Multilayer Ceramic Capacitors (MLCCs)

Design and Characteristics
Form Factor
Design
MLCCs

Capacitances in parallel are additive

\[ C_T = C_1 + C_2 + C_3 + \ldots + C_n \]

- Dielectric Material
- Inner Electrode
- End Termination
- Barrier Layer
- Termination Finish

\[ C = \frac{\varepsilon_0 KA(n-1)}{d} \]

- \( C \) = Design Capacitance
- \( K \) = Dielectric Constant
- \( A \) = Overlap Area
- \( d \) = Ceramic Thickness
- \( n \) = Number of Electrodes

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Common Failure Modes
Ceramic Materials are Inherently Brittle

Ceramic Properties
• High chemical bond strength
• High Elastic Modulus
• Low Ductility
• Very Hard
Typical Crack Signatures

The major sources of MLCC cracks are:

- **Mechanical damage (impact)**
  - Aggressive pick and place
  - Physical mishandling

- **Thermal shock (parallel plate crack)**
  - Extreme temperature cycling
  - Hand soldering
    - *Do not touch electrodes while hand soldering!*

- **Flex or Bend stress**
  - Occurs after mounted to board
  - Common for larger chips (>0805)

Failure is **not always immediate**!
External Forces on Ceramic Material

**Compression**

- Strong under compression

**Tension**

- Weak under tension
Flex Cracking
Excessive Bending

MLCC Under Tension

High Stress Region

Finite Element Analysis
Flex Cracking

Excessive Bending

MLCC Active Area

-45°

Flex crack signature

Starts here
Capacitor Mitigation Solutions
Level 1 Protection – Basic Level of Crack Protection

Floating Electrode

**Pros**
- Serial design
- Fails open

**Cons**
- Reduced capacitance in the same volume

Open Mode

**Pros**
- Crack doesn’t go through active area
- Fails open

**Cons**
- Reduced capacitance in the same volume
Capacitor Mitigation Solutions
Level 2 Protection – Intermediate Level of Crack Protection

Flexible Termination (FT-CAP)

Pros
• Increased flex capability
• High volumetric efficiency

Cons
• Fail short

End Termination/External Electrode (Cu)
Flexible Termination Epoxy Layer (Ag)
Barrier Layer (Ni)
Termination Finish (100% Matte Sn/SnPb–5% Pb min)

Conductive-Epoxy
Crack
Capacitor Mitigation Solutions
Level 3 Protection – High Level of Crack Protection (Hybrid Technology)

**Pros**
- Increased flex capability
- Floating Electrode design
- Fail Open

**Cons**
- Reduced capacitance in the same volume
Thermal Shock

Why is it an issue?

CTE – Coefficient of Thermal Expansion

Thermal Shock Cracks → CTE Mismatch

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Thermal Shock
Causes – Hand Soldering

Internal Temperature Gradients
Uneven Expansion and Contraction

Hand Solder Tips
- Don’t touch capacitor termination
- Pre-heat assembly
- Larger case sizes are more sensitive
Thermal Shock
Causes – Solder Wave

PCB Travel

Solder Wave

Molten Solder

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What is MLCC Surface Arcing?

Electrical breakdown between the two MLCC terminations or between one of the terminations and the internal electrodes of the capacitor within the ceramic body.

Influences
- Humidity
- Surface Contamination
- Creepage Distance
The Phenomenon of Surface Arcing

First Counter Electrode

Ionization of Air

Electric Field

Opposing Electrodes

Opposing Terminations

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The Phenomenon of Surface Arcing
Surface Arcing Between MLCC Termination and the Internal Electrode Structure

Termination Surface

First Counter Electrode

Internal Electrodes
Surface Arcing Failure Modes

Terminal-to-Terminal Arcing

Terminal-to-Active Arcing

Carbon Traces

Voltage Breakdown Failures
**Solutions for MLCC Surface Arcing**

### Surface Coatings
- MLCC Coating
  - Added by MLCC supplier
  - Additional process step
  - Critical that there is no damage to or air gap under the coating
- PCB Coating
  - Added after PCB assembly
  - Additional process step
  - Added cost
  - Cannot rework

### Serial Electrode Designs
- Reduce electric field strength
  - Available capacitance in a MLCC package size is lowered
  - Allows for higher voltage capability
  - Reduces the probability of MLCC failure due to flex crack

### ArcShield Designs
- Reduce electric field strength
- Reduce ionization of air at MLCC surface
- Maximizes available capacitance in a MLCC package size
The Benefits of Coating Technology

- Low K Coating
- Creepage Distance
- Ionization of Air
Issues With Coating Technologies

- Electric Arc
- Damaged Coating
Serial Electrode Design

Reduction of Electric Field

Single MLCC

- 1uF, 1000V

Five Series MLCCs

- Electric Field Distributed Across Individual MLCCs
- 1000V
- 1000V
- 1000V
- 1000V
- 1000V

\[ \frac{1}{C_{eff}} = \sum \frac{1}{C_N} \]

- 0.22uF, 5000V

Single Monolithic Structure (Serial Design)

- Electric Field Distributed Across Each Serial Design
- 1000V
- 1000V
- 1000V
- 1000V
- 1000V

- 0.22uF, 5000V

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Serial Electrode Design

High-Voltage Ceramic

Also known as “Floating Electrode” or “Cascade Electrode” designs

Capacitive Area

Capacitive Area

Separation Between Series Elements

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“Serial” to “Shield” Design Comparison

“Serial” Design
- With capacitors (N) in series, the acting voltage on each capacitor is reduced by the reciprocal of the number of capacitors (1/N).
- Effective Capacitance is reduced:
  \[
  \frac{1}{C_{eff}} = \sum \frac{1}{C_N}
  \]

“Shield” Design
- Larger electrode area overlap A so higher capacitance while retaining high voltage breakdown.
- Thickness d between opposing electrodes increased:
  \[
  C = \frac{\varepsilon_0 K N A}{d}
  \]
KEMET ArcShield Technology

Shield Electrodes

Shield Electrodes

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Explanation of Shield Design
Reduction of Electric Field

Terminal-to-Terminal Arcing
Standard Design
• Opposite Field extends close to terminal of opposed polarity so low energy barrier

Terminal-to-Terminal Arcing
ArcShield Design
• Opposite Field is longer distance from terminal of opposed polarity increasing size of energy barrier
Consider a Standard Design

• In a standard overlap X7R MLCC there are 3 ways of failing high voltage:
  1. Arcing between terminal and 1st electrode of opposite polarity
  2. Arcing between terminals
  3. Internal breakdown

Shield designs solve these voltage breakdown issues by:

  a. Adding a shield to prevent 1.
  b. The shield also creates a barrier to 2.
  c. Thicker actives for higher breakdown 3.
KEMET ArcShield Technology
Summary

• Permanent Protection

• No protective coating necessary

• Higher breakdown voltage capability than similarly rated devices using coating technology.

• Downsizing and board space saving opportunities.
ArcShield Key Features and Benefits

- **Patented Electrode Design**
  - Suppresses an arc-over event while increasing available capacitance

- **Permanent protection!**
  - Competitive versions often use a non-permanent surface coating

- **BME X7R Dielectric**

- **500, 630 and 1,000Vdc**

- **0603 - 2225 Case Sizes**

- **1.0nF – 560nF**

- **Flexible Termination Available**

“The World’s Smallest High Voltage MLCC’s”
Thank You