Application Note AN37-0012

Soldering Guidelines for SMPS Multilayer Ceramic Capacitor Assemblies

1. Introduction

With a very low ESR and ESL and the ability to withstand very high levels of di/dt and dv/dt, SMPS stacked ceramic capacitors have been found to provide an extremely effective alternative to electrolytic and film capacitors, utilized for filtering and power management applications related to high frequency switch mode power supplies (SMPS). Choice of ceramic capacitors is not totally without risk however and information presented in this Application Guideline is intended to provide general recommendations for handling, mounting and soldering of SMPS capacitor stacks. These suggestions reflect industry recognized protocol and should, if applied properly, provide the basis for a dependable soldering operation and help ensure the continued reliability of these ceramic designs.

These recommendations should under no circumstances be construed as a guarantee against failure. They may not apply to every situation, and as such it becomes the engineer's responsibility to confirm results and make adjustments where necessary to accommodate specific conditions.

2. General

Multilayer ceramic capacitors (MLCC's) are intricate mechanical structures consisting of alternating layers of a dense ceramic substrate and metal electrodes which are coated at each end by a metal termination. Each of these components is characterized by its own unique Coefficient of Thermal Expansion (CTE) and as such, makes the completed structure vulnerable to thermal shock.

The risk of encountering thermal shock conditions can be influenced by several factors including the overall size, mass and geometry of the device, the number, thickness and density of the ceramic layers and metal electrodes, the type of termination and the integrity of the ceramic to metal interface. In addition, several external stimuli such as the use of wire leads, the range of temperatures encountered, the means and time of exposure, as well as the type of substrate (CTE) and / or the thermal characteristics and proximity of other components in the assembly, can also have an effect on the degree to which the capacitor may or may not be stressed.

While thermal shock conditions exist, the possibility of introducing substantial stress within the structure is significantly increased and unless preventative measures are introduced that mitigate these conditions, formation of micro fractures within the capacitor body are highly likely. Micro fractures, depending on their severity, may or may not be detectable through common testing and inspection practices. This poses a significant concern inasmuch as a damaged unit may represent a latent failure condition, whereby the product initially presents itself as an acceptable capacitor and may continue to operate until such time as moisture penetrates the flaw site, and / or it is subjected to further mechanical or thermal stress. Actual failure may be

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delayed for an extended period of time and in some cases may not be encountered until the finished product has been placed in the field.

Recognizing that the mass and size of larger ceramic capacitors may make them more vulnerable to damage, design engineers have developed a series of leaded alternatives that provide a degree of relief from thermal and mechanical shock. The use of a leaded capacitor does not by any means totally eliminate the risk, especially for thermal shock and any process being considered must properly manage those risks.

One critical area where the potential for thermal shock can be addressed is in the soldering processes utilized for mounting SMPS ceramic capacitors. Ensuring adequate pre-heat and post heat conditions and the selection of the most appropriate soldering process are critical to the success of this operation. This Application Guideline outlines principles and recommendations related to Infrared / Convection Reflow soldering and Hand soldering processes and should, if applied properly and tailored to the specific application, minimize the risk for thermal shock and subsequent micro fracturing in these types of capacitors.

3. Handling Considerations

Like thermal shock, ceramic capacitors are also susceptible to mechanical shock if not handled properly. SASP takes great care during the manufacturing cycle to ensure that these capacitors are not damaged throughout processing and shipment and the same care needs to be taken by the user from the point of receiving, throughout the assembly process and final testing sequence. Failure to do so may result in internal micro fractures and / or surface chip outs that may negatively affect the reliability of the device.

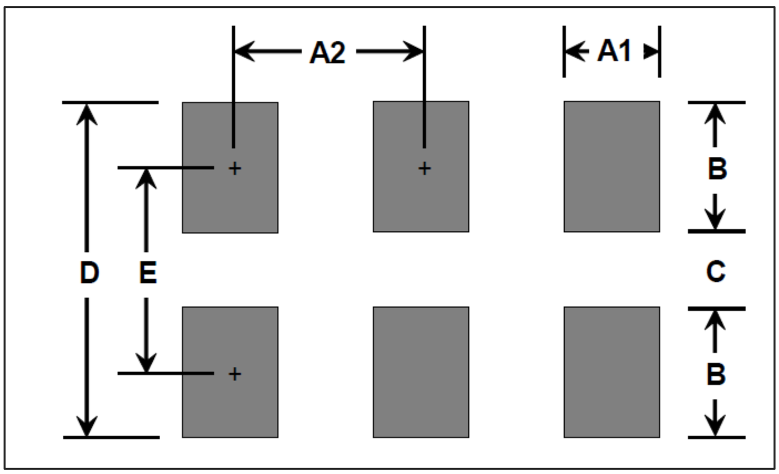
While preparing SMPS capacitors for shipment to the customer, SASP will utilize packaging materials, cushioning and containers that are specifically suited for the size and shape of the device. Small MLCC's are quite often shipped in bulk containers with little concern for damage, but larger leaded capacitor assemblies will usually require a packaging that individually secures each device and keeps it separate from the other capacitors being shipped. Whenever possible, the user should try to maintain these capacitors in their original packaging until such time as they are being mounted on the board. If for some reason this recommendation cannot be adhered to and the capacitors need to be removed from their original packaging, care must be taken to ensure that these large capacitors are kept separate and do not contact each other to prevent chipping and metal marking. Furthermore, if an SMPS capacitor is dropped on a hard surface, it should be discarded, even if there is no apparent damage to the device.

Capacitors should not be handled by bare hands or metal tweezers because of potential issues related to contamination and metal marks. The use of nonmetal tweezers, finger cots or non-contaminating gloves is recommended. In addition, if performing visual inspection or some other operation outside of the original packaging, capacitors should be placed on a clean glass or hard plastic surface.

4. Land Pattern (Solder Pad) Layout Considerations

Table I provides suggested land pattern layout dimensions for surface mount SMPS capacitors. At present, there are no established standards that specifically address "J" and "L" lead surface mount configurations. Consequently, IPC 7351 methodology was utilized for the purpose of establishing the recommended dimensions included with this Application Guideline. Although these recommendations reflect typical industry dimensions, the engineer may encounter specific design considerations that require a deviation from these limits.

In addition for certain designs there may be concerns over being able to adequately clean the underside of the SMPS capacitor and / or penetration of a specified conformal coating. In these cases, the engineer may want to consider incorporating a slot or groove in the area between the pads to facilitate this process. This may be of particular importance on higher voltage components where adequate cleaning and isolation of the lead terminals is critical to preventing a potential arc over condition.



Package Size	Pads Per Side	J Lead						L Lead					
		A1 (Typ)	A2 (Typ)	B	C	D (Ref)	E (Ref)	A1 (Typ)	A2 (Typ)	B	C	D (Ref)	E (Ref)
SMP1	20	0.040	0.100	0.120	0.295	0.535	0.415	0.040	0.100	0.120	0.395	0.635	0.515
SMP2	15	0.040	0.100	0.125	0.645	0.895	0.770	0.040	0.100	0.125	0.750	1.000	0.875
SMP3	10	0.040	0.100	0.120	0.295	0.535	0.415	0.040	0.100	0.120	0.395	0.635	0.515
SMP4	4	0.040	0.100	0.110	0.260	0.480	0.370	0.040	0.100	0.110	0.355	0.575	0.465
SMP5	3	0.040	0.100	0.102	0.118	0.322	0.220	0.040	0.100	0.102	0.218	0.422	0.320
SMP6	20	0.040	0.100	0.125	1.095	1.345	1.220	0.040	0.100	0.125	1.205	1.455	1.330

Table I – Land Pattern / Solder Pad Layout Recommendations

5. Solder Attachment Methods

If given the option between using an Infrared / Convection Oven Reflow soldering or a Hand soldering process, preference should always be given to the oven reflow process, as there are fewer variables involved and this process is much easier to control. Hand soldering is generally discouraged because of the risk associated with this process and the general lack of controls

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that can effectively be put in place. Given the mass associated with SMPS capacitor designs, other popular soldering processes like wave soldering and vapor phase soldering are also discouraged because of their inability to adequately address preheat requirements.

If given the option between using an Infrared / Convection Oven Reflow soldering or a Hand soldering process, preference should always be given to the oven reflow process, as there are fewer variables involved and this process is much easier to control. Hand soldering is generally discouraged because of the risk associated with this process and the general lack of controls that can effectively be put in place. Given the mass associated with SMPS capacitor designs, other popular soldering processes like wave soldering and vapor phase soldering are also discouraged because of their inability to adequately address preheat requirements.

Preheat and post heat cool down are critical steps in every soldering process and generally speaking, any soldering operation being considered should be capable of ensuring a maximum rate of change that is less than 3℃ per second. In addition, potential temperature spikes that may be encountered during the transition from preheat to reflow should also be controlled and limited to no more than 50℃. The size and / or mass of a device will certainly dictate the degree at which heat is transferred and larger package sizes may require that this rate of change be further reduced to minimize the possibility of thermal shock. Specific recommendations related to package size and / or the type of soldering process being considered, are shown below.

5.1 Infrared / Convection Oven Reflow Soldering

Infrared / Convection Reflow Ovens are highly recommended as they are easy to control and present a lower level of risk to the capacitor during installation. Generally speaking, heat transfer rates are low, which allows the ceramic, electrodes and terminations of the part to heat up and cool down at the same rate. It is important to note however that larger ceramic bodies can act as heat sinks and that the ramp up in their body temperature may lag the balance of the components on the PWB. Consequently, an adequate pre-heat cycle and thermal soak zone is critical to ensuring that the capacitor(s) heats up at the desired rate and that other components on the PWB are not exposed to excessive temperatures.

The majority of modern IR / Convection Oven reflow processes in use today are also capable of incorporating an inert gas like nitrogen to the system, which helps to minimize the possibility of oxidation during the soldering process. This may be especially important for those processes where the PWB assembly is exposed to higher temperatures and / or longer soldering times. In addition, the use of nitrogen improves the flux cleaning action, promotes proper wetting of the solder and makes the completed assembly easier to clean.

Information provided in Figure 1 outlines recommended solder profiles and process parameters that should provide the basis for a successful reflow process. Where applicable, these parameters are based on the limits defined in J-STD-020D. That said, these recommendations may need to be adjusted to accommodate specific capacitor sizes and mass, board size and material, the density and types of components already mounted on the PWB and the solder type being utilized. Wherever possible, keep the soldering time to a minimum, particularly above the solder liquidus temperature.

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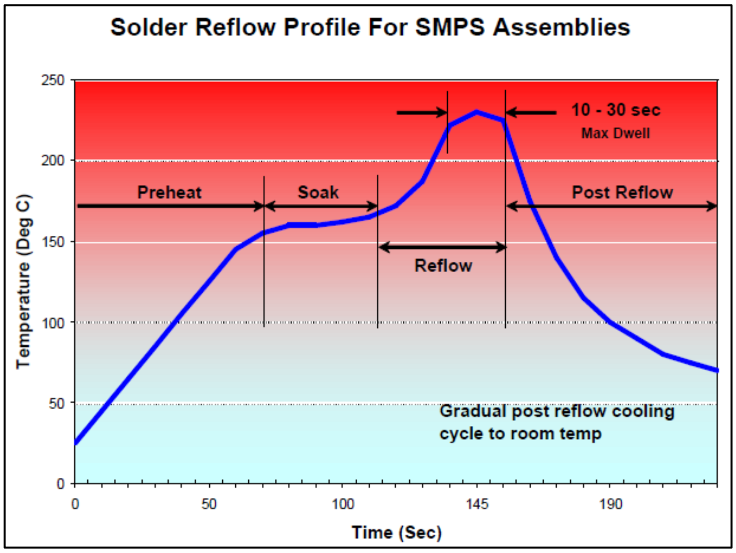

Low Temp Solder – Reflow Profile Recommendations		
Stage	Sn / Pb / Ag	Sn / Ag / Cu (RoHS)
Solder Reflow Temperature	179 - 189°C	217 - 220°C
Preheat Ramp Rate	1.5 to 2°C max / sec	1.5 to 2°C max / sec
Preheat Temperature	150 - 170°C	200 to 210°C
Max Change Preheat to Reflow	50 to 60°C Max	50 to 60°C Max
Reflow Cycle Ramp Rate	3°C max / sec	3°C max / sec
Reflow Temperature	220 to 240°C	245 to 265°C
Post Reflow Cooling Cycle	3°C max / sec	3°C max / sec

Figure 1 – Typical Solder Reflow Profile for SMPS Capacitor Assemblies

Summary – Key Process Considerations

- **Infrared / Convection oven is the preferred method for SMPS soldering**
- **Proper preheat and post heat temperature profiles are critical**
- **Utilize nitrogen atmosphere to facilitate soldering process**
- **Keep solder time, temperature and solder volume to a minimum**
- **Do not force cool soldered assemblies**
- **Allow assembly to cool completely to room temperature before cleaning**

5.2 Hand Soldering

Due to a significant mismatch in thermal gradients and the inherent process control limitations associated with this method, SASP strongly discourages the installation of ceramic capacitors using a soldering iron. There will be instances however, where installation by a reflow system is not practical and the utilization of a soldering iron cannot be avoided. In those situations, there are a number of precautions that should be taken to limit the risk of thermal shock as much as possible.

The use of a leaded capacitor should always be considered for a process involving hand soldering. This approach may not be feasible and less warranted for smaller chip sizes, but larger packages, especially 1812 and up, are much more susceptible to thermal shock and the use of a leaded configuration like an SMPS assembly, offers a certain degree of thermal relief between the ceramic body and the high temperature soldering iron.

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Although somewhat more difficult to implement than an enclosed reflow system, where possible, steps should still be taken to adequately preheat the capacitor prior to soldering. The approach that provides the best results requires that the entire board assembly be placed in an air circulating oven and be slowly brought up in temperature. Once the desired preheat level is reached, the assembly should be quickly transferred to the soldering station and placed on a heated surface that is maintained at the same temperature as the oven.

To further limit excessive heat transfer a low wattage, small tip iron should be utilized and under no circumstances should the soldering iron tip be allowed to make direct contact with the capacitor lead frame. Solder should instead be applied directly to the tip of the iron and then touched to the solder pad, allowing solder to flow around the lead and into the lead to pad interface. In addition, for "N style", through-hole, leaded capacitors, solder should be applied to the opposite side of the board from the capacitor. In this manner, the board itself provides a certain amount of thermal relief.

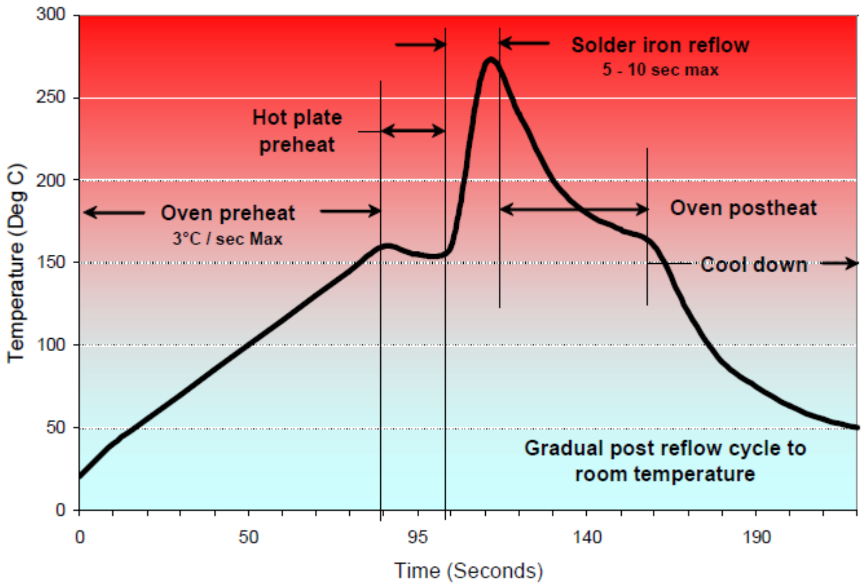
The type and volume of solder utilized and the time at which the capacitor is exposed to reflow is also extremely important to the success of the operation. Solder volume should be kept to a minimum and soldering time and reflow temperature should also be limited as much as possible. Wire solders with a rosin or non-activated flux core are preferred and the use of an alloy that incorporates a small percentage of silver may be beneficial, especially when soldering to silver plated lead frames.

Whereas adequate ventilation for any soldering process needs to be incorporated, the soldering station should be protected from external drafts that might otherwise cause the surrounding ambient temperature to undergo frequent fluctuations.

Even with adequate shielding of the solder station, exposure to the localized environment will make maintaining the capacitors at the required preheat temperature impossible for any length of time.

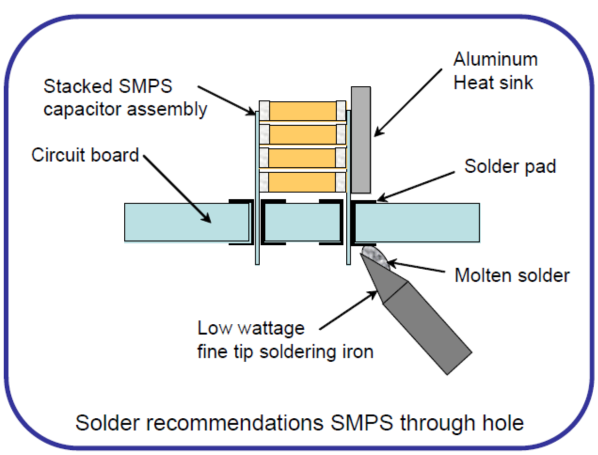
Consequently, where multiple capacitors need to be mounted, the board assembly will most likely need to be returned to the oven, where the capacitors can again be brought up to the desired preheat temperature. Given the rapid cooling of the assembly, the preheat process typically needs to be repeated after 3 to 5 capacitors have been soldered

Hand Solder Profile With Preheat Cycle

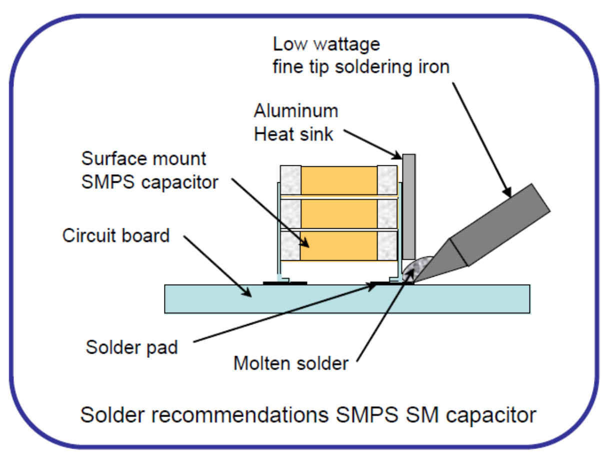


SMPS Low Temperature Hand Solder Recommendations	
Process Step	Limit
Preheat Ramp Rate	2 - 3°C max / sec
Solder Iron Wattage	35 watts max
Solder Time	5 – 10 sec max
Solder Iron Tip Temperature	290 to 310°C max
Max Temp change Preheat to Reflow	55 to 65°C max
Post Reflow Cooling Cycle	3°C max / sec

For the larger SMPS capacitors, the option of preheating the component becomes extremely difficult to implement and the engineer may need to consider the use of a heat sink as an alternative approach. The use of an aluminum block for example, placed against the ceramic body, will limit exposure of the ceramic to excessive temperature gradients and help prevent a thermal shock condition.



Solder recommendations SMPS through hole



Solder recommendations SMPS SM capacitor

After soldering is completed, assemblies should be allowed to cool naturally to room temperature. If an oven was utilized for the purpose of preheating the assembly, the circuit

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Summary – Key Process Considerations

- **Use preheat or heat sink whenever possible**
- **Use low wattage, small tip soldering iron**
- **Do not contact lead frame with soldering iron**
- **Maintain time, temp and solder volume to a minimum**
- **Solder from opposite side of board for through hole configurations**
- **Do not force cool soldered assemblies**
- **Allow assembly to cool to room temperature before cleaning**

6. Rework

The best approach for dealing with inadequate solder joints is to prevent defects from occurring in the first place. As indicated earlier in this applications guideline, the process for mounting SMPS ceramic capacitors can be a very complicated procedure and may require a significant level of up front development and analysis. The size, mass, type and placement accuracy of the assembly being installed, the process chosen and its soldering profile, the size and location of the solder pads and the amount and type of solder can all influence the result. One should not expect to achieve ideal results in initial trials and the engineer may be required to run several prototype lots to establish an acceptable outcome. Even after a process has moved into the production phase, unforeseen circumstances may require some further tweaking of the process.

Considering the risk of damaging the capacitor assembly, the board and / or surrounding components, rework should always be the last consideration. The engineer should first determine whether the anomaly will in fact pose some type of reliability concern, or whether the defect is purely cosmetic. If it is determined that the condition poses no risk to the integrity of the device, then the engineer should not attempt repair, but should instead focus efforts on determining root cause, corrective action and implement changes to the process to minimize the likelihood of reoccurrence.

If it is determined that some type of repair to the capacitor assembly is in fact necessary, the engineer will need to classify the type of repair required and determine the most reliable course of action. Repairs can generally be categorized into one of three categories, touchup, realignment, or removal / replacement.

Guidelines covered in section 5.2, Hand Soldering, will apply for the majority of repairs although concerns related to thermal shock are much more difficult to address at this point. To facilitate preheating, the engineer may want to consider the use of a hot air torch to localize heat around the lead to board interface and bring the component up in temperature to the point where the soldering iron will present much less risk and be much more effective. Under no circumstances should the soldering iron tip be allowed to make direct contact with the lead and the time to complete the reflow operation should be kept to a minimum, at roughly 1 to 2 seconds.

6.1 Touchup

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Touchup essentially implies that there is either insufficient or excess solder present. If there is insufficient solder present and the capacitor appears to be properly aligned adding a small amount of solder should correct the problem. The solder should be added to the tip of the soldering iron and then flowed into the deficient solder joint area.

If excess solder exists, and the capacitor appears salvageable, a similar approach to adding solder should be taken. A small amount of flux may be required to facilitate reflow and solder can be removed with the aid of a braided copper solder wick or a vacuum extractor.

6.2 Realignment

Realignment of a capacitor assembly is not recommended as a successful soldering process is strongly dependent on a precise volume and placement of the solder paste, along with an accurate initial positioning of the capacitor. Disturbing this precondition by sliding or rotating the part will drastically increase the probability of encountering solder balls, bridging and / or incomplete solder joints.

If realignment is still being considered, one would need to recognize that there is a problem prior to beginning the initial solder reflow process. If the soldering process has been completed, the number of leads and the mass of the device make realignment extremely problematic and damage to the capacitor is highly likely. In this case rework should instead be limited to removal and replacement of the capacitor. If soldering has not been completed and an adjustment is necessary, the best approach would be to carefully lift the capacitor straight off the board and then reinsert the unit into the solder paste.

6.3 Removal and Replacement

If it has been determined that rework requires removal of the SMPS capacitor, the most reliable approach would be to first cut the leads and remove the ceramic body. By removing the larger mass of the device, the leads can easily be unsoldered and removed with little risk to the rest of the board assembly.

If the leads cannot be separated from the body, the use of a fine tip, hot air torch may be required to facilitate the process and help bring the entire assembly up in temperature. Care needs to be taken to ensure that air flow is limited to the area of concern and that surrounding components are not placed at risk for thermal damage. Removal of solder using a soldering iron and braided copper wick or solder vacuum should also help.

To limit the possibility of damage to the board and surrounding components keep reflow time to as short as possible. As a guide, soldering irons or tweezers should not be in contact with the circuit pad for more than 5 to 6 seconds.

Prior to placing a new capacitor assembly, the board should be properly cleaned, excess solder should be removed and the board should be inspected to ensure pad lifting has

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not occurred and that no other damage has taken place during the removal process. If the board assembly is acceptable, the pad areas should be prepared by either adding new solder paste or pre-tinning the surface. As outlined in the section 3, non-metal tweezers, finger cots or non-contaminating gloves should always be utilized for handling capacitors and the rework soldering process can be performed using the same approach outlined in section 5.2 for hand soldering. In lieu of pre-heating the entire assembly in an oven and if heat sinks are not practical, use of a fine tip, hot air torch may help facilitate the reflow process but as previously stressed, care needs to be taken to limit the heating process to only the area being soldered.

Once rework has been completed, specific attention needs to be given to re-inspection of the entire board assembly. Capacitors are highly susceptible to thermal shock using any hand rework process. In addition, there is an increased risk of damaging the board and surrounding components and assemblies should be inspected carefully to ensure that the integrity of the complete assembly has been maintained.

Summary – Key Process Considerations

- **Rework should always be the last option**
- **Removal and replacement is preferred over realignment**
- **Restrict heating process as much as possible to rework area**
- **Limit reflow time as much as possible**
- **Complete re-inspection of entire assembly is critical**
- **Always determine root cause and implement corrective action**

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