in an absence of data collection to ascertain specification compliance. As a result, SMT attach profiling protocol does not generally include the specifications of these temperature sensitive components and subsequently, any induced damage may propagate over time. Depending on the lifetime reliability requirements of the product, product owners risk quality and reliability impacts caused by time dependent failures.

This paper examines the risks that temperature sensitive components pose to high reliability Pb-free server product PCBAs and discusses various issues including smaller process windows, profiling methods and accuracy, time zero quality, and expected reliability performance when using these components. Additionally, the intent of this work is to document the need to identify and monitor temperature sensitive components within industry standards, to extend awareness, and to enable designers / card assemblers to adopt optimum design features and processing techniques. The intended result is to help ensure that products can meet specified lifetime reliability requirements.

Introduction

Worldwide regulatory pressures continue to encourage the Enterprise and Telecom markets to adopt Pb-free manufacturing processes. In this high reliability application space, however, it is imperative to first verify that all Pb-free sub-systems, components and circuit board assemblies meet the same historical performance and quality standards without undue degradation in the field. The increased melting temperature of SnAgCu based Pb-free solder alloys have driven processing temperatures up into regimes where temperature sensitive components have significant body temperature and time limitations. Monitoring of these sensitive components within the elevated temperature windows then becomes a critical element for ensuring long term product reliability.

Server and storage class products for use in Enterprise and Telecom markets necessarily have substantially higher product reliability requirements and customer expectations than do general consumer electronic products. As such, the earlier conversion of consumer electronics to Pb-free assembly processes may not prove an adequate field trial for a similar Pb-free conversion of server class product. Consequently, the high reliability electronics industry is diligently pursuing appropriate reliability test data that would fill this knowledge gap and support a potential Pb-free conversion in more complex products. Much of this industry investigation has focused on establishing the thermal cycle reliability of board level Pb-free solder interconnects, primarily through the use of strategically designed test vehicles that carefully monitor the interconnect reliability in select high risk packages. Rarely though are these test structures designed to monitor the reliability of non-semiconductor components (*e.g.*, passives). Even rarer still would degradation in the electrical performance specifications of these passives be monitored over time. The focus is most typically on the interconnection to the device rather than the device function. There is a clear need to supplement Pb-free test vehicle evaluation with functional product trials before viability of server class Pb-free assembly can be established. Moreover, these trial functional boards need to be monitored for electrical performance changes associated with degraded function of key passive devices.

Because of the lower process temperatures available to conventional SnPb solder attach, a majority of the temperature sensitive components to be discussed below have not historically been a reliability risk. Figure 1 illustrates nominal SMT and PTH solder joint process temperature windows for SnPb, Mixed and Pb-free assembly operations. In this instance, 'Mixed' refers to the SMT attachment of SAC BGA components using SnPb solder paste. The process temperature windows shown are bounded at the low end by the minimum temperature required to produce an acceptable solder joint. A range of temperatures above that minimum is required to enable all solder joints on the board to achieve the minimum required process temperature. The maximum allowed body temperature ratings of non-semiconductor components are typically in the range indicated. (In the context of this paper, 'non-semiconductor components' will be defined as any electronic component that falls outside the scope of J-STD-020 and, as such, includes passives, connectors, fuses, and other non-IC components.)
In the SnPb case (left), SMT primary attach and rework operations generally remain below these limits for all components. In the Pb-free case (right), the elevated processing temperature windows often exceed the limitations of such temperature sensitive components. Pb-free SMT primary attachment and rework operations are mainly affected; driving smaller process windows during assembly or forcing alternate attachment processes (*i.e.*, hand solder attachment of SMT electrolytic capacitors).

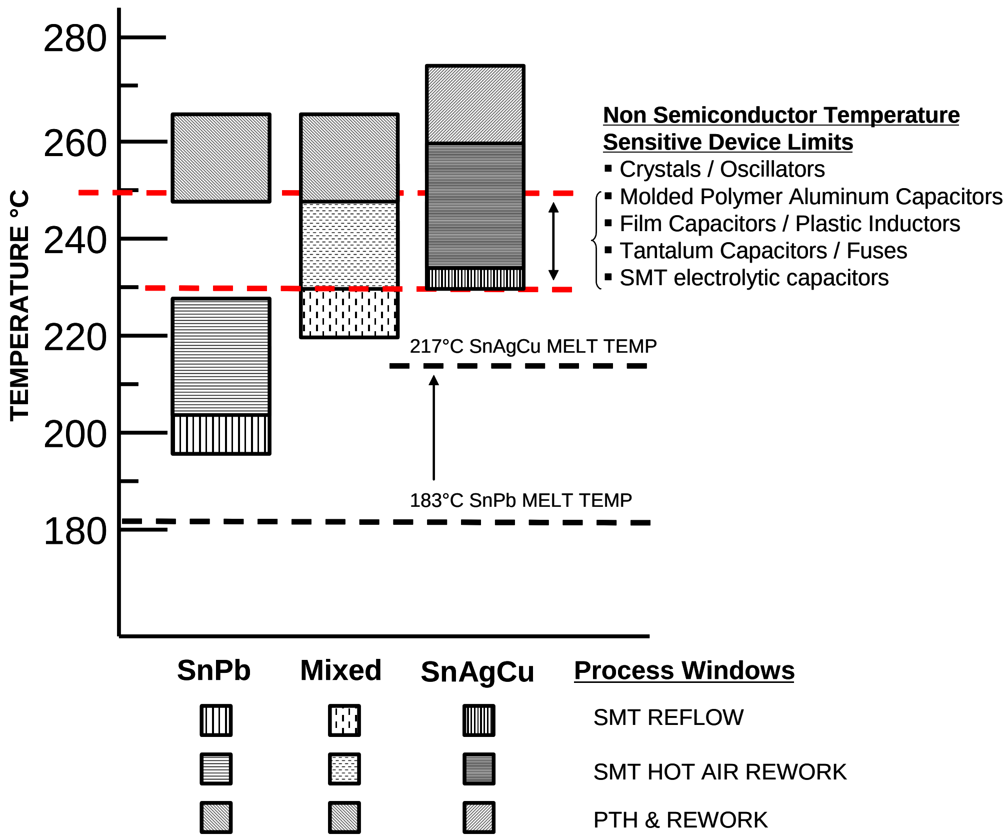

Figure 1. Approximate process temperature windows for available card assembly manufacturing operations.

Early manufacturing design reviews for all Pb-free PCBAs must include a detailed assessment of all temperature sensitive components contained within the bill of material. In addition to confirming that all critical semiconductor packages conform to J-STD-020 temperature robustness standards, the temperature exposure limitations for non-semiconductor components must be noted as well. These limitations then pose very real constraints to the assembly process engineer in the definition of all solder reflow processes required for the assembly of the PCBA. To assist in this effort a joint industry standard, J-STD-075, is being proposed that will standardize the characterization and reporting of temperature exposure limitations for all components outside the scope of J-STD-020.

Attainment of a viable Pb-free reflow profile that meets all component temperature exposure constraints is not a given. As will be shown in several case studies, there may well be several non-semiconductor components that can't quite be held within the supplier recommended temperature limits. These instances must be assessed carefully with the participation of the component supplier to ensure that the field risks posed by the overexposure are manageable within the product reliability requirements. With the increased PCBA complexity found in high end Server and Telecom applications, the ability to simultaneously meet all component process temperature constraints diminishes; and this for the same applications in which customer reliability expectations are increased. Without significant advances in the temperature tolerance of non-semiconductor components, the potential for complete elimination of SnPb assembly for high end server applications may be limited.

Component Failure Mechanisms

Historically, non-semiconductor electronic components have been able to meet the reflow profiles required for SnPb solder systems. For wave solder, components are qualified to 265°C for 10 seconds per IPC-9504, 'Assembly Process Simulation for Evaluation of Non-IC Components (Preconditioning Non-IC Components)', though actual wave temperatures can be as low as 255°C. Similarly for SMT reflow soldering, components were qualified to 245°C for 40 seconds per IPC 9504, though component body temperatures can reach 240°C during SMT reflow. With the shift to Pb-free solder systems, the maximum temperatures and time at temperature to which a component might be exposed to have increased for both wave and SMT reflow soldering. Wave solder components can be exposed to 275°C maximum (270°C nominal), and up to 260°C maximum for SMT reflow soldering. Pre-heat times and other thermal profile characteristic have also changed accordingly.

As semiconductor component manufacturers began to evaluate the effects of elevated lead-free reflow profiles on their existing components they reclassified these components to the newly updated J-STD-020, 'Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices'. In some cases, components previously classified as Moisture Sensitive had their Moisture Sensitivity Level (MSL) changed to indicate an increased sensitivity level at the elevated Pb-free profile temperatures. For most semiconductor components this was the extent of technical concerns supporting a Pb-free assembly process. Encompassing a larger variety of packaging materials, design and assembly techniques however, non-semiconductor components encountered more significant challenges with the new elevated thermal profiles. Many non-semiconductor commodities had barely been able to support the SnPb assembly profiles. It was not well known in the industry just how little thermal safety margin existed on many such passive components. This marginal condition became evident when passive suppliers were unable to support the Pb-free evaluation profile for MSL classification as outlined in J-STD-020 (based on typical worst case thermal profiles). As these suppliers began to encounter reliability failures, it became clear that there was a technology limit to the thermal exposure of many non-semiconductor components, especially when the market was requesting components survive three reflow cycles.

To date, the following component types have been identified as thermally sensitive (*i.e.*, unable to meet the classification profiles stated in J-STD-020 without degradation):

- Aluminum Capacitors (both can and plastic molded types)
- Polymer Aluminum Capacitors
- Film Capacitors
- Polymer Tantalum Capacitors
- Double Carbon Layer Capacitors
- Inductors and Transformers with insulated wire type coils
- Crystals / Oscillators / Resonators
- Fuses
- Non-Solid-state Relays
- Light Emitting Diodes (LEDs)
- Connectors

The thermal capability of each of these sub-commodities varies, even within that sub commodity. For example, aluminum capacitors with a can type construction having a diameter >10 mm diameter can only withstand a peak temperature of 230°C (as measured on the center of the top side of the component body), whereas cans of □□6.3mm diameter and a height of > 4.5 mm withstand a peak temperature of 250°C.

The nature of the failure mechanisms associated with thermal overstress of electronic components is cause for significant concern. Some temperature induced damage is immediate. Moisture induced delamination (pop corning), dimensional instability, and local structural damage such as melting of a connector housing. More insidious though are those damage mechanisms which are time dependent. The actual failure mechanism can vary by commodity but in most cases the assembly induced failures are not readily detected by electrical measurement post card assembly or by visual inspection. A card assembler would not likely detect any post assembly effects or component damage. Most card assemblers would instead focus on thermo coupling solder joints to insure a good quality connection and not monitor non-semiconductor component body temperatures for comparison to the maximum temperature limits. The practice of reflow process definition at card assemblers must now change to include thermal profiling of all temperature sensitive component bodies to ensure no hidden damage is being generated in these components.

Aluminum capacitors are among the most temperature sensitive components. The level of sensitivity as noted previously can be related to package size and/or volume. The primary failure mechanism for these capacitors is damage to the seal retaining the electrolyte. In extreme thermal excursions one can see both package bulging (see Figure 2) and limited cases of “vented” capacitors. However, at temperatures of 260^{o}C or slightly less, seal damage and/or package bulging is not easily seen. A compromised seal leads to early dry-out and electrical degradation. Greater damage to the seal will lead to earlier electrical failure.

Although still restricted by peak reflow temperatures, plastic molded tantalum capacitors have been found to be more robust than aluminum capacitors. In a study by T Zednicek [2], several tantalum capacitor types from various suppliers were exposed to a peak reflow temperature of 260^{o}C. These samples exhibited only minor parametric failures at this high reflow temperature, while the aluminum capacitors in the same study suffered a high percentage of catastrophic failures. This study reinforces the classification temperature of the tantalum capacitors as 250^{o}C, while the limits for aluminum capacitors range from 230^{o}C to 250^{o}C, depending on the specific construction.

Polyester capacitors used in high frequency digital circuits may exhibit poor performance after Pb-free reflow not because of a capacitance change, but because of an increase in the loss tangent [1]. Physically, the polyester capacitors may exhibit a deformation in height and/or cracks at the ends (Figures 3 and 4). While loss tangent normally increases at higher frequency, the exposure to Pb-free reflow temperatures can result in an increase in loss tangent at high frequency that exceeds the specification by a considerable factor.

Figure 2. 100□F Electrolytic Capacitor after Pb-free reflow. Note temperature induced bulging of the can. (After M. Wickham, *et al.*, 2003. [1])

Figure 3. Cracks in the End of the Polyester Capacitor (After M. Wickham, *et al*., 2003. [1]).

While not so sensitive to the peak temperature, ceramic capacitors and resistors may be sensitive to the ramp rate of the thermal profile [3]. This difference in sensitivity illustrates the difficulty of developing an appropriate Pb-free reflow profile for a complex PCBA. Not only must the peak temperatures be monitored for numerous components, but also the pre-heat temperatures and durations, temperature ramp rates, times above liquidus (TAL) and dwell times within 5^{o}C of the peak temperature must also be managed.

For inductors and transformers the failure mechanism is associated with the breakdown of the lacquer coating on the coil wires, leading to intermittent shorts. For crystals and oscillators excess heat leads to a drift or permanent shift in the oscillation frequency, especially noticeable on tight tolerance, high stability components. For fuses, excessive thermal exposure degrades the fuse element itself altering the threshold current of the fusible element leading to early “nuisance” blows--again another reliability failure mechanism.

The thermoplastic resins used for many connectors, such as polybutylene teraphthalate (PBT), may not be compatible with Pb-free reflow temperatures [4]. The PBT matrix may soften and distort at these higher reflow temperatures causing problems with the tolerances for pin and socket locations. New compounds designed for high temperature compatibility, but maintaining similar shrinkage factors for ease of molding, are required.

Figure 4. Deformation of Polyester Capacitor; note bulging of top surface. (After M. Wickham, *et al.*, 2003 [1]).

In addition to non-semiconductor components and connectors which are not covered by J-STD-020, power electronic modules may also be sensitive to the higher reflow temperatures of Pb-free soldering. Power electronic modules can have complex construction leading to reflow temperature sensitivities for various reasons. While some DC/DC converter modules can withstand 260^{o}C reflow, others are limited to 245^{o}C [5]. One noteworthy example is that the lifetime of the aluminum wire bonding within the D-PAK power device was found to decrease nearly 30% as the peak reflow temperature was increased from 220^{o}C to 260^{o}C [6].

As the transition to Pb-free solder drove an increase in SMT reflow temperatures, it became apparent that an industry standard should be established for the temperature sensitivity classification of non-semiconductor components given the reliability risks associated with elevated temperature exposures for many of these components. Even in SnPb SMT processes, reflow temperatures may be elevated to achieve acceptable solder joints for components that are only available in SAC BGA packages (*i.e.*, mixed solder assembly). The proposed industry standard, J-STD-075, 'Classification of Non-IC Electronic Components for Assembly Processes', is being drafted to address this need.

The risks of ignoring these temperature sensitivities are significant. The damage caused by excessive temperature exposure is not identified at in-circuit test or functional test. Any damaged components would be shipped with the possibility of failure in the field. There are no known predictive models for the progression of these failure modes and thus, their initiation must be avoided.

Based on the reflow profile sensitivities described here and others documented in the proposed J-STD-075, it becomes imperative for the assembler to monitor the temperature exposure of more than just the traditional moisture sensitive components documented in J-STD-020. These increased constraints on the reflow profile present a significant challenge for the assembler to maintain all of the components within a safe temperature window, yet also achieve reliable Pb-free solder joints. The case of mixed solder assembly (MSA), where the assembler is constrained by the reflow temperature limitations imposed by Pb-free BGA solder balls and SnPb solder paste reflow, may present even greater challenges in satisfying all of the reflow requirements.

Elevated Temperature SMT Profiles with Temperature Sensitive Components Case Studies

The primary driving force for higher reflow temperatures is the transition to Pb-free soldering. As previously mentioned, this transition has an impact not only when the card assembly process changes to Pb-free solder, but also when certain components in BGA packages are only available with Pb-free BGAs. The integration of Pb-free BGA packages into the SnPb assembly process, mixed BGA solder assembly, drives enough of an increase in the SMT reflow temperature to be of concern for temperature sensitive components. The following case studies examine both the situation of mixed BGA solder assembly (SAC BGA with SnPb SMT attach) and fully Pb-free (SAC SMT attach) printed circuit board assembly. Both case studies describe the necessary methodology for optimizing the reflow profile by monitoring and assessing both the solder joint temperatures for process optimization and component body temperatures to remain below the temperature limits. Case Study 1 examines the profile iterations that resulted in the best profile for a mixed BGA solder assembly (MSA) scenario. Case Study 2 examines the process modifications that may be required for full Pb-free solder assembly when the temperature restrictions cannot be achieved within the standard process.

Case Study 1: Mixed Solder Assembly Profile Development with Temperature Sensitive Components.
This case study illustrates the challenges in developing the optimum SMT reflow profile when considering multiple factors such as solder joint quality and temperature sensitive component limits, while documenting key observations from this experience. In this study, a high end scalable Server product application board, Assembly A, having the following attributes was considered. The printed circuit board was 29 cm x 24 cm x 2.5 mm with 16 layers and a pin density of 12 pins per cm^2. The assembly bill of material included six BGA components (below), each requiring solder joint temperature profiling, and several temperature sensitive active and passive components requiring component body temperature profiling.

- BGA652H99
- BGA624P_25X25
- BGA624P_25X25_ALT1
- FPBGA320P_18X18
- HFCBGA676P_26X26
- BGA575P_24X24

Of the six required, one of the large BGA components was available only with SAC solder balls. A reliable assembly of this SAC BGA with SnPb solder then requires an elevated reflow temperature to ensure complete mixing of the SAC ball alloy with the SnPb attach solder [7]. To ease the difficulty of developing a profile that would achieve adequate reflow of the SAC BGAs without exceeding the temperature limits of SnPb BGAs, all of the BGA components were specified to have SAC solder balls. To achieve complete mixing in the SAC BGA solder joints, all BGA components solder joints were targeted for a minimum reflow temperature of 220°C. Figure 5 illustrates the component layout of the PCBA and the thermocouple attachments used to define the SMT reflow profile.

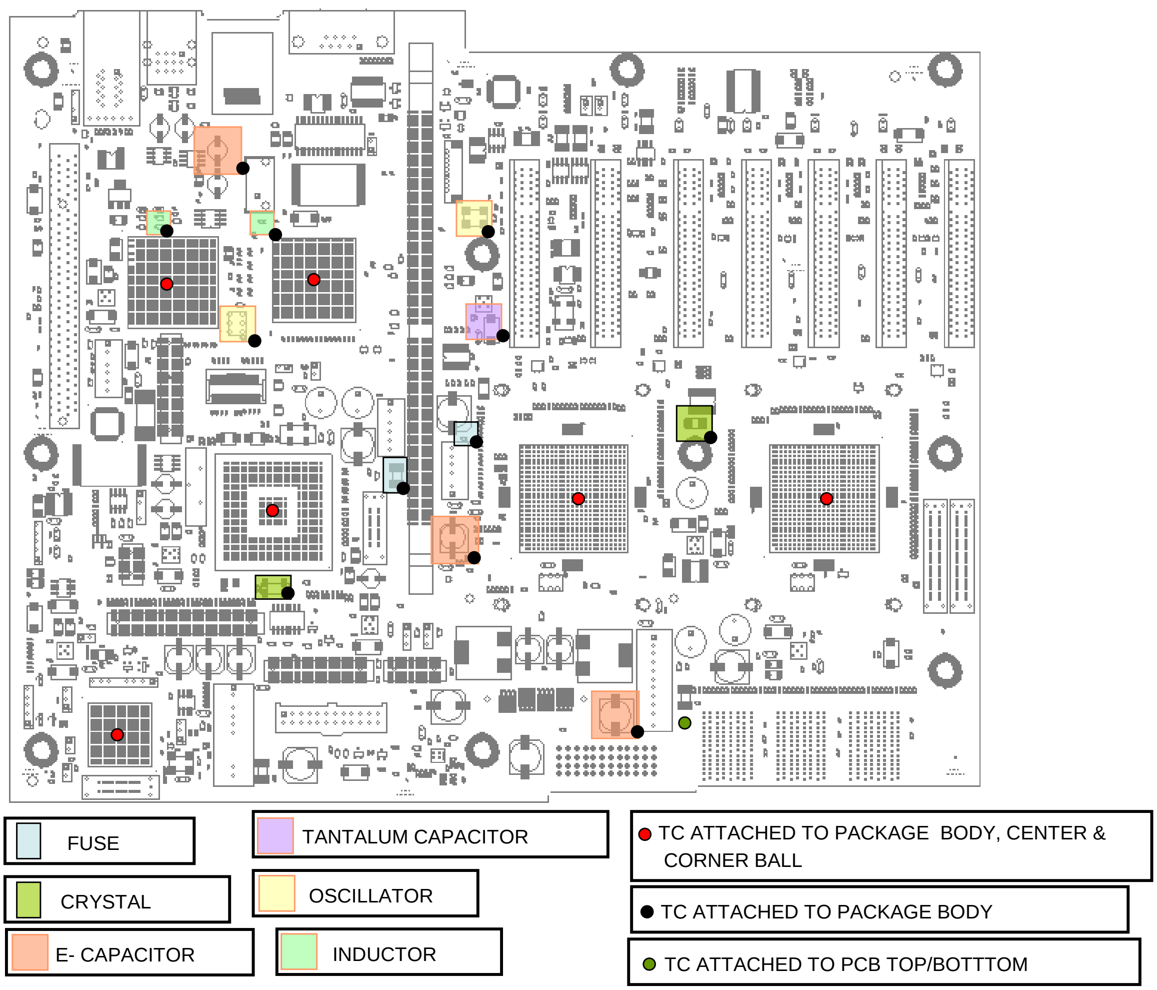

Figure 5. Assembly A Temperature Sensitive Components and SAC BGA locations

The BGA reflow conditions for the SAC BGA joined with SnPb solder required a profile with a Time Above Liquidus (TAL) greater than 30 seconds and a peak temperature on the coldest (center) BGA ball joint of 220°C. The PCB used a laminate material qualified for a maximum temperature exposure of 245°C. This PCB temperature limit set the upper bound of the reflow profile. Additional thermocouples were attached to the package bodies of temperature sensitive components such as tantalum capacitors, electrolytic capacitors, fuses, oscillators and crystals. The constraint conditions were obtained from the internal IBM specification as well as component specifications.

Several iterations were necessary to define a satisfactory reflow profile within the component temperature constraints. Key profile metrics of these profile iterations are tabulated in Table 1. An initial profile, Pass 1, was established on a 10 zone convection oven with an inert atmosphere of less than 200 ppm 0_2 levels. These zone settings and reflow conditions were typical of those used for a Pb-free profile. As can be seen from the Table 1, nearly all of the temperature sensitive components failed to meet the required limits for the time above the SAC solder liquidus temperature (TAL), although they were within the peak temperature limits. In the next set of profile conditions, Pass 2, the conveyor speeds and zone temperatures were reduced to lower the TAL for the temperature sensitive components. The resulting profile did bring the TAL of some of the components within their limits, but it also reduced the TAL for the BGA solder joints. To determine the actual impact on the product of the lower TAL for the BGA solder joints, a few cards were built and characterized using computed tomography X-ray techniques to assess solder voiding, ball collapse shape parameters and reflow conditions.

Table 1. Reflow profile iterations to address temperature sensitive component constraints.

Temperature Sensitive Components	**Component Body Temperature Profiles**							
	Component Limitations		**Measured Peak Temperature (°C) / TAL217 (sec)**					
	Peak Reflow Temperature	**Time Above Liquidus, 217°C**	**Pass 1** Reference Ramp Profile		**Pass 2** Reduced Ramp Profile		**Pass 3** Optimized Soak Profile	
			Peak	**TAL**	**Peak**	**TAL**	**Peak**	**TAL**
Fuses	□ □ 260°C	□ □ **65** secs	234	**84**	222	38	227	38
Electrolytic Capacitors	□ □ 250°C	□ □ **60** secs	242	**77**	227	**63**	234	54
Crystals	□ □ 260°C	□ □ **90** secs	240	85	224	53	231	44
Oscillators	□ □ 260°C	□ □ **90** secs	240	86	226	60	232	52
Inductors	□ □ 250°C	□ □ **60** secs	236	**86**	225	**61**	229	44
Tantalum capacitors	□ □ 260°C	□ □ **40** secs	240	**80**	223	**55**	231	**47.5**
BGA Components	**Solder Joint Temperature Profiles**							
Coldest solder joint	> 220°C	**> 30** secs	233-238	82-85	222-226	45-49	223-228	44-49
PCB Laminate	□ □ 245°C		238		226		230	

It was observed that some of the BGA solder balls had voiding near, or even exceeding, the IPC specification of 25% ball volume. This voiding level indicated that the temperature profile was providing inadequate heat flow into some of the BGA solder balls and thereby preventing the volatiles from escaping. To address this solder voiding, the soak profile was modified with further changes to both zone temperatures and conveyor speed. The resulting profile metrics are shown in Pass 3 where it can be seen, that despite several efforts to operate within the component temperature constraints, the tantalum capacitors were still slightly above the specification limit.

After developing the optimum reflow profile conditions, several PCBA cards were built and subjected to multiple stress conditions to validate solder joint integrity and field performance. These stress conditions included vibration tests, thermal ship shock tests, and accelerated temperature cycling (ATC). ATC cycling is ongoing as this paper goes to press, but all initial results to date are positive.

From the above studies, it was observed that a smaller process window was available for profile development and that an iterative approach was required to address all of the temperature constraints. It is imperative that the profiling approach should include identifying all temperature sensitive components, monitoring the body temperatures of these components via thermocouple attachments and developing a balanced profile. It is also suggested that an early evaluation of component selection and profile options be completed during the design/development stages of a new product, rather than waiting to develop an optimum profile.

Case Study 2: Pb-Free Solder Process Definition with Multiple Temperature Sensitive Components

This case study illustrates the challenges of accommodating temperature sensitive components with very low peak temperature limits within a standard Pb-free SMT reflow process. As part of standard new product introduction procedures, the bill of materials (BoM) for Assembly B, shown below in Figure 6, was reviewed to identify any temperature sensitive components.

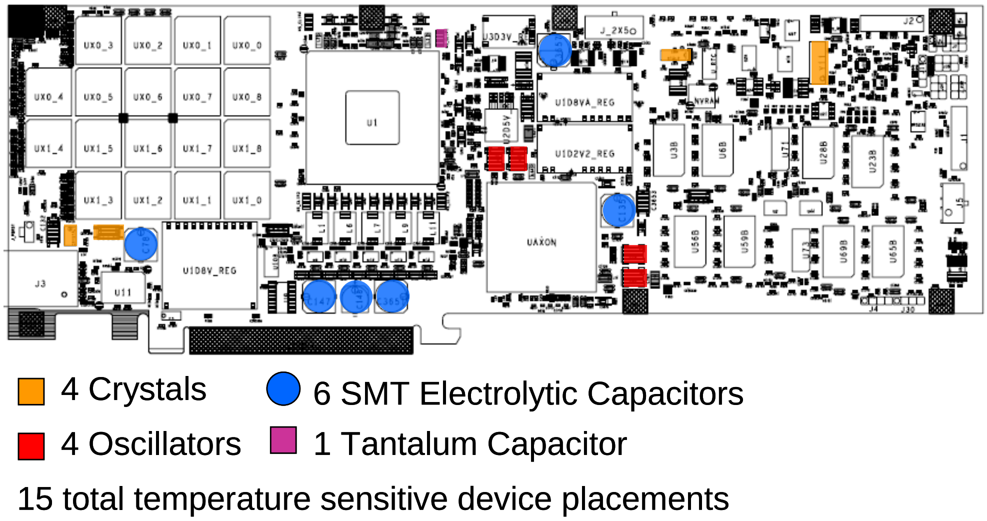

Figure 6. Assembly B Temperature Sensitive Component Population

Fifteen temperature sensitive components were identified from the BoM review. Consequently, many of these components were monitored during SMT and hot gas rework profiling trials. In total, eighteen thermocouples were used to monitor the top side of Assembly B. Resultant profiles were generated ensuring that all temperature sensitive components remained within specified limits. Table 2 illustrates the populated component limitations along with nominal processing temperatures / times obtained from process window profiling.

Table 2. Temperature sensitive component limits and nominal temperatures / times on Assembly B

Temperature Sensitive Components	**Component Body Temperature Profiles**					
	Component Limitations				**Final Measured Profile**	
	Preheat	**Peak Reflow Temperature**	**Time at Peak**	**Time Above Liquidus, 217°C**	**Peak**	**TAL(217)**
Aluminum SMT Electrolytic Capacitors	100-150°C for <120 sec.	□ □ **240°C**	**5 sec**	□ □ **40** secs	Hand Soldered	Hand Soldered
Tantalum Capacitors	150 – 180°C for <120 sec	□ □ **250°C**	**5 sec**	□ □ **40** secs	248°C	**95 sec**
SMT Crystals / Oscillators		□ □ **260°C**	**5 sec**	□□ **90** secs	245°C	90 sec

These data reveal several important points. First, due to the integration of six SMT electrolytic capacitors, a hand placement and soldering process was required. The elevated Pb-free SMT processing window did not allow for SMT reflow processing of these components. To achieve the minimum solder joint temperature of 230°C at all locations, the electrolytic capacitors could not be maintained below their 240°C allowed peak body temperature. Second, the data show that the resultant TAL exposure on the tantalum capacitor was over twice the recommended time of 40 seconds. Since the robustness of tantalum capacitors has been well documented within the literature [2] and after verifying the reflow conditions with the specific tantalum capacitor supplier, a decision to extend the TAL to 95 seconds was made for this assembly. Thirdly, it was noted that all other components, including crystals and oscillators, were processed at or near their recommend exposure limits – leaving little to no room for process window expansion.

Assembly B was subjected to several different environmental reliability tests including:

- ATC (accelerated thermal cycling). 0-100°C @ 1 cycle per hour for 1000 cycles
- HTS (high temperature storage). Isothermal soak @ 125°C for 1000 hours
- Construction analysis. IMC formation, bulk solder joint formation, etc.

Overall, there were no catastrophic failures observed in any of the identified temperature sensitive components. There were however two key observations made as a result of this study. Firstly, all SMT electrolytic capacitors were required to be hand soldered. These components cannot currently withstand Pb-free SMT reflow temperatures. Although implementing a hand placement and solder process for this component type will protect it against elevated SMT reflow temperature exposures, the process choice significantly slows SMT card throughput during volume manufacturing. This manual process also exposes the assembly's quality to variations in operator Pb-free hand soldering skills. If SMT electrolytic capacitors are left exclusively to a hand soldering process, new quality issues will arise including excess liquid flux application (dendritic growth risks) and component body burns as shown in Figure 7 below.

Secondly, one isolated oscillator failure was detected during ATC cycling. Upon failure verification, the component was removed from the assembly and was further examined to understand if there was indeed internal component damage. Figure 8 shows the resulting output waveform of the "failed" oscillator; indicating no phase shifting had occurred. Therefore the "failed" oscillator was determined not to be the root cause of the failure.

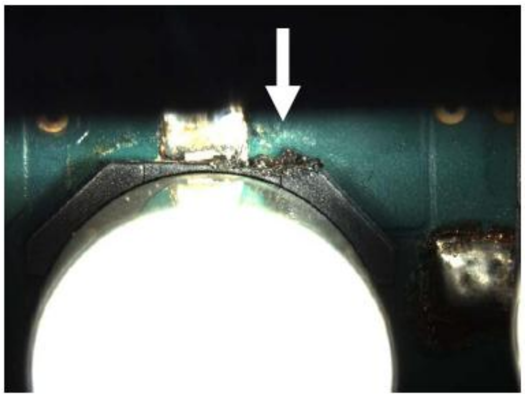

Figure 7. SMT Electrolytic Capacitor body burn as a result of Pb-free hand soldering operations

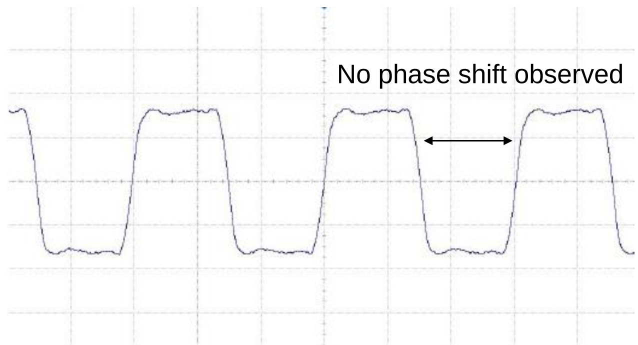

Figure 8. Suspect oscillator wave pattern shows no phase shifting.

This case study illustrates several points:

1. It highlights the need to ensure that all temperature sensitive components are identified in a detailed BoM review.
2. During profile window definition activities, a sufficient selection of temperature sensitive components must be included in thermocouple mappings; ensuring time and temperature limitations are not exceeded.
3. Pb-free SMT processing windows ranging from 230–250^{o}C will result in a majority of temperature sensitive components likely being processed at their allowable maximum exposures; the long term reliability consequences of which is often unknown.
4. SMT electrolytic capacitors cannot withstand Pb-free SMT reflow profiles and therefore must be manually placed and hand soldered creating alternate quality / reliability risks.
5. While not recommended, tantalum capacitors can be processed with an extended TAL with explicit supplier approval. Some have been determined to be acceptably robust during assembly.
6. Internal component failure analysis techniques should be conducted if temperature sensitive device failures are identified to better understand root cause failure mechanisms.

Industry Standardization

With the serious nature of the potential reliability failures of temperature sensitive components, it is critical that component Suppliers, Card Designers, and Card Assemblers be aware of the process restrictions imposed by temperature sensitive components. For this reason the Electronic Industries Alliance (EIA), JEDEC and IPC have joined together to develop a joint industry specification J-STD-075 "Classification of Non-IC Electronic Components for Assembly Processes" which will replace the IPC specifications 9501 - 9504. This standard outlines worst case industry solder assembly process conditions for non-semiconductor electronic components, along with commodity specific exceptions to these worst case solder assembly process conditions. See Figure 9 below for the Temperature Sensitivity Level (TSL) classification flow [8]. The solder assembly process conditions listed in J-STD-075 represent the maximum limits of a given component or component family. An assembler needs to take into account many factors when establishing a safe thermal profile for a given PCBA. This standard outlines a process to classify and label the thermal and moisture sensitivity of non-semiconductor electronic components consistent with the classification levels used by the semiconductor industry as stated in J-STD-020 "Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Devices" and J-STD-033, "Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices". J-STD-075 does not establish rework conditions, only initial attach. It is important for Component Manufacturers, Users and Card Assemblers to fully understand the information and processes in this standard to ensure optimal product quality and reliability. This specification is currently being balloted, with initial publication expected in early 2008.

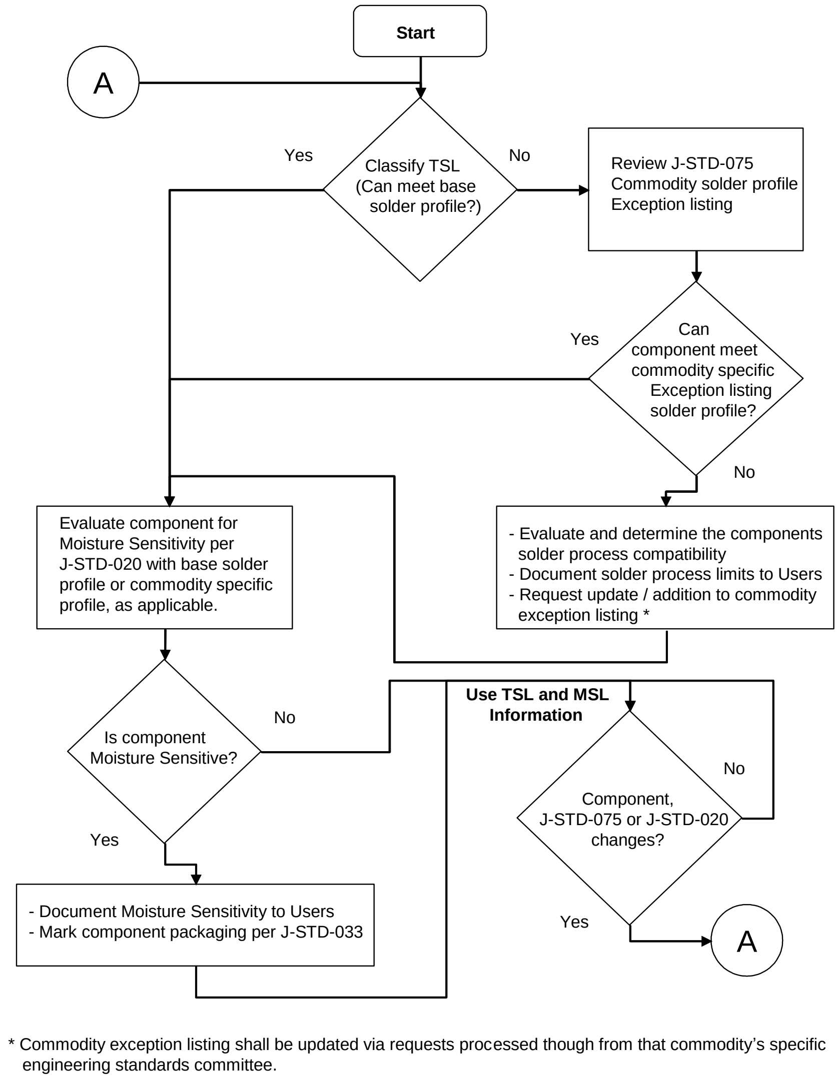

Figure 9. J-STD-075 Temperature Sensitivity Level (TSL) Classification Flow

Conclusions

To ensure a reliable product using Pb-free card assembly, attention is required beyond a process definition that provides high quality and reliable Pb-free solder joints. An acute awareness of all reflow profile compatibility issues with the semiconductor components, the PCB, the connectors and the non-semiconductor components must be maintained throughout. This paper has highlighted the Pb-free reflow compatibility issues associated with a variety of non-semiconductor components. The lack of robustness exhibited by many of these components when subjected to Pb-free reflow is a reliability exposure that must be addressed. Notable examples of temperature sensitive components include aluminum capacitors, tantalum capacitors, crystals, oscillators, fuses, etc. The reflow limitations of such temperature sensitive components may be restricted to peak reflow temperatures as low as 230^{o}C or perhaps very short TAL exposures, depending on the component. These limitations may be a key issue that will drive the continued use of the SnPb card assembly process for high reliability, high complexity PCBAs. Even when these temperature sensitive components can be maintained within their thermal limits, they are likely to be assembled at the extremes of those limits. Their long term reliability performance when exposed to these extremes during Pb-free processing is unknown.

The constraints that these temperature sensitive components place on the card assembly reflow profile add significant challenges to the development of an optimized thermal profile. The profiles must meet all the requirements for reliable solder joints while protecting any temperature sensitive components from unsafe thermal exposure. Board design factors may contribute to the challenges of achieving an optimal reflow profile.

Although alternate attachment processes such as hand placement will protect temperature sensitive device operation, manufacturing throughput levels will likely decline if such processes are implemented. Additionally, hand attachment processing will expose operator inexperience levels with Pb-free soldering. Increased flux residues, card handling, and component body burn risks can be expected when moving to a manual soldering process.

Continued development by the suppliers of these components to extend the temperature compatibility for a wider Pb-free assembly reflow process window would increase the robustness of the finished PCBA. At this point, material construction and design of these components has not changed significantly while the PCBA assembly process temperatures have significantly increased. Greater thermal robustness of these components would reduce the risk of subjecting them to unacceptable temperatures. And a wider process window would simplify the optimization of the reflow profile and increase the opportunity to focus on improving solder joint quality.

Recommendations

To mitigate the risks associated with temperature sensitive components assembled in elevated processing temperature windows the following recommendations are provided:

- An industry specification is needed to monitor non-semiconductor components, standardize their usage and educate the electronics industry.
- When conducting BoM reviews, temperature sensitive components must be identified along with moisture sensitive components.
- Ensure that identified temperature sensitive components are sufficiently monitored during thermal profiling activities and ensure that time and temperature limitations are not exceeded as outlined within the proposed J-STD-075. Thermocouple monitoring during primary attachment and rework operations is strongly recommended.
- Thermocouple attachment accuracy improvements are required due to small component form factors and small process windows.
- Continued development of new material constructions and reliability assessment by temperature sensitive device suppliers is recommended to help improve overall reliability performance of these components.
- Hand placement of all SMT electrolytic capacitors will be required until suppliers have improved their construction to allow for higher process temperature exposures.

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