# SOLDERING RECOMMENDATIONS FOR SMPS STACKED 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 are limited to Case Code 3, 4 and 5 package sizes, but 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 mechanical structures composed of alternating layers of a rigid 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 along with the brittle nature of ceramic, makes the completed structure susceptible to both thermal and mechanical shock.

Where thermal and mechanical shock conditions exist, the possibility of introducing substantial stress within the structure is significantly increased and unless preventative measures are taken 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 risk inasmuch as, the suspect part may present a latent failure, whereby the product initially exhibits itself as an acceptable unit and may continue to function until such time as moisture penetrates the flaw site, and / or it is subjected to further mechanical of thermal stress. In a worst case scenario, 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.

For smaller MLCC's, concerns regarding mechanical and thermal shock can generally be addressed through proper handling and selection of a suitable soldering process. Their relatively small size makes them less vulnerable to cracking under tension and leads to a reduced temperature gradient within the body of the ceramic during installation, which in turn minimizes the likelihood of a high stress condition. In contrast, larger ceramic capacitors, especially those with footprints greater than an 1812 chip size, can be exposed to a much more pronounced level of tension if not handled properly and an excessive thermal deviation across the chip during installation, making them much more susceptible to damage.

Understanding that mass, size and geometry can play a major role in determining the impact that mechanical and thermal shock conditions can have on long term reliability, an assortment of leaded alternatives have been engineered for these larger ceramic capacitors that provide a level of protection not possible in the same unleaded alternative. A single wire mounted in either a radial or axial configuration, is generally sufficient for a single chip capacitor, but where multiple chip capacitors are sandwiched together, a specially designed terminal that connects the entire stack together has been developed. Like the single wire terminals, these lead frames have proven to be effective in providing an enhanced level of stress relief. That said, the use of a leaded capacitor does not totally eliminate the threat, especially for thermal shock and any installation process being considered, must properly address those concerns. 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 SMPS ceramic 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.


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## GENERAL CONSIDERATIONS

Larger ceramic capacitors and SMPS capacitor stacks, 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 compromised solder joints, and the formation of internal micro fractures and / or surface chip outs to the ceramic capacitor, which may in turn 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 SMPS capacitors generally require a packaging container that keeps individual capacitors separate from one another, secures each device and protects their lead frames from damage. 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 and that they are not picked up by the leads themselves. 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 mechanical stress on the lead frame to capacitor and lead frame to board interface and this may damage the solder joint, or the capacitor itself. As stated above, damage to the capacitor may cause the capacitor to fail, and although damage to the solder joint may not result in a similar failure mechanism, it can result in an increase in either ESR or ESL, which in turn can affect the functionality of the system.

## SOLDER ATTACHMENT METHODS

If given the choice between soldering techniques, preference should always be given to an Oven Reflow, or Infrared / Convection soldering process. With this approach, there are fewer variables to deal with and these options are much more adaptable to the specific requirements of the capacitor being installed. At the other extreme is Hand soldering, which is generally discouraged for installing larger chip capacitors and SMPS capacitor stacks. There is a significant risk associated with this process and the over-all lack of controls available to the operator, generally limits this approach to repair situations only. In addition, although other options like Vapor Phase reflow and Wave soldering may be considered as reliable process alternatives for soldering smaller chip capacitors, they are likewise discouraged for SMPS capacitor designs. The larger mass associated with SMPS capacitor stacks in particular, present a major obstacle for Vapor Phase and Wave soldering processes, due to their inability to address the need for an adequate preheat cycle prior to reflow.

To limit risk and improve the likelihood of success, the engineer should always consider process optimization through the use of thermocouples that help to establish a workable baseline. Placement is dependent on the type, size and mass of the PWB, the mass and size of the SMPS capacitor and for an Oven Reflow, Infrared / Convection process, a thermocouple is generally mounted to the solder pad. Calramic Technologies utilizes a solder type for lead attachment that has a solidus temperature of +221°C, and use of additional thermocouples mounted on the lead frame / capacitor stack can help to determine temperature gradients between the point of solder reflow and the capacitor itself, therefore allowing the engineer to set a reflow profile that prevents the possibility of lead frame detachment from the capacitor stack.

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 during preheat and cool down to something less than 2°C per second. Secondly, any temperature spikes incorporated during the preheat / soak to reflow stage should be limited to something less than +50°C for SMPS capacitors. These are general guidelines and depending on the actual size and mass of the MLCC, these temperature limits may need to be further constrained to minimize the risk of thermal damage.

## 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 assembly during installation. Generally speaking, heat transfer rates are low, which allows the lead frame and capacitor body to heat up and cool down at roughly 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, a pre-heat cycle combined with a thermal soak zone, may be necessary to ensure that the capacitor stack heats up at the desired rate and achieves the intended pre-reflow temperature level, without damaging other components on the PWB.

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-020E. 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.

## SUMMARY – KEY CONSIDERATIONS

- **Infrared / Convection oven soldering is the preferred method for SMPS capacitor installation**
- **Proper pre-heat and post heat cycles are critical**
- **Utilization of a pre-reflow thermal soak may be necessary to insure adequate preheat**
- **Use a low temperature solder for mounting**
- **Keep solder time, and temperature to a minimum**
- **Utilize Nitrogen to facilitate soldering process**
- **Do not force cool soldered assemblies**
- **Allow soldered assembly to reach room temperature before cleaning**



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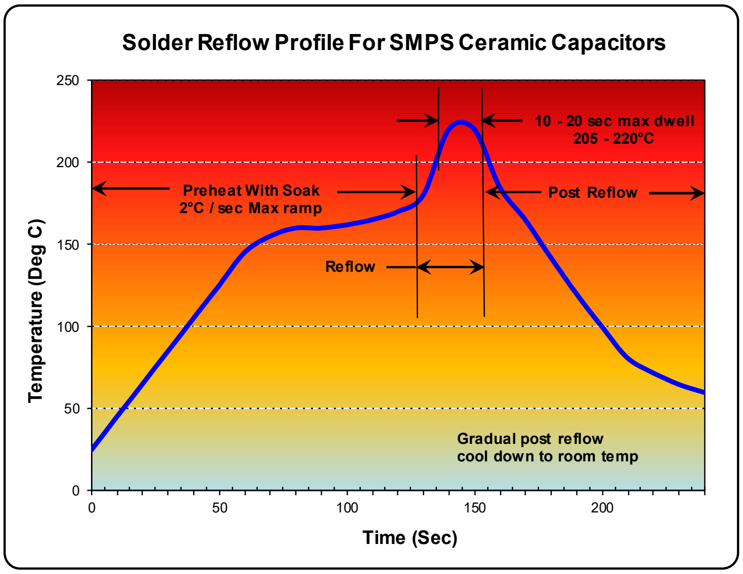



| Solder Reflow Profile Recommendations | |
|---|---|
| Stage | Parameter |
| Preheat Ramp Rate | 1.5 to 2.0 sec / °C |
| Preheat Temperature | 150 to 170°C |
| Max change Preheat to Reflow | 50 to 60°C Max |
| Reflow Cycle Ramp Rate | 3°C / sec Max |
| Reflow Temperature | 205 to 220°C |
| Post Reflow Cooling Cycle | 3°C / sec Max |

Figure 1 – Oven Reflow Soldering Profile / Recommendations

## HAND SOLDERING

Hand soldering processes as a means of installing SMPS capacitors, pose a considerable risk inasmuch as, the process is difficult to control and may result in a much greater possibility that the capacitor assembly 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.

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 terminal. For N lead through hole SMPS configurations, solder connections should be made to the underside of the board whenever possible. (See figure 3)

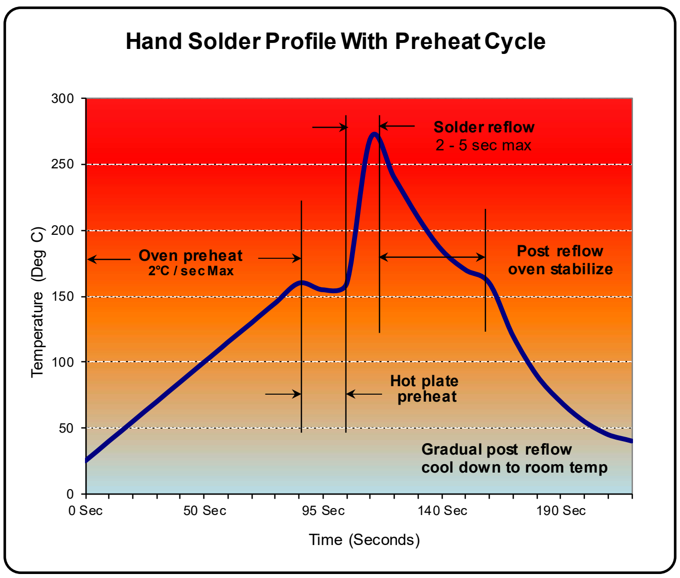
The type and volume of solder utilized and the time the capacitor is exposed to reflow conditions is also extremely important to the success of the operation. Wire solders with a rosin or nonactivated flux core, are preferred and solder volume, solder time and reflow temperature should be limited as much as possible. Implementation of a hot air gun during this phase of the operation, may be beneficial in helping to maintain the pre-heat temperature and minimize the solder time. Information presented in this application note is based on the use of a low temperature solder alloys like Sn60/Pb40, Sn63/Pb37Pb, or Sn62/Pb36/Ag2, with a reflow temperatures of less than +190°C.

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 again be returned to the pre-heat oven to allow the temperature of the SMPS capacitor 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 never be cleaned in a cold degreasing bath until the assembly has reached room temperature.

## SUMMARY - KEY CONSIDERATIONS

- **Incorporate a preheat and post heat step in the process**
- **Limit transfer time from preheat to solder station as much as possible**
- **Use a small tip, low wattage soldering iron**
- **Keep solder time, temperature and solder volume to a minimum**
- **Do not contact the capacitor or lead frame with the soldering iron**
- **Solder N lead, through hole configurations from opposite side of PWB**
- **Do not force cool soldered assemblies**
- **Allow soldered assembly to reach room temperature before cleaning**
- **Multiple pre-heat cycles may be required**




| Hand Solder With Preheat Recommendations | |
|---|---|
| Stage | Larger Chip Size and SM Assemblies |
| Preheat Ramp Rate | 1.5 to 2.0 sec / °C |
| Solder Iron Wattage | 30 watts max |
| Solder Time | 2 - 5 sec Max per lead |
| Max change Preheat to Reflow | 55 to 65°C Max |
| Solder Iron Tip Temperature | 290 to 300°C Max |
| Post Reflow Cooling Cycle | 3.0 sec / °C Max |

Figure 2 – Hand Soldering Profile / Recommendations

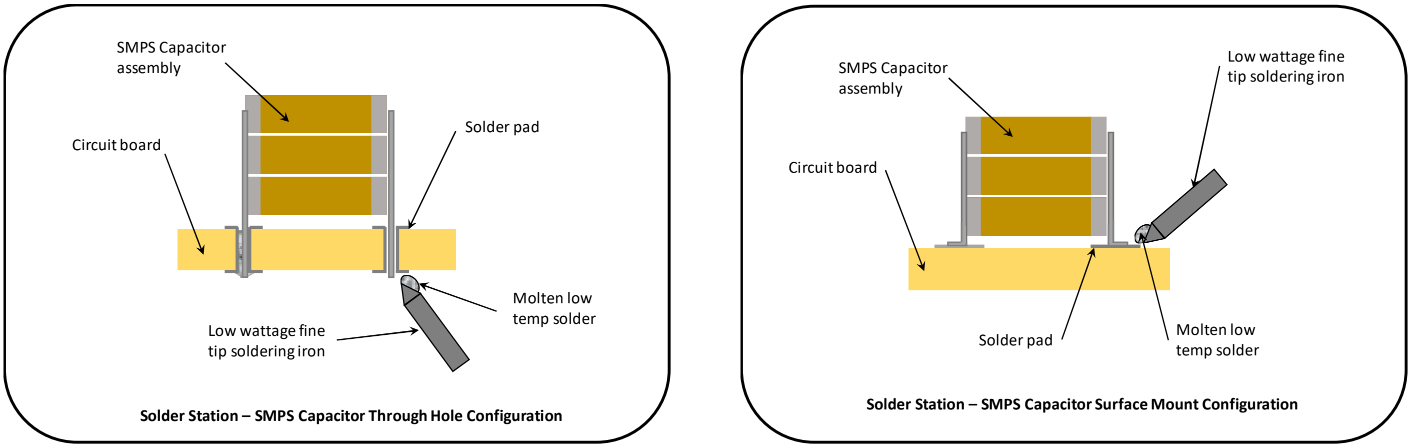



Figure 3 – Hand Soldering Installation Station

## 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 capacitor stack. 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 situation.

Unfortunately, rework is most often limited to a hand soldering approach, as reuse of an oven environment to complete a repair is not feasible. That said, acknowledging that use of any hand soldering process presents a considerable level of risk for damaging the capacitor assembly, the PWB and adjacent components, rework should always be the last option. The engineer and / or quality department should first establish whether the abnormality will in fact pose a reliability concern, or whether it is simply cosmetic. If it is determined that the anomaly will not affect the integrity of the capacitor and in turn system performance, the operator should forego repair and instead focus resources towards mitigation efforts for future builds.

If, on the other hand, the physical condition of the SMPS capacitor poses a risk and the decision to proceed with a repair becomes necessary, the engineer will need to first classify the type of repair required. As with any soldering operation, particular attention needs to be given to reducing thermal shock and since the original reflow oven approach is not viable, use of a localized heat source like a soldering iron, will likely be required, Heat transfer rates for soldering irons are extremely high, which means that options including the use of a hot plate, a hot air torch and / or a heat sink, will all need to be considered in order to safe guard the capacitor, the PWB and other adjacent components.

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. Use of a hot air torch to facilitate preheating, allows the operator to localize heating around the lead to solder pad interface, and in combination with a hot plate, can help to reduce solder time and limit temperature gradients between the point of lead attachment and the fragile ceramic capacitor.

- **Touch Up** – By definition, touch up suggests the least evasive level of rework and implies that there is either an inadequate, or an excess amount of solder present. If there is insufficient solder and the capacitor appears to be properly aligned, adding a small amount of solder should rectify the issue. For application, solder should be added to the tip of the soldering iron and then allowed to flow into the defective solder joint area. If excess solder exists, adding a small amount of flux to facilitate reflow, and then using the soldering iron in combination with either a braided copper solder wick, or a vacuum extractor, should correct the issue.

- **Realignment** – Repositioning of a capacitor assembly can be broken down into two situations, whereby an adjustment is needed either before, or after, the initial soldering operation has been completed. The oven reflow process is highly dependent on precise volumes and placement of solder pastes and accurate positioning of the SMPS capacitor. Making an adjustment once the capacitor assembly has been positioned, significantly increases the likelihood that the solder joint may be defective, that bridging between solder pads may occur and that solder balls will be present. If an adjustment needs to be made, the best approach would be to avoid twisting or sliding the part and instead, lift the capacitor stack straight off the board and then replace.

  If the soldering process has been completed, the mass of the SMPS capacitor and the number of lead attachment points, makes realignment problematic and damage to the capacitor is highly likely. In this situation, it is best to consider the capacitor as non-salvageable and rework should instead be limited to removal and replacement of the SMPS capacitor.

- **Removal and Replacement** – This type of repair requires a removal of the SMPS capacitor and a guarantee that the PWB and other adjacent components, are not damaged in the process. The most reliable approach would be to first cut all of the capacitor leads, which would allow for easy disposal of the ceramic body. Once the larger mass has been removed, the remaining lead portions can be quickly and easily unsoldered and removed from the PWB with a soldering iron or solder tweezers, with minimal risk to the solder pads and the rest of the board assembly.

  If the location of the capacitor precludes the possibility of separating the capacitor body from the leads, the use of a fine tip, hot air torch may be required in conjunction with the soldering iron, to help elevate the temperature of the capacitor and facilitate the process. Care needs to be taken to ensure that air flow is limited to the SMPS capacitor assembly, which in turn will help mitigate the possibility that the surrounding components are not subjected to possible thermal damage.

  Removal of residual solder using a soldering iron and braided copper wick, or solder vacuum, should also help to recondition the solder pads for capacitor replacement. As a precautionary note, it is very important to keep reflow time to as short as possible to avoid damage to the PWB, solder pads and adjacent components. .As a rule of thumb, soldering irons or solder tweezers should not be in contact with the solder pad for any more than 5 to 6 seconds. Once residual solder has been removed, the board should be thoroughly cleaned and inspected to ensure there is no evidence of solder pad lifting and that no other damage has taken place during the removal process.

  If the board assembly is deemed to be acceptable, the pad areas should be prepared by either adding new solder paste, or by pre-tinning the surface. As outlined above in the General Considerations section, non-metal tweezers, finger cots or non-contaminating gloves should always be utilized for handling capacitors. In addition, installation can be performed using the same approach outlined above in the Hand Soldering section. 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 emphasized, the heating process should be limited to only the area being soldered.

  Upon completion of any rework step, the operator will need to perform a thorough re-inspection of the SMPS capacitor, solder joints and the board assembly. As noted above, ceramic capacitors are highly susceptible to thermal shock, especially when using a hand soldering process, and this inspection will provide assurance that the overall integrity of the completed assembly has been maintained.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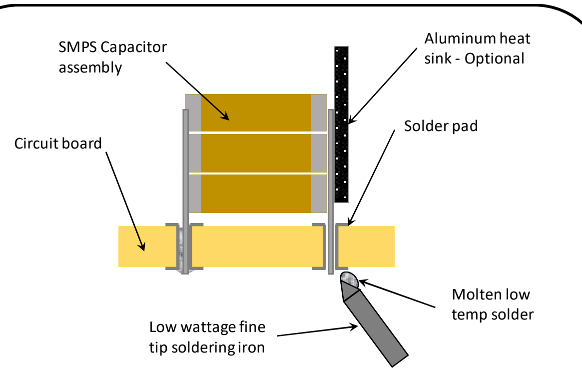
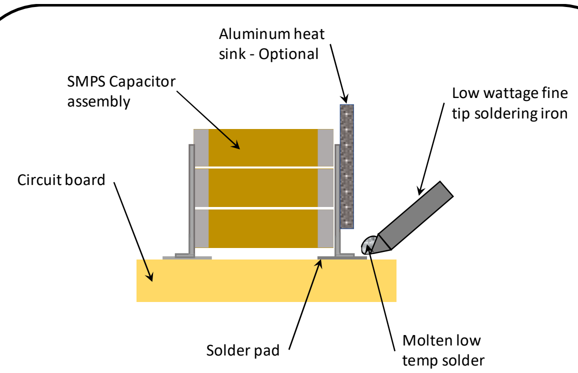
## SUMMARY - KEY CONSIDERATIONS

- Concerns over reliability and performance always trump cosmetic issues
- Rework should always be the last option
- Removal and replacement are preferred over re-alignment
- Keep solder reflow time, to a minimum
- A hot air torch can be an effective means of facilitating removal
- As much as possible limit reflow and restrict auxillary heating to the rework area
- A heat sink can be an effective means of protecting the capacitors from thermal shock
- Do not force cool soldered assemblies
- Thorough re-inspection of entire assembly is essential
- Eliminate rework through root cause / corrective action analysis




Solder Station – SMPS Capacitor Through Hole Configuration




Solder Station – SMPS Capacitor Surface Mount Configuration

Figure 4 – Rework Station