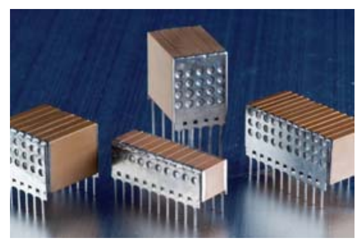
Soldering and Handling Recommendations for large size MLC Capacitors

Introduction

Multilayer Ceramic Capacitors (MLCC) come in a broad range of sizes, geometries, and values, offering design engineers with many options for designing circuits. In many cases these MLCC's offer advantages over other types of capacitors including low ESR/ESL, mechanical robustness, high temperature capabilities, lack of polarity, and ability to withstand high levels of dv/dt. MLCC's must be handled carefully to prevent damage and for larger sizes ($\geq$2220 size) are susceptible to thermal shock damage during solder attachment if proper precautions are not taken. Using common sense and some simple rules, thermal and mechanical damage can be avoided.

Background

MLCC design incorporates metal electrode layers sintered into a monolithic block of ceramic (commonly a Barium Titanate based material). These electrodes, which can be printed from base metals such as Nickel or Copper or precious metals such as Ag/Pt or Ag/Pd alloys, form an alternating pattern which provides for the high volumetric efficiency. To connect these alternating electrodes, end caps are added using thick film or thin film methods. Each of these materials has a Thermal Coefficient of Expansion that is different from the other, making the MLCC susceptible to thermal cracking if exposed to large thermal excursions.



Capacitor design can help to overcome this tendency. For example, the use of lead-frames on high CV capacitors, such as the stacked capacitors pictured above-right, not only isolate the caps from mechanical stresses but also provide a measure of thermal isolation. For very "low-active" designs that are common in through-hole filtering caps such as planar array capacitors and discoidal caps, there are specialized electrode designs that can allow faster heat dissipation.

MLCC's are inherently strong in compression but are inherently weak on tension and need to be protected from mechanical stresses during manufacture, handling, and installation. Much care is taken at the Holy Stone manufacturing sites worldwide to ensure that mechanical stresses are not introduced during manufacture. This document helps define some of the preferred handling and installation techniques to protect the larger MLCC's during these phases of their lives.

Handling

As stated above, although robust in their design and manufacture, large size MLCC's can be damaged during handling and installation. Once the caps have completed their manufacture, proper selection of packaging materials is key. Large size MLCC's should be kept from coming into contact with each other during handling and shipping so a good tape and reel package or waffle packaging is recommended. Bulk packaging should never be used for caps $\geq$2220 in size or for devices with lead-frames or other specialty lead attachment. Any large size capacitor that is dropped or otherwise exposed to abnormal conditions should be discarded. Such damaging conditions can lead to micro-cracking which may not be detectable during routine testing or inspections and can lead to failure modes which may not occur right away. These latent failures are to be avoided at all cost.

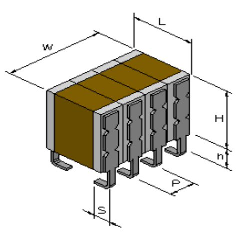
If possible, the original packaging materials should be used during inspections and storage to maintain the protective environment. Once issued to manufacturing, precautions should still be taken to protect the large MLCC's including instructions to the manufacturing team about not allowing individual capacitors to come into contact with each other. MLCC's are not susceptible to ESD so additional protection against this condition is not typically required.

MLCC's should never be handled with bare hands or with metal tweezers to avoid surface contamination with oils, salts or metal marks that could cause reduction in insulation resistance. Further, the surfaces that the capacitors are placed on during processing must be kept clean and should preferably be low porosity surfaces such as glass.

Board Design

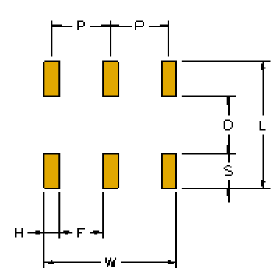
At the time this paper was written, no industry standard for laying out solder pads for lead-frame capacitors could be found. There are many sources for pad layouts for surface mount devices (SMD) but for larger sizes, many of these guidelines do not carry the same weight as for the more plentiful smaller SMD sizes such as 0603, 0402, and 0201. Some common sense precautions are listed here to assist board designers:

- High voltage creepage and clearance concerns typically don't apply to large size MLCC's due to their large length dimension (between end caps) but board designs need to consider allowance to clean the underside of the caps after soldering. For surface mount caps, this may warrant a slot in the board under the cap.
  - IT SHOULD BE NOTED THAT HOLY STONE OFFERS AN ARC PREVENTION COATING FOR ITS CAPACITORS THAT IMPROVES THE SURFACE POROSTIY OF THE CAPS AND ALLOWS MORE EFFECTIVE CLEANING OF THE SURFACES OF THE CAPACITORS.
- Solder pad designs for surface mount should consider the need to keep solder mass to a minimum. Excessive amounts of solder can place undue mechanical stresses on the MLCC during freezing of the solder. This is especially important for very large size surface mount devices.



- If conformal coating is to be used at the board level, care should be used to be sure that the coating can penetrate below the MLCC after assembly. This can be accomplished with a groove or slot in the board.
- Solder volume for lead-frame capacitors is much less of an issue but should still be considered.
- Lead-frame devices typically come with three choices of leads. N-leads are through hole leads which typically allow the most robust (shock and vibration resistant) attachment to the board. L and J leads are considered surface mount. L leads bend out from the body of the capacitor while J leads bend under the cap body. For the smallest sizes of stacked capacitors, consideration for clearance of the solder pads needs to be considered, especially for higher voltages.

Holy Stone's solder pad recommendations for lead-frame stacked capacitors follow:



J-Lead

Recommended Solder Pad Layout/Dimensions (mm) (typical)

Insert Size	HEC Prod. Code	Leads per side	H (minimum)	P	S	D	F	L	W
1210	SMC*5	1	---contact factory---						
1812	SMC*6	2	0.6	2.54	2.54	1.3	1.0	6.3	3.1
2220	SMC*7	3	0.6	2.54	2.54	1.5	1.3	6.6	5.7
1825	SMC*8	3	0.6	2.54	2.54	1.3	1.3	6.3	5.7
2225	SMC*9	3	0.6	2.54	2.54	1.5	1.3	6.6	5.7
Case size 1	DSC*1	20	0.6	2.54	3.00	7.5	1.8	13.5	48.9
Case size 2	DSC*2	15	0.6	2.54	3.00	16.0	1.8	22.0	36.2
Case size 3	DSC*3	10	0.6	2.54	3.00	7.5	1.7	13.5	23.5
Case size 4	DSC*4	4	0.6	2.54	2.75	6.5	1.5	12.0	8.2
Case size 5	DSC*5	3	0.6	2.54	2.54	3.0	1.3	8.1	5.7
Case size 6	DSC*6	20	0.6	2.54	3.00	27.8	1.8	33.8	48.9

L-Lead

Recommended Solder Pad Layout/Dimensions (mm) (typical)

Insert Size	HEC Prod. Code	Leads per side	H (minimum)	P	S	D	F	L	W
1210	SMC*5	1	---contact factory---						
1812	SMC*6	2	0.6	2.54	2.54	3.7	1.0	8.8	3.1
2220	SMC*7	3	0.6	2.54	2.54	4.0	1.3	9.0	5.7
1825	SMC*8	3	0.6	2.54	2.54	3.7	1.3	8.8	5.7
2225	SMC*9	3	0.6	2.54	2.54	4.0	1.3	9.0	5.7
Case size 1	DSC*1	20	0.6	2.54	3.00	10.2	1.8	16.2	48.9
Case size 2	DSC*2	15	0.6	2.54	3.00	19.4	1.8	25.4	36.2
Case size 3	DSC*3	10	0.6	2.54	3.00	10.2	1.7	16.2	23.5
Case size 4	DSC*4	4	0.6	2.54	2.75	9.1	1.5	14.6	8.2
Case size 5	DSC*5	3	0.6	2.54	2.54	5.6	1.3	10.7	5.7
Case size 6	DSC*6	20	0.6	2.54	3.00	31.0	1.8	37.0	48.9

Solder Attachment

Ceramic materials used in MLCC's are relatively poor conductors of heat when compared to the metals that make up the end caps, electrodes, solders, and the conductors of the PC board or substrate to which they are attached. This creates challenges that must be addressed to prevent thermal cracking of the ceramic materials. The mass of the ceramic is a key determinant of the susceptibility to thermal cracking with the larger, higher mass, capacitors providing the biggest challenge.

Three keys to successful soldering of large size ceramics are:

- Preheat
- Ramp rate for the solder process of choice
- Cool down

Various solder methods are available for assembly. Some are preferred over others and some are not recommended at all due to potential for damage.

It is highly recommended that the **preheat** step in the soldering process be controlled to a ramp rate not to exceed 3°per second. The **preheat** should allow the ceramic to stabilize at a temperature of within 100°C of the peak soldering temperature. Given the large mass of large size MLCC's and the relative poor thermal conductivity, profiling of the preheat step should include use of a thermocouple imbedded in a ceramic block. Only then, will the actual thermal profile be well understood. Holy Stone recommends use of a convection oven for preheating.

If there is any time delay between the **preheat** step and the actual soldering process, care must be taken to not allow the capacitor to significantly cool before the heat profile begins. One method to achieve this is to rest the device on a hot plate near the entry of the solder process. Alternatively, an IR lamp could be used but care should be taken to understand and control the effective temperature of the IR lamp.

Below is a discussion of the various methods of soldering along with recommendations and warnings about each. They are listed in order of preference with the most preferred method first:

- **Reflow soldering** **Reflow soldering** includes convection, IR, and radiant heating or combinations thereof. **Reflow soldering** is the preferred method for soldering large size MLCC's due to the controlled ramp rated and peak temperature.
  - To ensure success, the oven should be profiled properly using a thermocouple imbedded into a ceramic block (similar size and material to the capacitor to be soldered is preferred).
  - Oven load is also a key consideration when profiling an oven. Care must be exercised not to exceed the oven load (total mass of capacitors and fixtures) that was used in profiling, when performing the **Reflow Soldering** process.
  - Many reflow solder ovens allow for an inert atmosphere blanket. Most often, Nitrogen is introduced into these systems to reduce the tendency for oxidation. While not a requirement for acceptable soldering, a Nitrogen blanket can improve the process and should be considered.
  - Peak temperature should be selected carefully based on the solder of choice.
  - Ramp rate for **Reflow soldering** should be controlled to less than 2°C per second. Some ovens allow for ramp and hold profiles which can be beneficial.
  - Peak temperature should be maintained for the minimum time in which proper reflow occurs. This may have to be established on a trial and error basis. Under no circumstances should the

soak at peak temperature be more than 15 seconds and efforts should be made to limit this soak to less than 10 seconds.

- **Vapour Phase Soldering** **Vapour Phase Soldering** became very popular for small scale soldering but has limitations for large size MLCC's. The same considerations should be applied to a **Vapour Phase Soldering** process as are used for **Reflow Soldering** (above), including profile and ramp rate. Since **Vapour Phase Soldering** uses a boiling liquid to establish the peak temperature, in many cases the ramp rate cannot be controlled as effectively as in a **Reflow Soldering** process. It is for this reason that **Vapour Phase Soldering** is not preferred for large size MLCC's.
- **Wave Soldering** **Wave Soldering** is not recommended for large size MLCC's although with significant work, a **Wave Soldering** process can be theoretically controlled to a point where it can meet the preheat and ramp rate requirements. This level of control is difficult and problematic and therefore **Wave Soldering** is not recommended for large size MLCC's.
- **Hand Soldering (solder iron)** **Hand Soldering** is not recommended due to relative lack of controls available. This is especially true for large size MLCC's that do not have lead-frames. The possibility for thermal cracking is very high using **Hand Soldering** methods.
  - For MLCC's with lead frames, it is possible to successfully use **Hand Soldering** (although not recommended). This is due to the buffer that the lead-frame offers to the MLCC body. If **Hand Soldering** is chosen, however, at no time can the solder iron tip be allowed to come into contact with the lead-frame or the ceramic body. Other key considerations include:
    - Low power solder iron should be used (30 Watt maximum power).
    - Proper preheating should be employed. See recommendations listed under the **Reflow Soldering** process.
    - It is advisable to perform the hand soldering process on a hot plate to help maintain preheat temperature during the process.
    - If at all possible, a heat sink (Aluminum recommended) should be employed when hand soldering a lead-frame device. The heat sink should remain in contact with the lead frame throughout the **Hand Soldering** process.
    - The solder iron tip should be chosen to be the smallest tip that will adequately reflow the solder. This may require a trial and error method.
    - The solder iron tip should be placed into contact with the solder pad on the PCB and **NEVER** allowed to touch the lead-frame or the ceramic body.

The **cold down** step of the process is often ignored or prioritized lower than the other steps. Often this happens with negative if not disastrous consequences. The author has spent extensive time doing failure analysis of large size MLCC's and more often than not, it has been determined that damage to the MLCC occurred during **cool down** and not the **preheat**, ramp, or peak temperature steps. The ceramic's poor thermal conductivity creates the same challenges during **cool down** as for **preheat** and ramping. It I not uncommon to see "forced cooling" of capacitors exiting the **Reflow Process**, such as the use of a fan, either to speed up operations or to accommodate handling. This is not advisable and should be avoided. Another cause of **cool down** problems is excessive drafts in the solder processing area. One successful method of cooling if the solder oven does not allow for adequate cooling within the confines of the oven is to place the capacitors into a static oven that is preheated to 150°C or approximately the same temperature as the capacitor exits the reflow oven. Once the capacitors are safely inside the oven, the oven can be turned off and allowed to cool slowly.

Since "Large size MLCC" is a relative term, devices on the smaller end of the spectrum may be able to be assembled successfully using one of the non-preferred methods, however, extra care should always be employed in choosing and preparing any soldering method besides **Reflow Soldering**.

Rework

Rework poses special problems for large size MLCC's. The best solution to rework is to provide a stable controlled Solder Reflow process that does not require a high level of rework. If reqork is required, the Hand Soldering precautions listed above should be adhered to as strictly as possible. For lead-frame capacitore, it is possible to salvage the capacitors after rework (if strict adherance to the methods above are maintained), however, for SMD large size MLCC's it is highly recommended that the capaitors requiring rework be discarded and replaced with virgin capacitors.

Recommended reading: Holy Stone Tech Paper titled: Selecting a capacitor to be used as a Switch-Mode Power Supply Filter.