CalRamic Technologies LLC

Application Note

AN101
07/15

SOLDERING HIGH VOLTAGE MULTILAYER CERAMIC CAPACITORS

INTRODUCTION

Recommendations offered in this Application Note are intended to provide general guidelines for soldering multilayer ceramic capacitors. They reflect industry accepted protocols and should, if applied properly, provide the basis for a reliable soldering process. These recommendations may not be applicable to all situations and as such should not be considered a guarantee against failure. Consequently, it becomes the engineer's responsibility to confirm results and make adjustments where necessary to accommodate specific conditions.

OVERVIEW

Multilayer Ceramic Capacitors (MLCC's) are complex composite mechanical structures composed of alternating layers of a dense ceramic substrate and metal electrodes, which are connected by a metal termination that typically contains a glass frit. Each of these materials is characterized by a different Coefficient of Thermal Expansion (CTE), which makes the completed structure highly susceptible to thermal shock.

The degree to which a ceramic capacitor may potentially be effected by thermal shock can be influenced by several factors including the overall mass, size, and geometry of the device itself, the number, thickness and density of it's ceramic layers and metal electrodes, the type of termination material utilized and the integrity with which these materials effectively form a single monolythic structure. In addition, there are several external influences that can also impact the degree to which a capacitor may be subjected to thermal stress including, but not limited to, the range of temperatures encountered, the means by which the part is exposed and time of exposure, the type of substrate to which the capacitor is being mounted, and the thermal characteristics and proximity of other components within the assembly.

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. These micro fractures, depending on their severity, may or may not be detectable thru common testing and inspection practices. This poses significant concern inasmuch as the suspect part may represent a latent failure whereby the product initially presents itself as an acceptable unit and may continue to operate until such time as moisture penetrates the flaw site, and / or it is subjected to further mechanical of thermal stress. In addition, the actual failure may be delayed for an extended period of time and may not be detected until the finished product has been placed in the field.

One area where the initiation of thermal shock can be addressed is in the soldering processes utilized for mounting ceramic capacitors. Ensuring adequate pre-heat and post heat conditions and the selection of the most appropriate soldering process can be critical to the success of the operation. This Application Note outlines some of the more common soldering processes utilized for mounting larger MLCC chip capacitors, including Infrared / Convection Reflow soldering, Vapor Phase Reflow soldering and Hand soldering. These recommendations if applied properly and tailored to the specific application, should minimize the risk for thermal shock and subsequent micro fracturing of these style capacitors.

GENERAL CONSIDERATIONS

Larger ceramic capacitors are especially susceptible to mechanical shock and they can be easily damaged if they are not handled properly. CalRamic Technologies has paid particular attention to ensuring that these capacitors are undamaged throughout processing and delivery and the customer in turn needs to assure that same level of care is taken from the point of receipt, thru assembly and final test. Failure to observe basic handling protocols may result in the formation of internal micro fractures and / or surface chip outs which may affect the reliability of the device.

In preparation for delivery to the customer, CalRamic Technologies utilizes a variety packaging containers and materials that are specifically tailored to provide a high level of protection for the type and size of the capacitor that is being shipped. Unlike small MLCC's which are far less susceptible to damage and quite often shipped in bulk containers, larger high voltage chips generally require a packaging container that secures each device and keeps individual capacitors separate from one another. Whenever possible the customer should attempt to maintain these capacitors in their original packaging until they are being mounted on the board. If it is not possible to adhere to this recommendation, care must be taken to ensure that these large capacitors do not contact each other so that chip outs and metal marks can be avoided. Furthermore, if a large capacitor is inadvertently dropped on a hard surface it should be scrapped, even if the part tests within spec and there is no visible damage to the device.

Capacitors should not be handled by bare hands or metal tweezers because of concerns over contamination and metal marks and the use of non metal tweezers, finger stalls or non contaminating latex gloves is strongly encouraged. In addition, if capacitors are to be removed from their original packaging for the purpose of performing visual inspection or some other operation they should be placed on a clean glass or hard plastic surface.

Once capacitors have been installed, the completed board assemblies also need to be handled very carefully. Bending or flexing of the board will place severe mechanical stress on the capacitor to board interface and MLCC capacitors are very susceptible to microfracturing when exposed to high levels of tension.

SOLDER ATTACHMENT METHODS

If given the choice between soldering processes, preference should always be given to an Oven Reflow or Infrared / Convection soldering process, as there are fewer variables to deal with and these options are much easier to control. At the other extreme is hand soldering which is generally discouraged for larger chip capacitors because of the significant risk associated with this process and the general lack of controls available to the operator. In addition, Vapor Phase reflow soldering is considered to be a reliable option but specific attention needs to be given to mass of the PWB to avoid thermal shock and achieve desirable results. Wave Soldering may be the most common process utilized for PWB mounting of chip capacitors, but it can pose significant risk when attempting to solder larger package sizes and for that reason is not recommended or discussed in this Application Note.

To increase the chance for success, the engineer should always consider profiling the process to establish a workable baseline. Thermocouples are recommended for this task with their number and placement dependant on the type, size and mass of the PWB and the type of process being utilized. For an Oven Reflow, Infrared / Convection or a Vapor Phase process, the thermocouple is generally mounted to the solder pad.

As with any soldering process, the use of proper pre-heat and post heat cool down cycles are extremely critical to the success of the operation. In general terms, any soldering operation being considered should have the capability to limit the maximum temperature rate of change to something less than 4°C per second. Secondly, any temperature spikes incorporated during the preheat / soak to reflow stage should be limited to something less than +60°C for chip sizes larger than 1812. These are general guidelines and depending on the size and mass of the MLCC and the type of soldering process being utilized, these temperature limits may need to be further constrained to minimize the risk of thermal damage. Please refer to the appropriate section below for more details and specific recommendations related to the soldering process being considered.

Solder pad or land pattern dimensions can also play an important role in determining the success or failure of the reflow process. Pad size is dependant on the dimensions of the chip capacitor being installed and the type of process being utilized. For additional information and pad size recommendations please refer to Application Note AN107.

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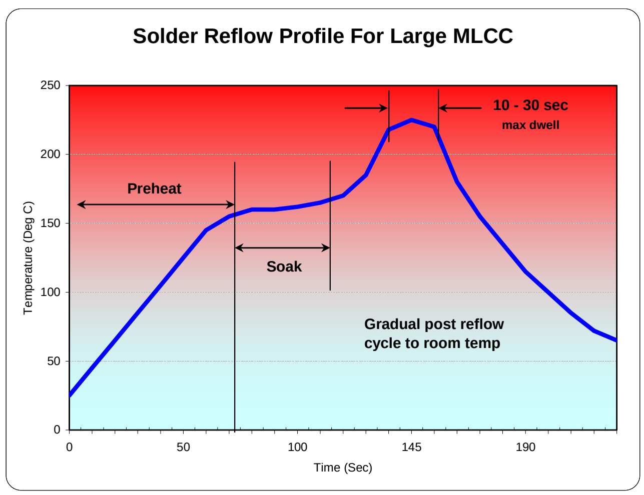
INFRARED / CONVECTION OVEN REFLOW SOLDERING

Infrared / Convection Reflow Ovens are highly recommended as they are easy to control and present a low 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 liquidous temperature and especially for those chip capacitors that utilize a silver of palladium silver termination.

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 2.0 sec / °C	1.5 to 2.0 sec / °C
Preheat Temperature	150 - 170°C	200 - 210°C
Max change Preheat to Reflow	50 to 60°C Max	50 to 60°C Max
Reflow Cycle Ramp Rate	3°C / sec Max	3°C / sec Max
Reflow Temperature	220 to 240°C	245 to 265°C
Post Reflow Cooling Cycle	6.0 sec / °C Max	6.0 sec / °C Max



SUMMARY – KEY CONSIDERATIONS

- Infrared / Convection oven soldering is the preferred method for MLCC soldering
- Proper pre-heat and post heat cycles are critical
- Keep solder time, temperature and solder volume to a minimum
- Utilize Nitrogen to facilitate soldering process
- Do not force cool soldered assemblies
- Allow soldered assembly to reach room temperature before cleaning

VAPOR PHASE REFLOW SOLDERING

Vapor phase soldering represents another effective and reliable method for reflow soldering of larger multilayer ceramic capacitors. Soldering is performed in an oxygen reducing atmosphere, peak temperatures are strictly limited to that of the condensing vapor, and the heat sinking effect of the capacitor is generally less than those seen with Infrared and Convection Oven processes. However, the highly efficient means by which heat is transferred during vapor condensation can result in rapid temperature changes, which may bring about thermal shock of the capacitors unless assemblies are adequately preheated prior to reflow. Most Vapor Phase Reflow chambers in use today are designed with multiple zones that incorporate gradual pre-heat and post heat phases to address those concerns.

Particular attention needs to be given to the total mass being exposed to the vapor and the rate at which the assembly transitions each zone. Failure to develop an optimum cycle time can result in not only the possibility of thermal shock, but the vapor zones may also collapse, which would in all likelihood prevent the capacitor from achieving the desired preheat and subsequent reflow temperatures. If this occurs, solder joints will be inferior and the operator will most likely experience a significant loss in productivity while having to wait for the vapor blanket to fully recover. It should be noted that the equipment carrier itself usually represents a significant amount of mass and it is recommended that the unloaded carrier be allowed to transition the pre-heat and reflow stages first to bring the carrier up to temperature and help stabilize the process.

Given the number of variables associated with the board assembly, it is difficult to provide with any accuracy a set of general recommendations for performing Vapor Phase soldering. General guidelines presented in the IR / Convection oven section should form the basis for establishing a starting point, but it becomes the responsibility of the engineer to establish a reliable profile that further takes into consideration the basic principles for pre-heat, reflow and post heat established in earlier sections of this Application Note.

SUMMARY – KEY CONSIDERATIONS

- **Proper pre-heat cycle is critical**
- **Pre-expose carrier to reflow cycle to help with pre-heat**
- **Keep solder time, temperature and solder volume to a minimum**
- **Do not force cool soldered assemblies**
- **Allow soldered assembly to reach room temperature before cleaning**

HAND SOLDERING

Hand soldering processes pose a considerable risk to the engineer inasmuch as the process is difficult to control and may result in a much greater possibility that the capacitor will encounter significant temperature gradients and subsequent thermal shock. If the use of a reflow system is not practical and a hand soldering process cannot be avoided, there are a number of precautions that need to be considered to minimize the likelihood of thermal shock.

As with any soldering process implementation of a preheat stage prior to soldering is strongly recommended and the best approach 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. (See figure 3)

Select a low wattage, small tip iron and under no circumstances should the operator allow the soldering iron tip to make direct contact with the lead. Solder should instead be applied directly to the tip of the iron and then touched to the solder pad so that the solder flows onto the pad and around the termination. (See figure 4)

The type and volume of solder utilized and the time the capacitor is exposed to reflow is also extremely important to the success of the operation. Wire solders with a rosin or non activated flux core are preferred and solder volume, solder time and reflow temperature should be limited as much as possible. If the capacitor being installed is manufactured with a silver, or palladium silver termination, it is recommended that a silver bearing solder be chosen, as the presence of silver can help mitigate the degree of termination leaching that can occur. Information presented in this application note is based on the use of a low temperature solder alloy with a reflow temperature of less than +190°C. Typical solder types would be Sn62 (Sn62 / Pb36 / Ag02), Sn63 (Sn63 / Pb37), Sn60 (Sn60 / Pb40) and.

If a lead free, RoHS compliant solder is required, a common choice would be Sn96.5 / Ag3.0 / Cu0.5, which has a plastic range of between 217 and 220°C. This higher reflow temperature would in all likelihood require an adjustment to the reflow times and temperatures necessary to achieve a reliable soldering operation. Any adjustments still need to take into consideration the basic principles related hand soldering of large ceramic capacitors.

Hand soldering of components is done in an open air environment and as such the ability to maintain the capacitors at the required preheat temperature for any length of time is usually not feasible. Consequently, where installation of multiple capacitors is required, the PWB assembly will need to be returned to the preheat oven. The typical rule of thumb would be 3 to 5 capacitors, after which the board assembly will again need to be preheated. This process should be repeated until all of the capacitors are soldered.

Once soldering has been completed, assemblies should first be returned to the pre-heat oven to allow the temperature to stabilize and then removed so that the board assembly can cool gradually to room temperature. Under no circumstances should the PWB assembly be forced cooled by using a fan or placement of the assembly on a metal table and product should not be cleaned in a cold degreasing bath until the assembly has reached room temperature.

Chip Capacitor Hand Solder Recommendations	
Process Step	**Limit**
Preheat Ramp Rate	2.0 - 3.0 sec / °C
Solder Iron Wattage	35 watts max
Solder Time	3 - 5 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	3.0 sec / °C Max

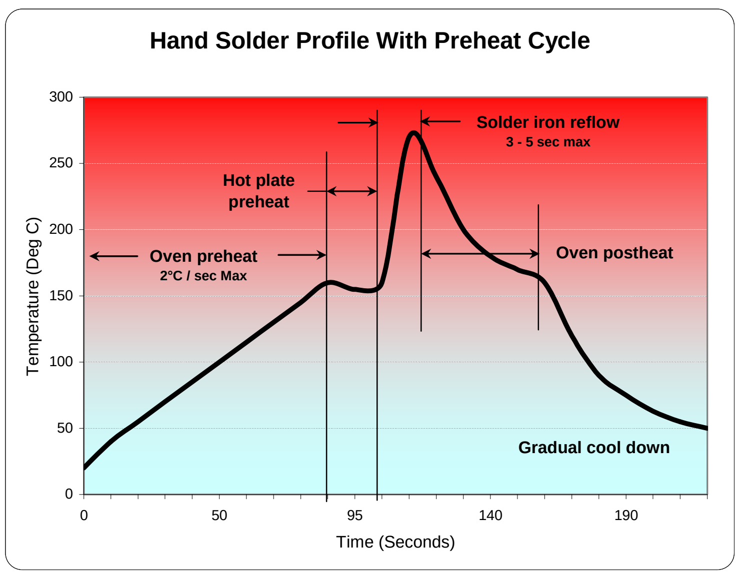


Figure 2 – Soldering Profile / Recommendations

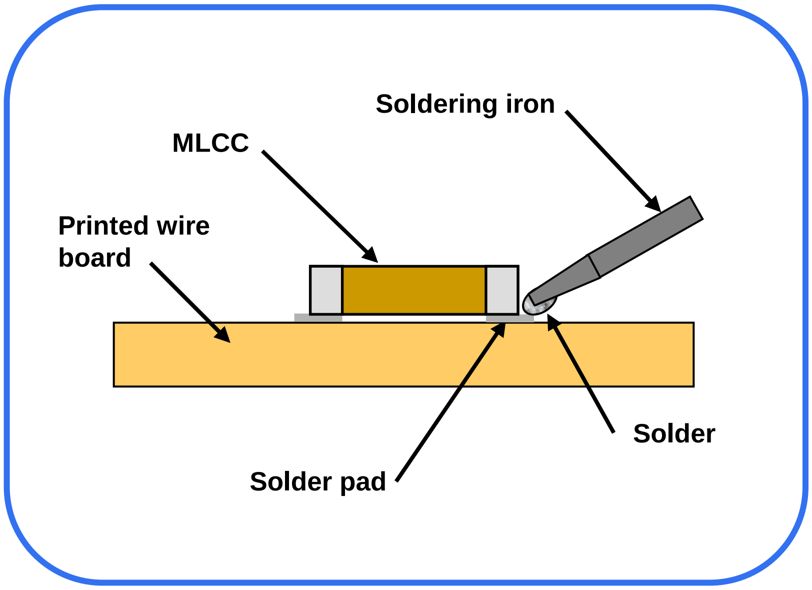


Figure 4 – Hand Soldering Technique

SUMMARY - KEY CONSIDERATIONS

- **Incorporate a preheat and post heat step in the process**
- **Use a small tip, low wattage soldering iron**
- **Keep solder time, temperature and solder volume to a minimum**
- **Do not contact the capacitor with the soldering iron**
- **Do not force cool soldered assemblies**
- **Allow soldered assembly to reach room temperature before cleaning**

REWORK

As much as one might spend countless hours trying to perfect a soldering procedure, it is impossible to eliminate all process variation and the need to repair or rework a solder joint will inevitably be encountered at some point. This process may require a simple touch up, a realignment of the capacitor or a total removal and replacement of the MLCC. Like any soldering process, undertaking a repair requires a considerable amount of upfront analysis and planning and CalRamic Technologies provides a number of recommendations for addressing this concern in Application Note 108.