

APEC 2011: Ceramic Capacitor Update

HiCV Material Development

Relationship between dielectric microstructure and characteristic

- Grain Boundary**
 - ✓ Insulation resistance
 - ✓ Reliability
- Core BaTiO₃**
 - ✓ High permittivity region
- Shell Diffusion sector**
 - ✓ Low permittivity region
 - ✓ Insulation resistance
 - ✓ Reliability

Optimizing microstructure

High permittivity

- 1 High Crystallinity of BaTiO₃
- 2 Increasing of core domain (thinner shell thickness)

High reliability

- 1 Grain/Shell boundary design
- 2 Interface design at dielectric / electrode

Dielectric grain size reduction typically leads to the shell having an increased role. Increasing the core volume in the grain structure slows dielectric constant reduction with smaller grain size.

APEC 2011: Ceramic Capacitor Update

Dielectric Layer Thickness Reduction

0.2μm ~ 0.1μm fine BaTiO₃ powder are required in order to compose submicron dielectric layers.
 → 4~5 grains are required between electrodes in order to maintain favorable reliability.

Beyond merely extending the CV product in the MLCC, reliability is also improved through these technology themes. Albeit with thin dielectric layers, reliability is preserved/improved, by maintaining/increasing the number of grains per dielectric layer.

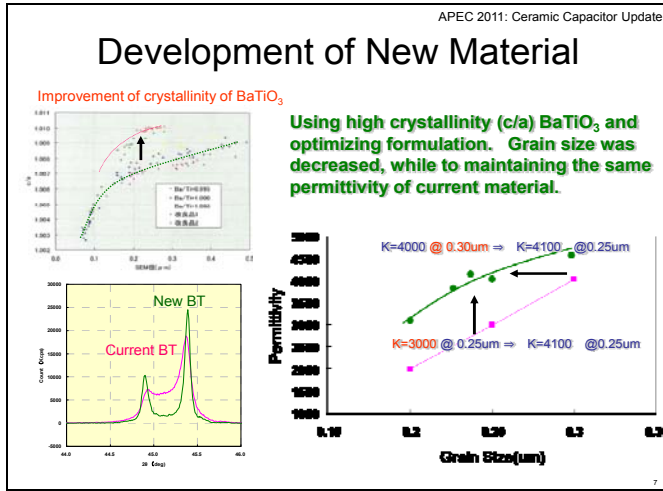
APEC 2011: Ceramic Capacitor Update

BaTiO₃ Powder Development

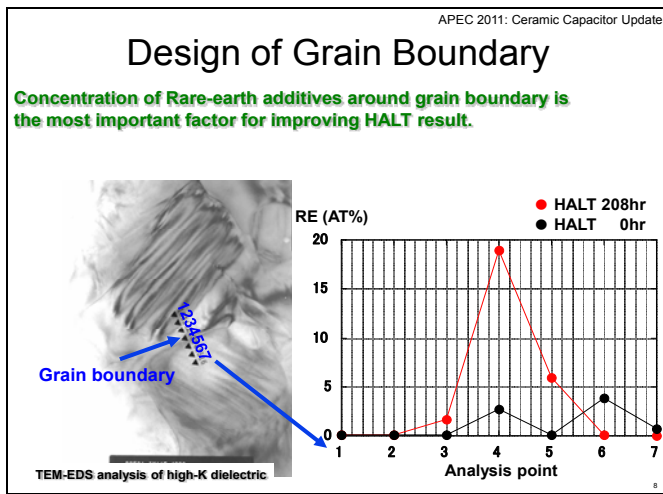
Fine BaTiO₃ is required in order to compose the thinner dielectric. However, permittivity of BaTiO₃ is reduced in smaller grain sizes. Both crystal anisotropy and crystallinity of BaTiO₃ decrease with particle size.
 → BaTiO₃ crystallinity improvements become more important for sub-micron high-K dielectric layer designs.

Grain size [μm]	Dielectric constant
0.15	~1800
0.2	~2500
0.35	~3000
0.5	~3300

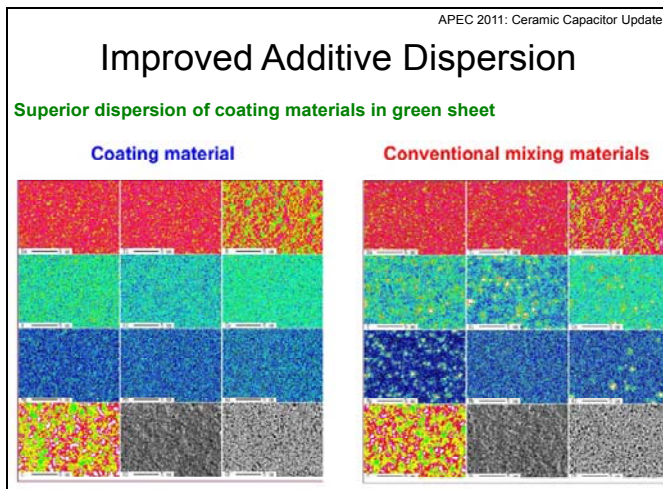
Within a material set, as barium titanate grain sizes decrease, crystallinity decreases leading to the dielectric constant being lower. The amount of capacitance per MLCC layer is reduced.



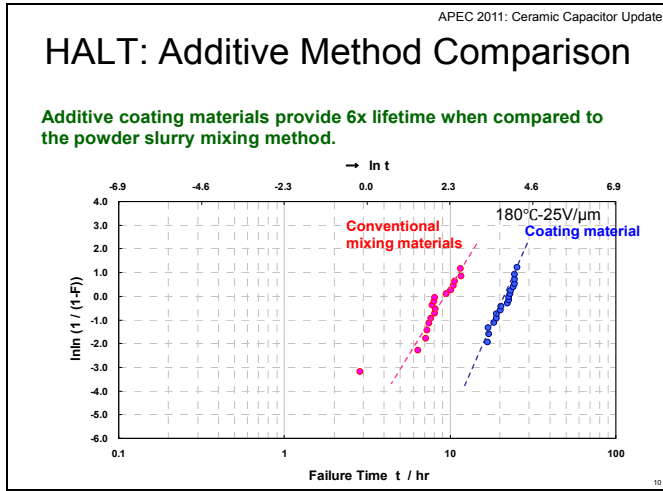
To overcome the drop in capacitance per layer, barium titanate grains with larger core volume (optimized microstructure) is used.



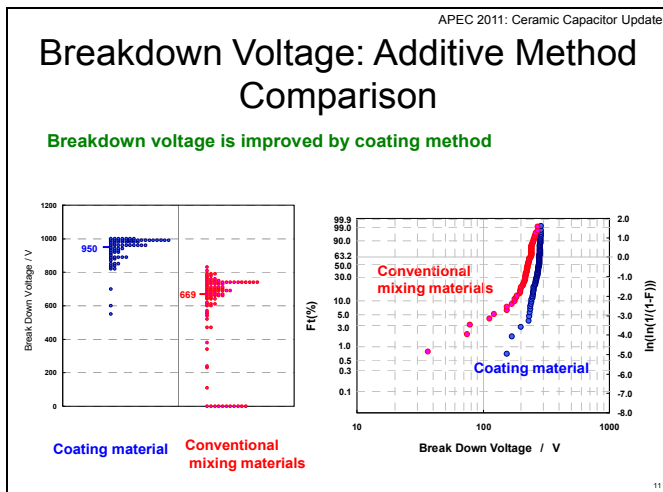
Reliability is directly related to the integrity of the grain boundaries in the ceramic layers.



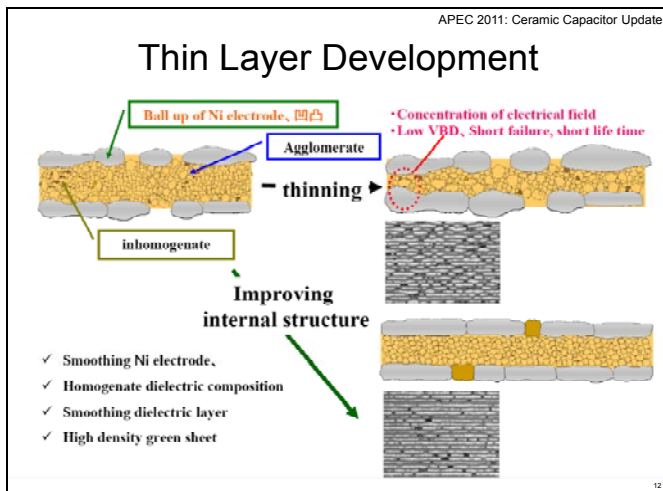
The traditional method of mixing dielectric and additive powders together has limited effectiveness. Coating the dielectric with the additives, on a liquid scale, prevents low insulation resistance regions caused by agglomeration of the additives. Coating processes provide even coverage on the grain surface.



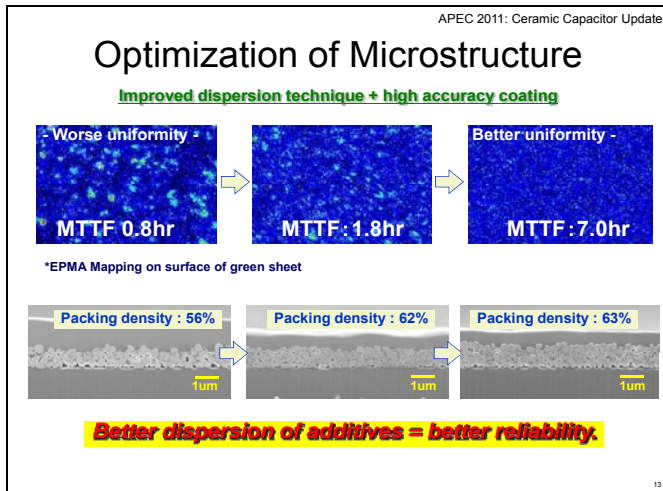
The improvement in HALT results indicates that the improved dispersion and even coating of additives on the dielectric grains is very effective. These failures are based on 10x increase in leakage current.



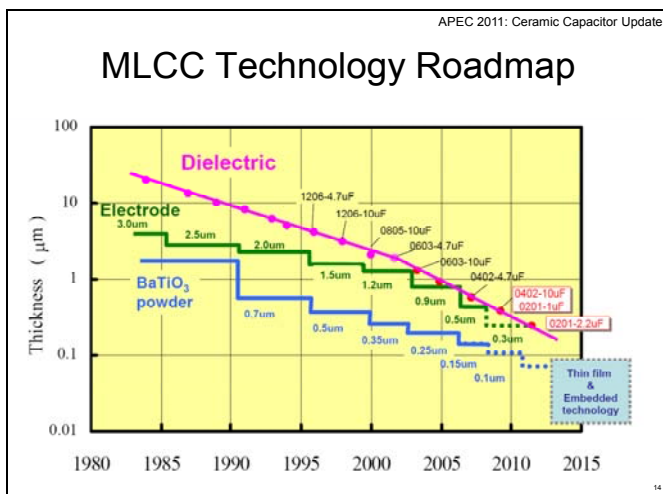
Breakdown voltage level and variation are improved. Failures here are based on true rupture of the dielectric (100V/sec)...usually audible cracking.



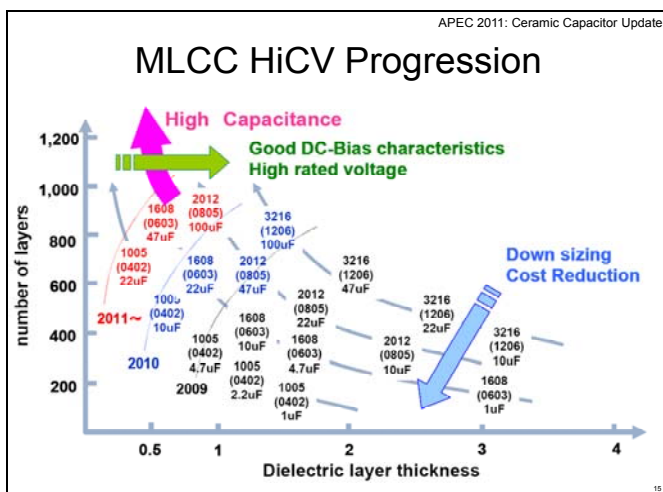
The MLCC construction quality is also dependent upon the electrode characteristics. Closely matching the firing profile performance of the electrode and the dielectric creates fewer gaps. Ceramic particle loading of the electrode paste improves the mechanical strength of the fired body.



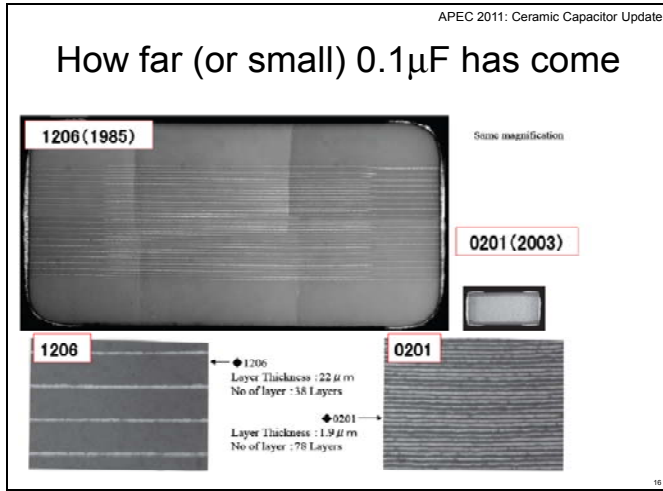
Dispersion of additives and consistent layer thicknesses eliminates electric field concentrations, improving long-term reliability and dielectric strength. The MLCC's volumetric efficiency gains through the improved packing density.



In particular, high CV MLCC capacitors have undergone remarkable case size reductions. Additionally, lower circuit voltages have allowed for lower rated voltage capacitors. The combined effect is great board space savings and improved cost-effectiveness.



The market is driven to provide high effective capacitance in small case sizes.



Getting more into finished MLCCs, let's take a look at a very common value. In 1985, a 1206 body size was needed to achieve 0.1 μ F, at 25V. Eighteen years later, this value was available in an 0201, at 6.3V. The reduction of IC operating voltages has enabled this volumetric downsizing.

APEC 2011: Ceramic Capacitor Update

HiCV Benchmark Developments

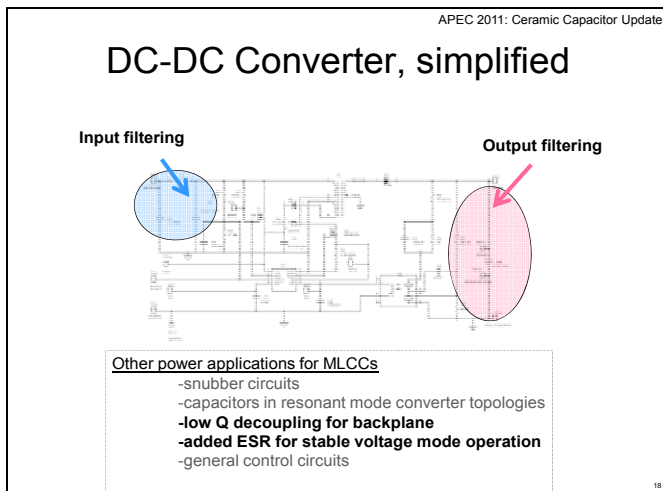
Reference	Traditional solution	Currently (near term)
50V, 1000pF	0805 NP0	0402 NP0
50V, 0.1 μ F	0805 X7R	0402 X7R 0805 NP0
100V, 1 μ F	1812 X7R	1206 X7R (0805 X7R, CY2012) 0805 X7S
6.3V, 10 μ F	1206 X5R	0402 X5R
6.3V, 22 μ F	1210 Y5V	0603 X5R (0402 X5R, CY2013)

Key points -typical ref. K values: Y5V ~ 3.5 times X5R/X7R ~ 3500 times NP0

-space savings:

0805 => 0402	80% less board space!
1812 => 0805	>80% less board space!
1206 => 0402	~90% less board space!
1210 => 0603	85% less board space!

In many cases, yesterday's 0805 can be replaced with an 0402, for a 80% board space and 92% volume savings.

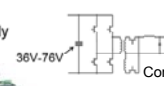


In response to power design challenges, MLCC development trends have resulted in a variety of new series of application solutions such as X7S, Soft Term, and Mega-Cap. These offer small size, Pb-free soldering process compatibility, wide operating temperature/voltage range for applications such as input filtering, resonant circuits and low Q decoupling. Portions of various power topologies will be used to illustrate the use of MLCCs in power design.

APEC 2011: Ceramic Capacitor Update

Applications: Input Filtering

Input filtering for switching power supply
 Effective as smoothing capacitor for wide range input switching power supply applications.




Commonly, 1-3uF at 100V

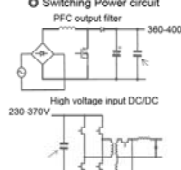
Current technology allows for component count and/or case size reduction.
 1812 → 1206, 0805

ex. Telecom/Datacom

Automotive power supply
 HEV DC/DC converter



Switching Power circuit
 PFC output filter



Typically, these applications require 500V-1kV box film caps, etc.

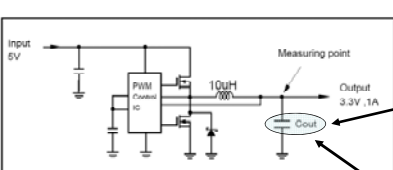
Current technology allows for MLCCs (and stacks) to be used.
 ex. 1uF at 630V in 2 stack 2220 size

19

For input filtering already using MLCC solutions, technology improvements allow for 2-3 case size reductions. In higher power/voltage applications, it is possible to switch to MLCCs.

APEC 2011: Ceramic Capacitor Update

Applications: Output Filtering

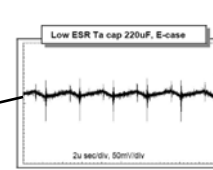


Input 5V

Measuring point

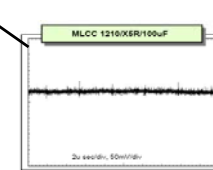
Output 3.3V, 1A

Low ESR Ta cap 220uF, E-case



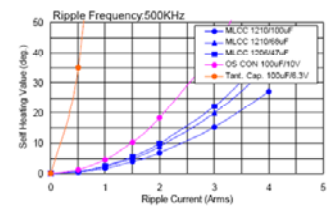
2u sec/div, 50mV/div

MLCC 1210/X5R/100uF



2u sec/div, 50mV/div

Ripple Frequency 500KHz



Self-Heating Value (Deg.)

Ripple Current (Arms)

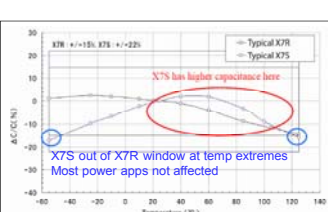
Legend:
 - MLCC 1210/100uF (blue triangles)
 - MLCC 1210/50uF (red squares)
 - MLCC 1005/50uF (green circles)
 - OS CON 100uF/10V (magenta diamonds)
 - Tant. Cap. 100uF/8.3V (orange stars)

20

It is widely known that MLCCs offer ultra low ESR/high ripple capability and capacitance stability with frequency. For high frequency converters (>100kHz or so), MLCCs can offer greater noise reduction and ripple suppression while using fewer capacitors.

APEC 2011: Ceramic Capacitor Update

MLCCs: Tailored for Application Conditions



MLCC (%)

Temperature (°C)

X7R +/-15% X7S +/-22%

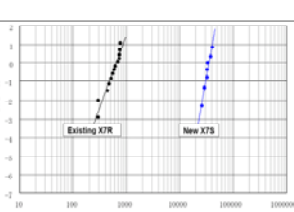
Typical X7R

Typical X7S

X7S has higher capacitance here

X7S out of X7R window at temp extremes

Most power apps not affected



ESR (mOhm)

Time (Index)

Existing X7R

New X7S

Growing trend in MLCCs:
 Higher effective capacitance at operating conditions esp. power supply and CPU/GPU applications.

- capacitance performance versus temperature
- capacitance versus DC bias

21

In general, capacitors are rated at room temperature, low voltage, and low frequency. At the actual operating conditions, capacitor performance is much different. For the power and CPU/GPU markets, MLCC manufacturers are responding with higher performance capacitors. X7S is one example.

MLCCs: Tailored for Application Conditions APEC 2011: Ceramic Capacitor Update

When the ESR is too low!

⊖ Decoupling of switching power supply
Optimal ESR value selection can prevent parasitic oscillation and secure phase margin

Parasitic oscillation with low ESR

Stable with optimum ESR

⊖ Decoupling of high current / low voltage circuit
Optimal ESR value selection can prevent unnecessary resonance and stabilize power supply impedance

Stabilize impedance by optimizing ESR

Too small ESR can cause large impedance peak with resonance

22

In most cases, having an ESR value in the single digit milliohm range is accepted as an attribute. However, in some power conversion applications, the ESR can be too low. Instability and unwanted oscillation can occur if sufficient ESR (damping resistance) is not present. Power backplane applications, that may use hundreds of MLCCs in parallel, may have stability issues. Adding ESR provides a level load line.

MLCCs: Tailored for Application Conditions APEC 2011: Ceramic Capacitor Update

When the ESR is too low!

Structure and equivalent circuit

Terminal electrode NC

Terminal electrode NC

NC terminal is not connected

Mounted photo

Controlled ESR 10µF

27 10µF

Freq.

23

Adding ESR turns the MLCC into an “anti-resonant cap” suitable for low Q decoupling.

Crack Mitigation Strategies APEC 2011: Ceramic Capacitor Update

MLCC stress simulation (Finite Element Method)
Bending TEST (2mm)

No Frame "Standard Cap"

6.8kg/mm²

Folded Frame "Spring J-type"

Below 1kg/mm²

Unfolded Frame "L-type"

5.1kg/mm²

"Open Space" Unfolded Frame "L-type"

Below 1kg/mm²

d

24

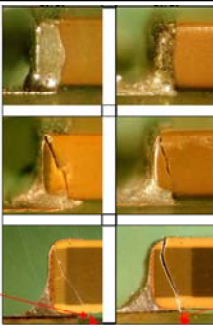
Post-solder handling of circuit boards (bending, torsion) continues to be the main cause for cracking of SMT components. Strategy one is to use the smallest possible component. This provides the shortest span between solder pads (bending moment) and the best aspect ratio (thickness:length) to resist cracking. Strategy two is to add a lead frame to the component. Three different styles provide varying stress relief to the component body.

Crack Mitigation Strategies APEC 2011: Ceramic Capacitor Update

“Open Mode” or “Fail Safe” Construction

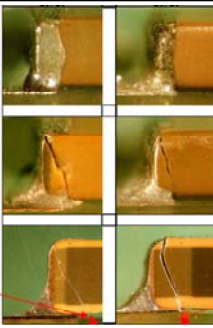
*active stack is moved inside of terminal bands

Left column:
Standard Design



Crack occurred from edge of the termination and caused a short cut

Right column:
Open Mode Design



Crack occurred from edge of the termination but did not cause a short cut due to the Open Mode design

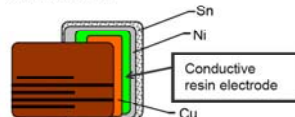
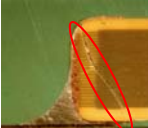

25

Typically, in MLCCs, the flexure crack propagation path is from the bottom termination edge toward the side edge of the termination. Moving the overlapping portion (active stack) inside of the bottom termination edges, the path is through common electrodes. This preserves insulation resistance.

Crack Mitigation Strategies APEC 2011: Ceramic Capacitor Update

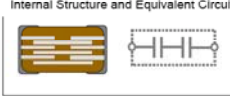
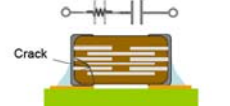
Soft/Flex Termination and Floating Electrode

Conductive resin electrode layer absorbs external stress and protects ceramic body.

Floating electrode construction prevents sudden insulation breakdown after flex crack formation.

Internal Structure and Equivalent Circuit

26

Two other additional countermeasures are soft termination and floating electrode. Soft term adds a polymeric resin material to the termination layering. This provides significant drop test improvements and 5-10 times board bending versus standard constructions.

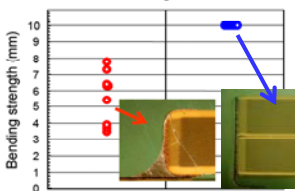
Floating electrode is constructed as two series-connected capacitors per layer. Similar to the “open mode” design, the insulation resistance is maintained.

Crack Mitigation Strategies APEC 2011: Ceramic Capacitor Update

Stacked designs

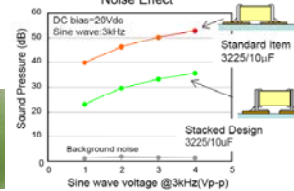
- Double capacitance in same X-Y space
- Thermal/mechanical isolation off-the-board
- Improved bending performance/reduced piezo noise

Bending Test



Standard MLCC Stacked w/leadframe

Noise Effect



Standard item 3225/10uF

Stacked Design 3225/10uF

Background noise

27

Another MLCC cracking countermeasure involves use of a lead frame. MLCCs are attached to a lead frame. Paying special attention to the position of the MLCC on the lead frame is required to minimize thermal and mechanical stresses. Reduced piezo noise is an additional benefit of the proper use of the lead frame construction.

MLCC Summary

1. Through material advancements, volumetric efficiency (CV product), reliability and stability at actual operating conditions continue significant improvements.
2. Developments in construction have allowed for greater thermal/mechanical robustness and board space savings.
3. MLCCs offer small size, high temp solder/environmental compatibility, and broad temperature/voltage ranges. Principal targets are high power density, high efficiency, and high reliability power applications.



Use of MLCCs with high effective capacitance (at real operating conditions), and high reliability continues to expand in power applications. This is especially so for those applications that require small size, high efficiency/power density, and maintenance-free reliability.