Ceramic Reliability Grades:
PSMA (Virtual) Capacitor Workshop 2020
Ceramic Capacitors for Harsh Environments

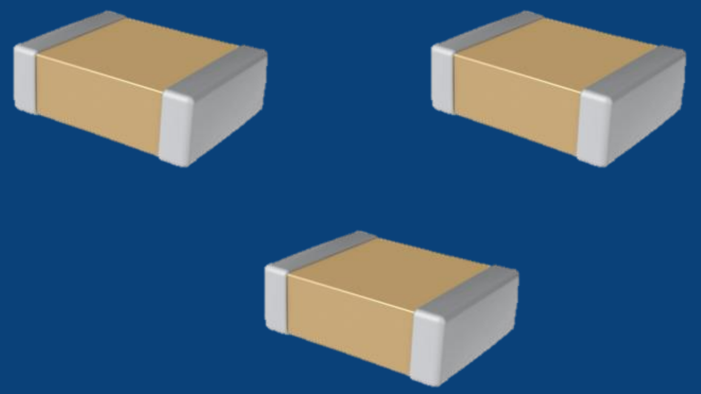
April 2020

Agenda

1. MLCC Reliability Grades
2. Solutions to voltage challenges
3. Solutions to mechanical challenges

Why are Ceramic Capacitors so Popular?

- Very reliable
  - Low ppm failure rates
  - Long life – Billions of hours
- Small form factor
- Wide operating temperature range
- Low cost



Reliability in Ceramic Capacitors

What do we mean?

Ability for the capacitor, under normal conditions, to operate within the specification over it's lifetime with few or no failures.

What we don't mean

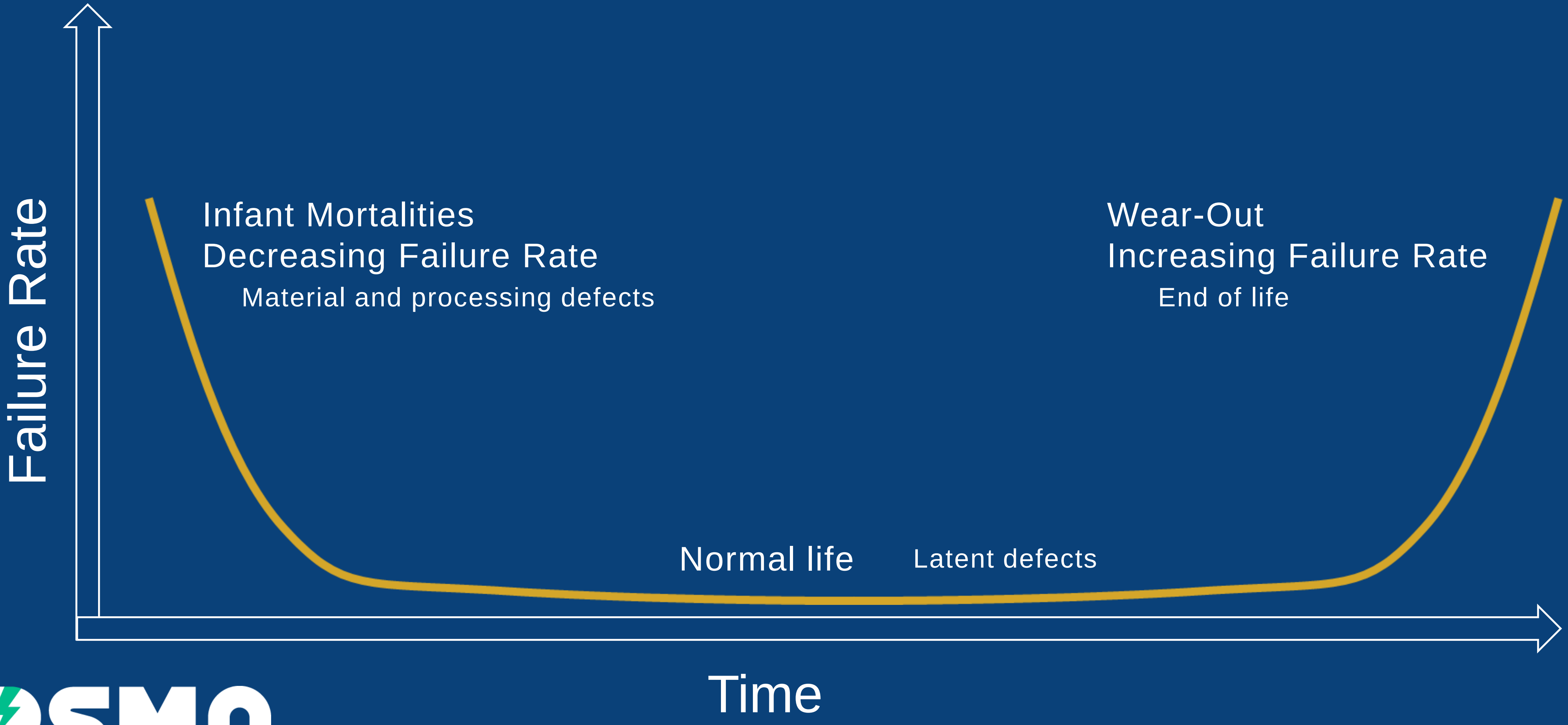
Excessive Mechanical Stress (Flex)

Excessive Voltage

Excessive Temperature

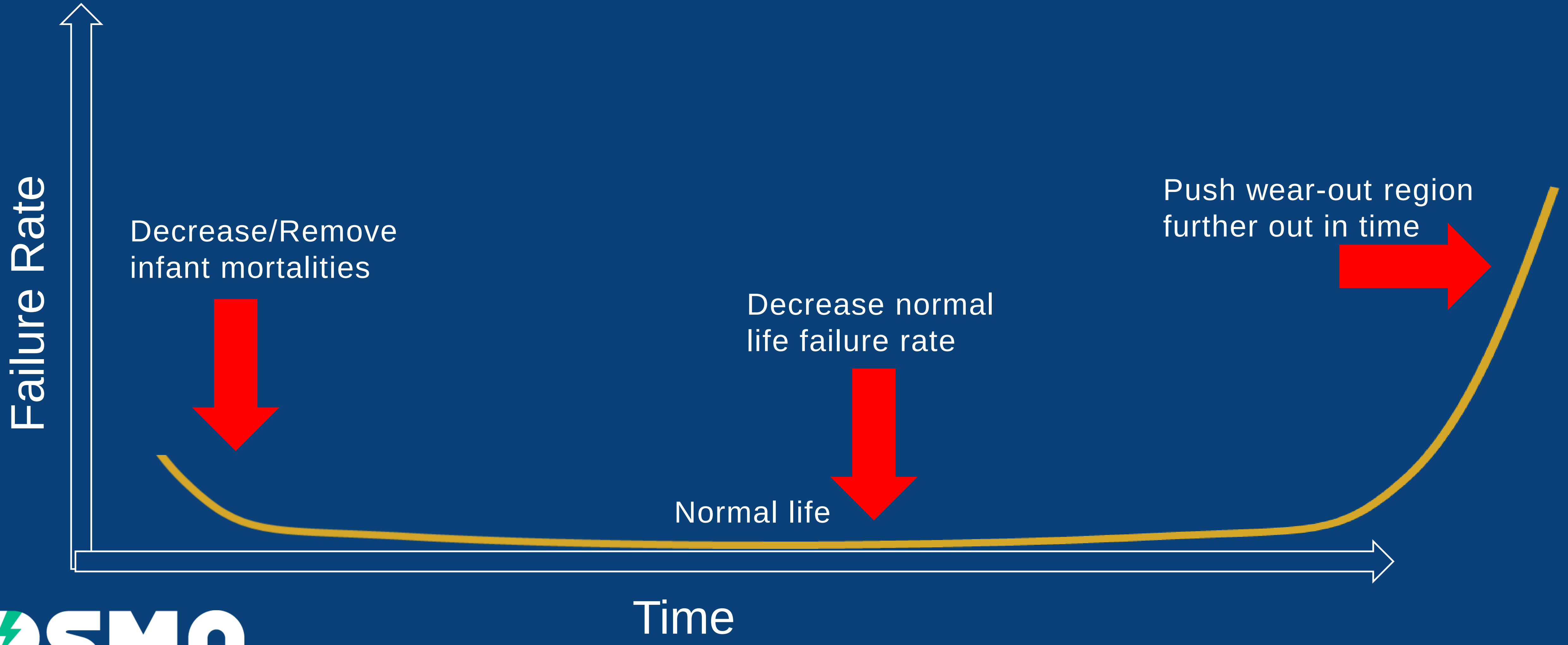
Voltage Transients

The Bathtub Curve



The Bathtub Curve

What does higher reliability do?

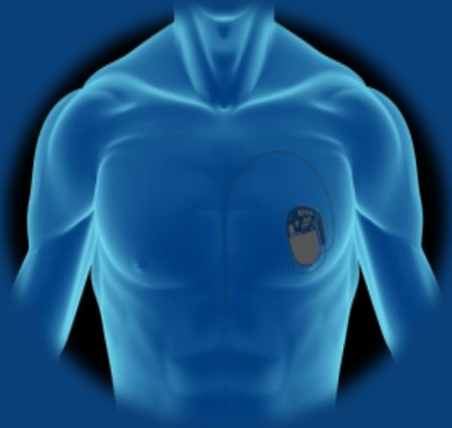


Increasing Reliability in Ceramic Capacitors

How is it done?

- More conservative designs
- Design and change control
- Full material traceability
- In process testing
- End of Line testing
- Burn-in / Voltage conditioning
- Strict oversight on materials and processes

What Drives Higher Reliability in Capacitors?

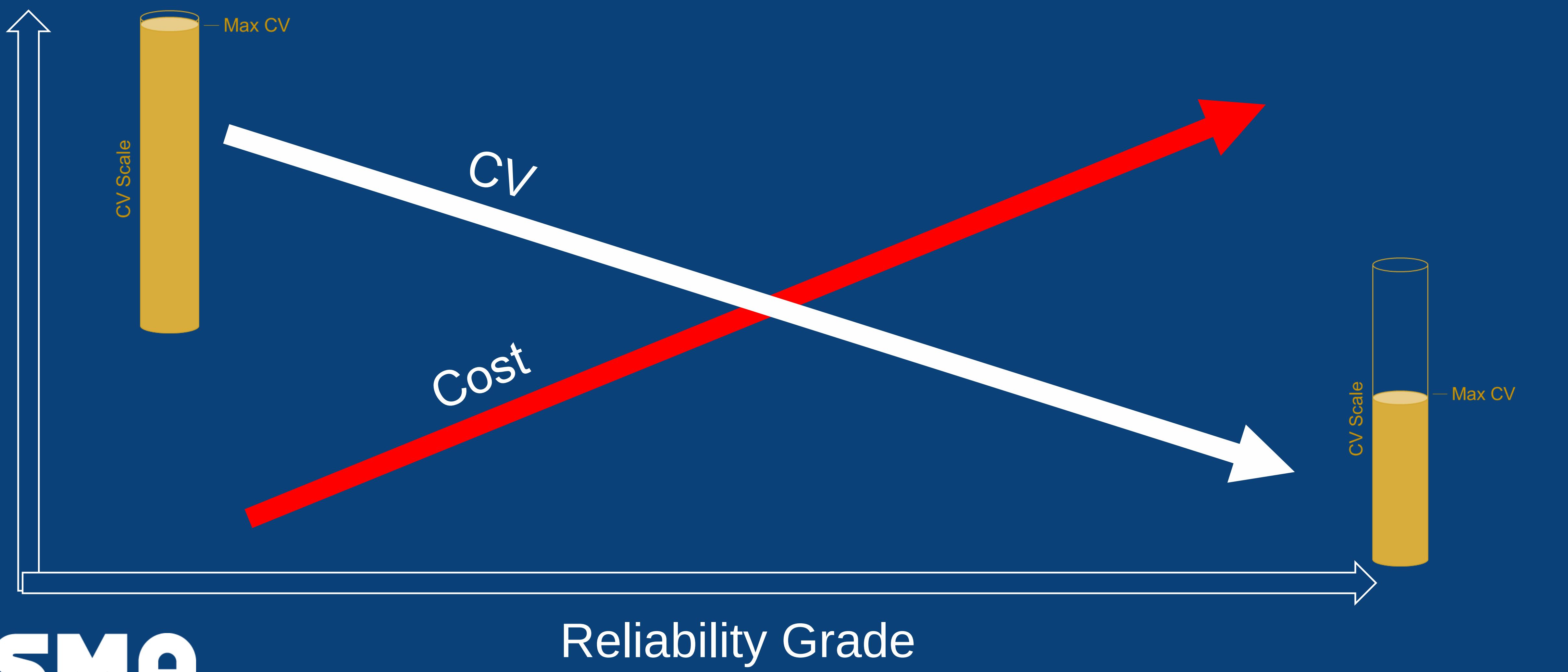


Cost of Failure

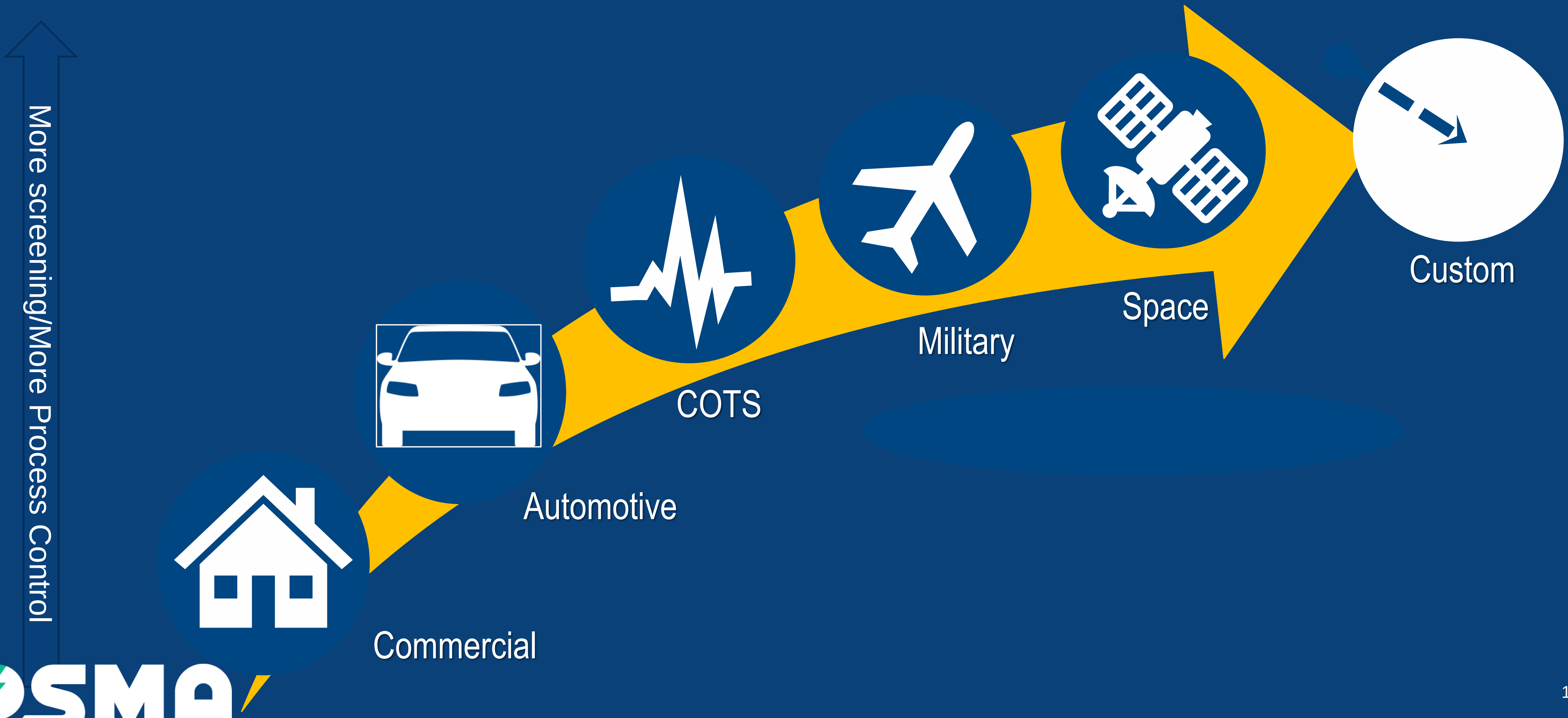
Inability to Fix

Safety

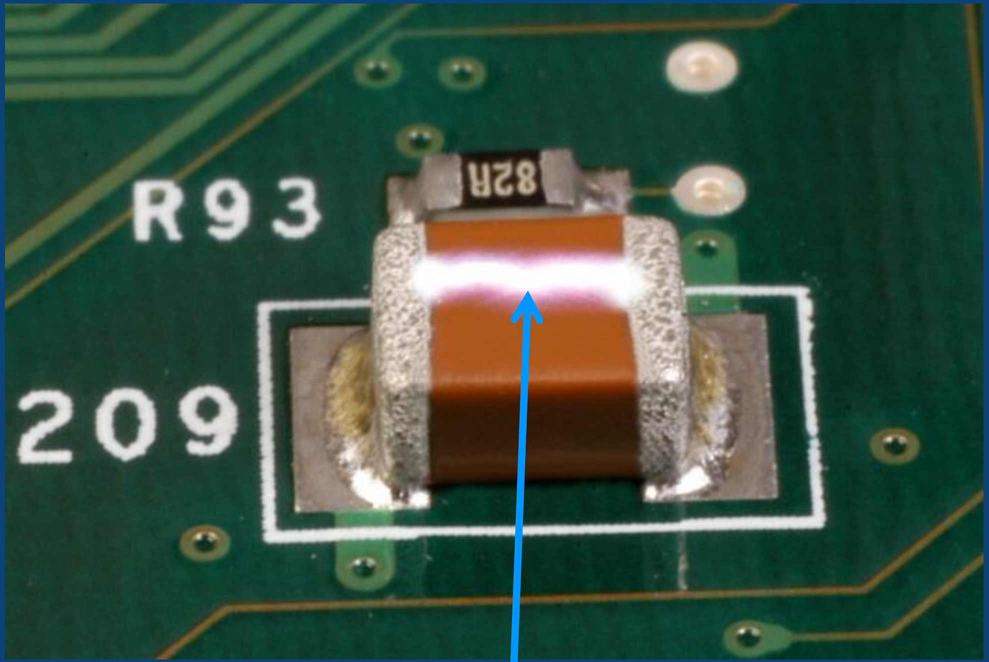
There's Always a Tradeoff



KEMET Ceramics Reliability Grades



What is MLCC Surface Arcing?



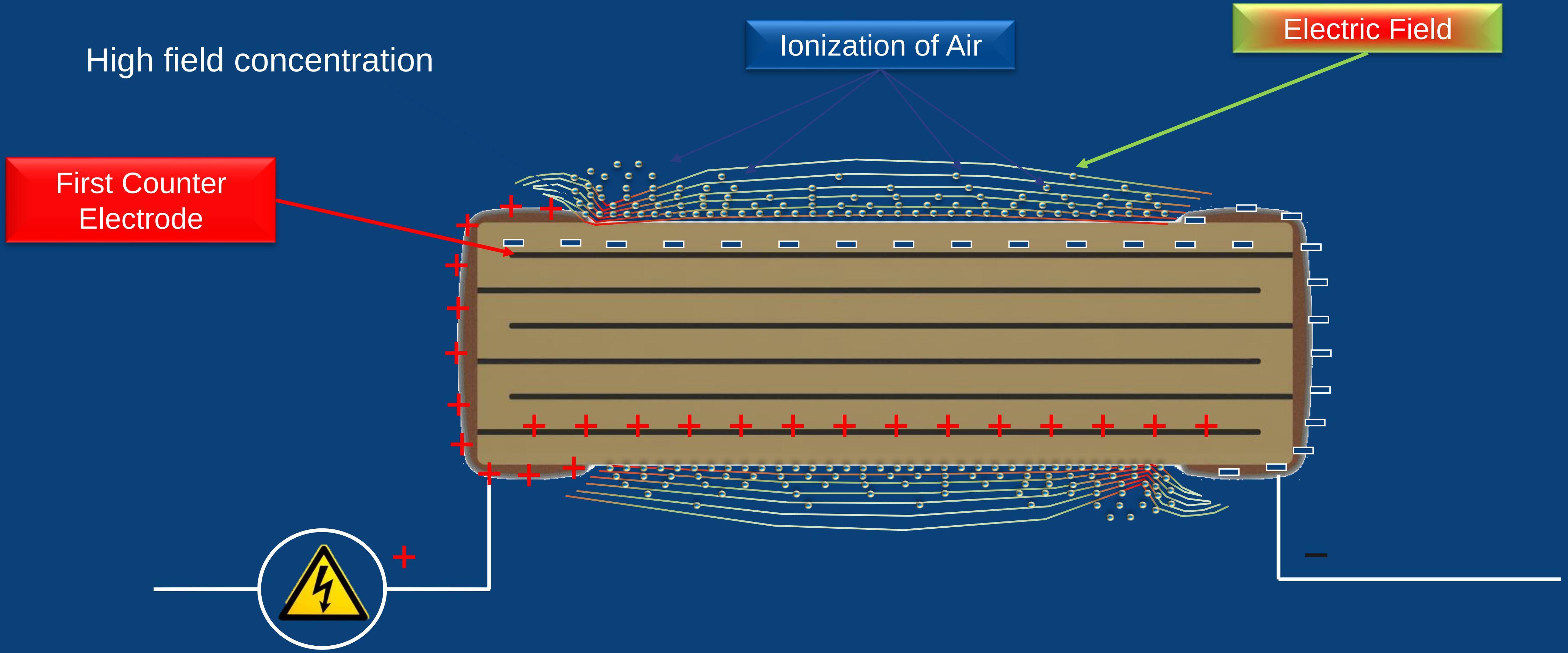
Electrical breakdown between the two MLCC terminations or between one of the terminations and the internal electrodes of the capacitor within the ceramic body.

Influences

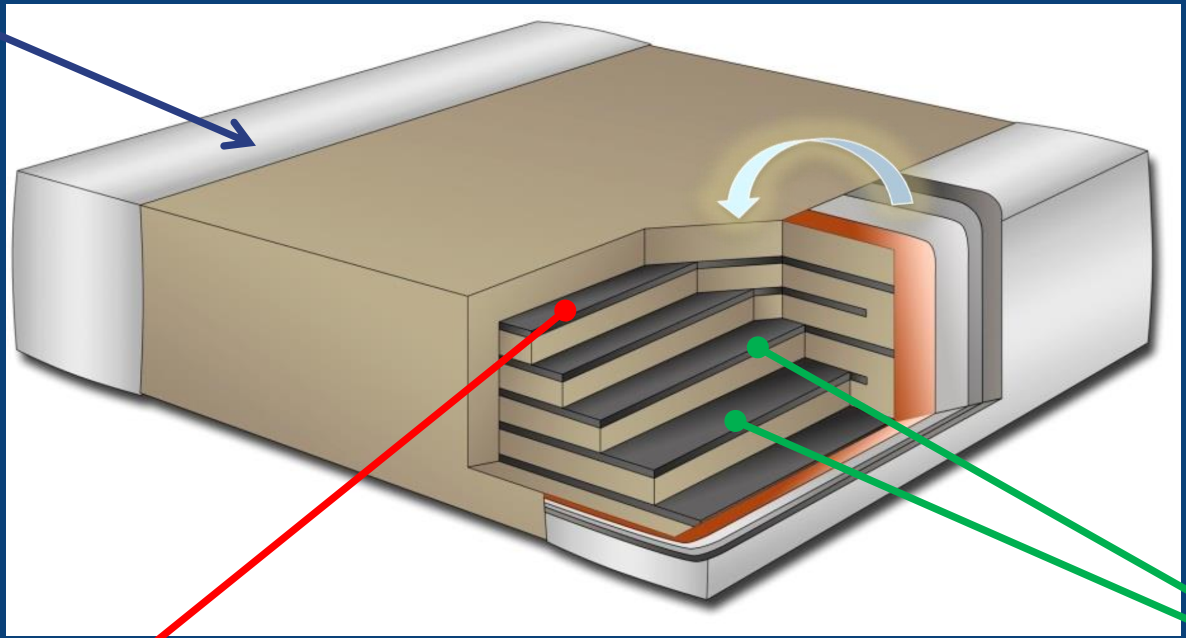
- Humidity
- Surface Contamination
- Creepage Distance

The Phenomenon of Surface Arcing

High field concentration



Surface Arcing Between MLCC Termination and the Internal Electrode Structure

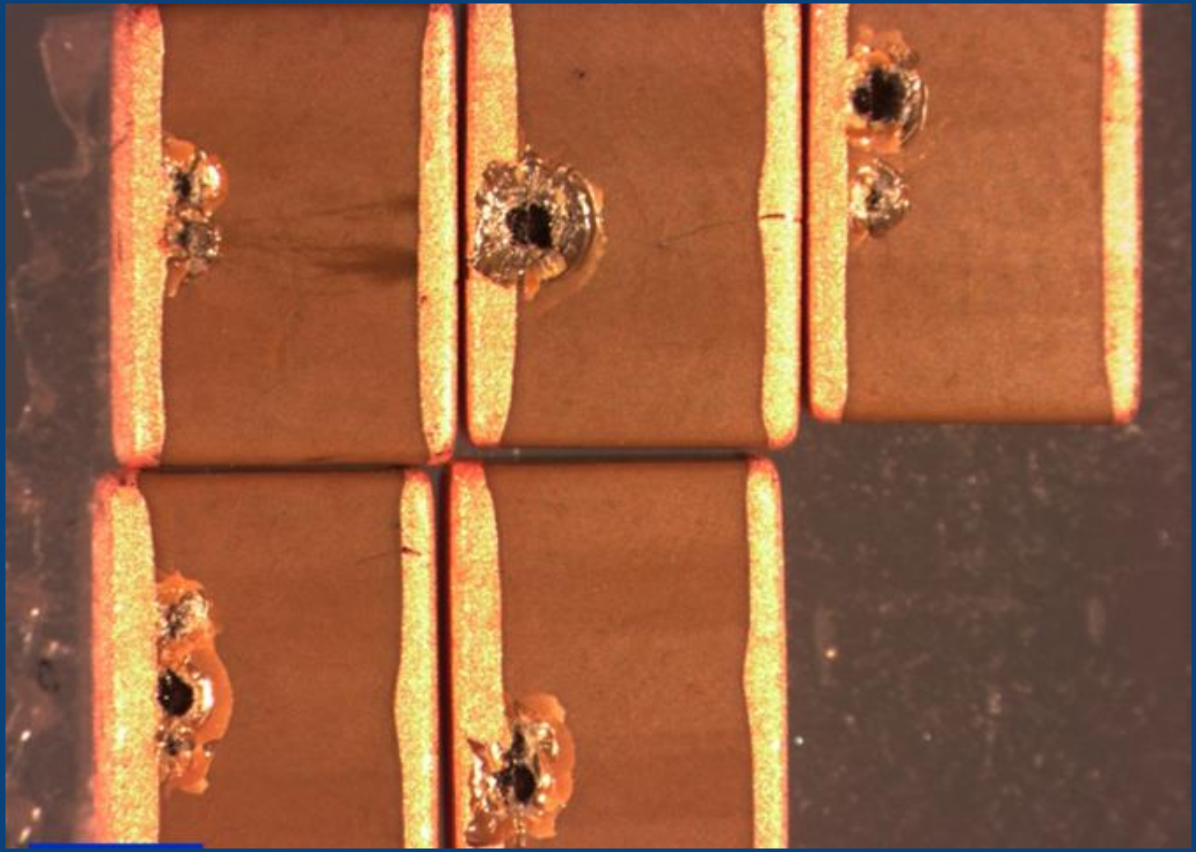


Surface Arcing Failure Modes

Terminal-to-Terminal Arcing

Carbon Traces

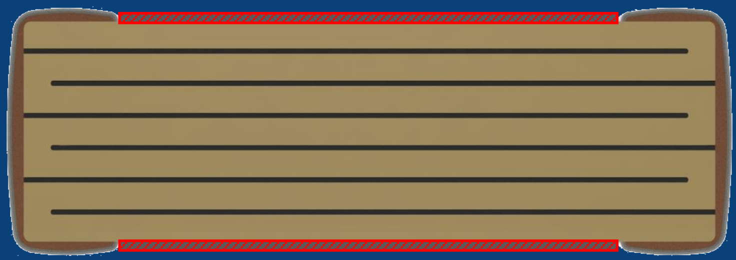
Terminal-to-Active Arcing



Voltage Breakdown Failures

Solutions for MLCC Surface Arcing

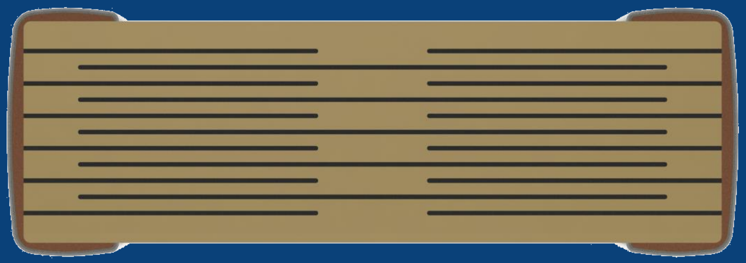
Surface Coatings



MLCC Coating
- Added by MLCC supplier
- Additional process step
- Critical that there is no damage to or air gap under the coating

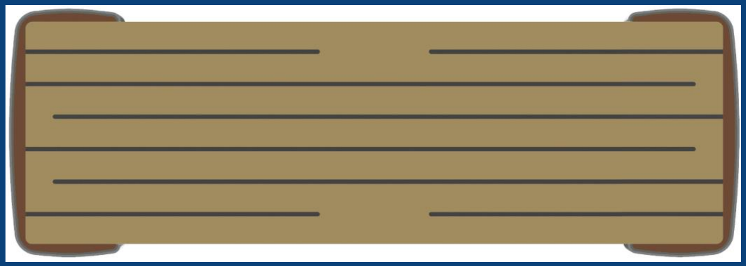
PCB Coating
- Added after PCB assembly
- Additional process step
- Added cost
- Cannot rework

Serial Electrode Designs



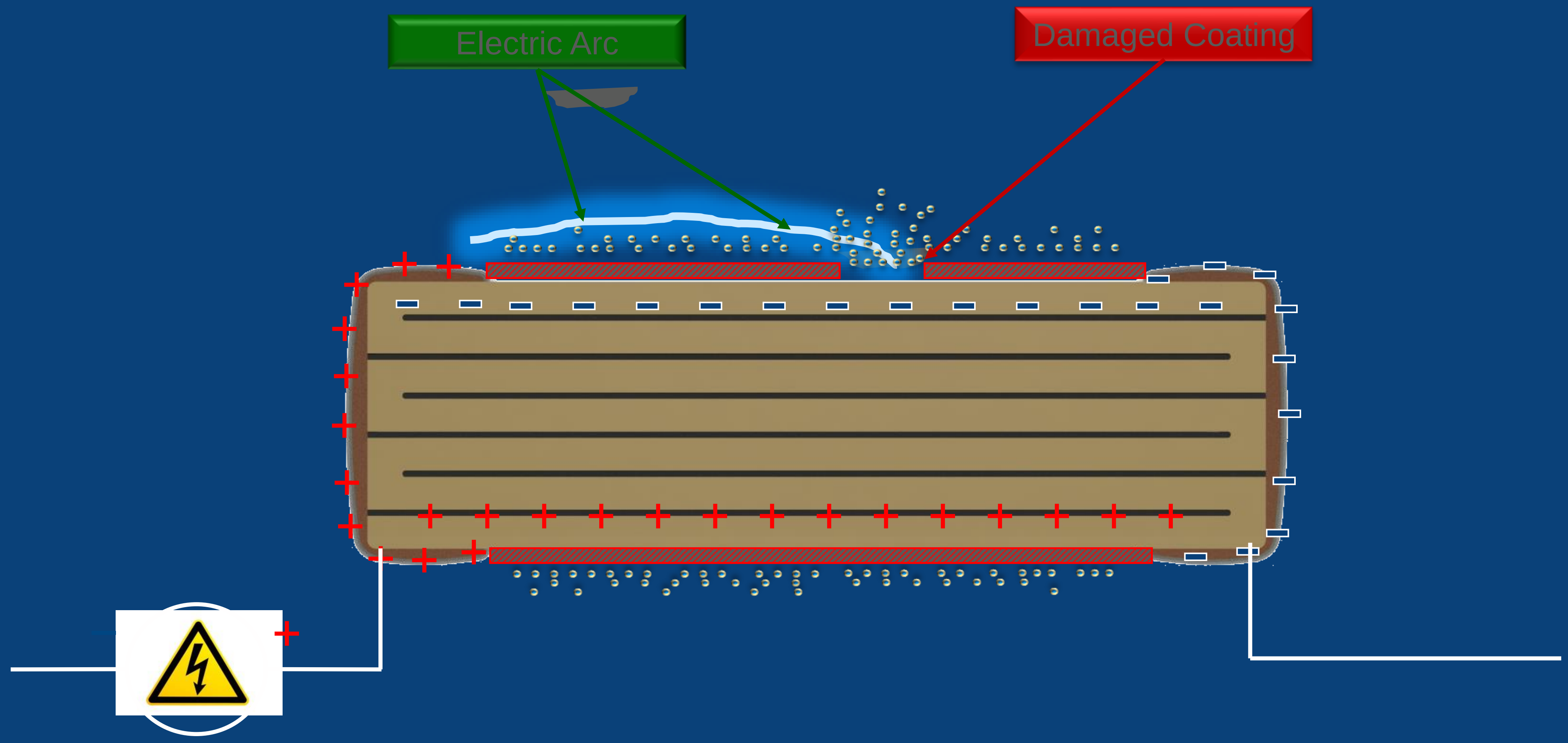
Reduce electric field strength
- Available capacitance in a MLCC package size is lowered
- Allows for higher voltage capability
- Reduces the probability of MLCC failure due to flex crack

ArcShield Designs



- Reduce electric field strength
- Reduce ionization of air at MLCC surface
- Maximizes available capacitance in a MLCC package size

Issues With Coating Technologies

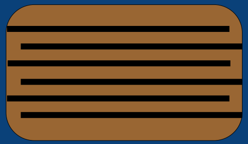


Serial Electrode Design

Reduction of Electric Field

Single MLCC

1000V



1uF 1000V

Five Series MLCCs

1000V 1000V 1000V 1000V 1000V

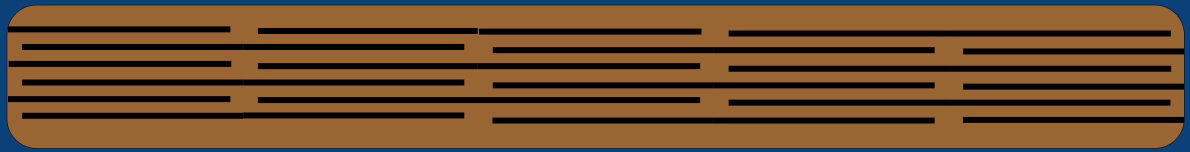
Electric Field Distributed Across Individual MLCCs

0.22uF 5000V

$$\frac{1}{Ceff} = \sum \frac{1}{C_N}$$

Single Monolithic Structure (Serial Design)

1000V 1000V 1000V 1000V 1000V

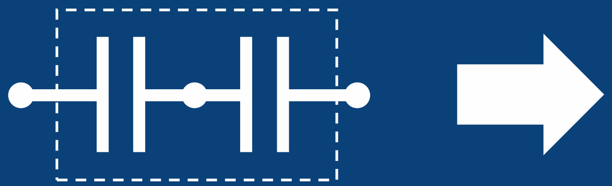


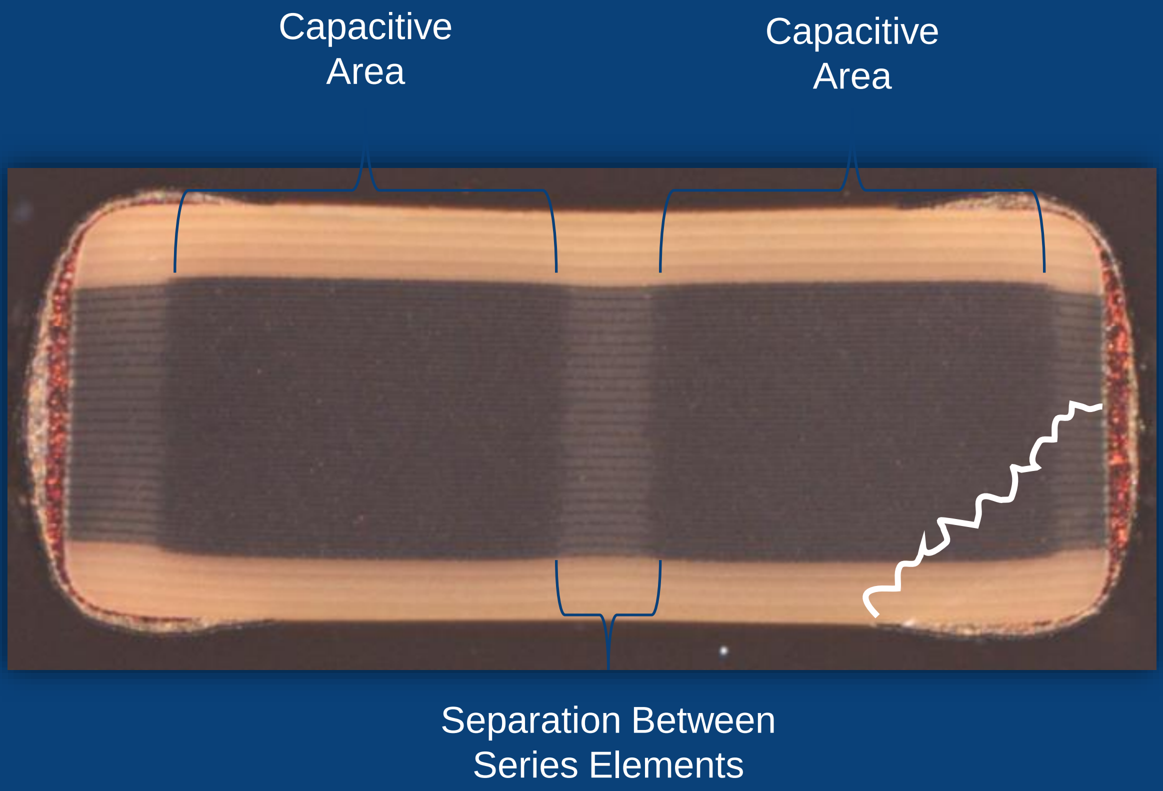
Electric Field Distributed Across Each Serial Design

0.22uF 5000V

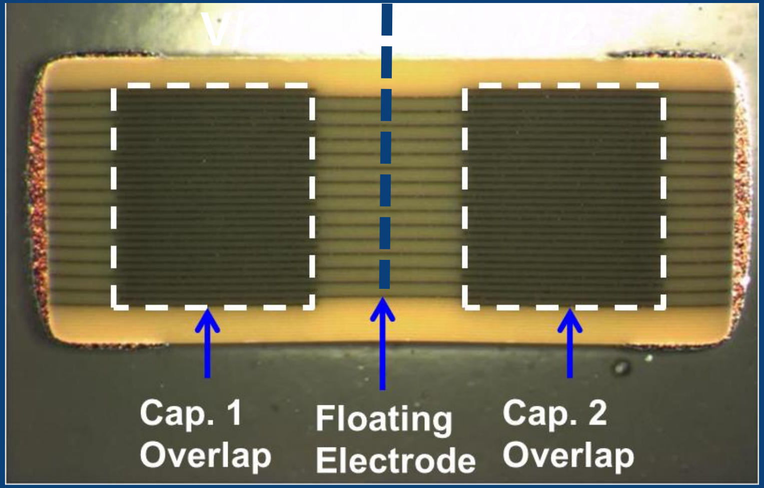
Serial Electrode Design

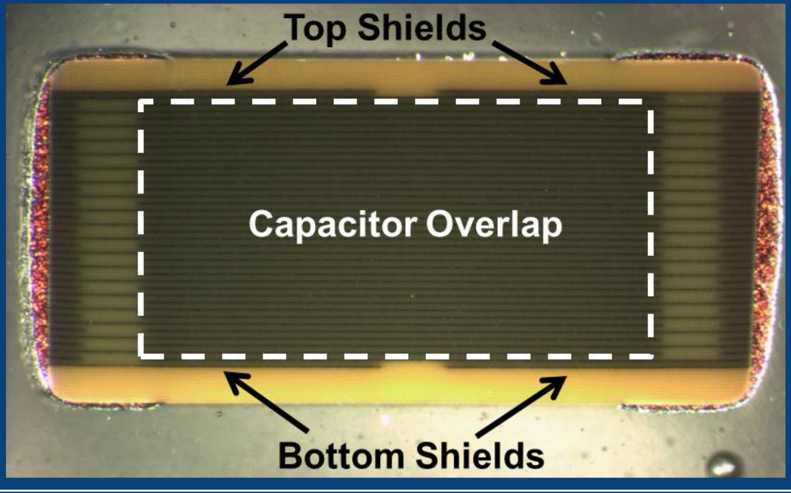
Also known as “Serial Electrode” or “Floating Electrode” designs





“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:

$$\frac{1}{Ceff} = \sum \frac{1}{C_N}$$

“Shield” Design

- Larger electrode area overlap **A** so higher capacitance while retaining high voltage breakdown.
- Thickness d between opposing electrodes increased:

$$C = \frac{\epsilon_o KNA}{d}$$

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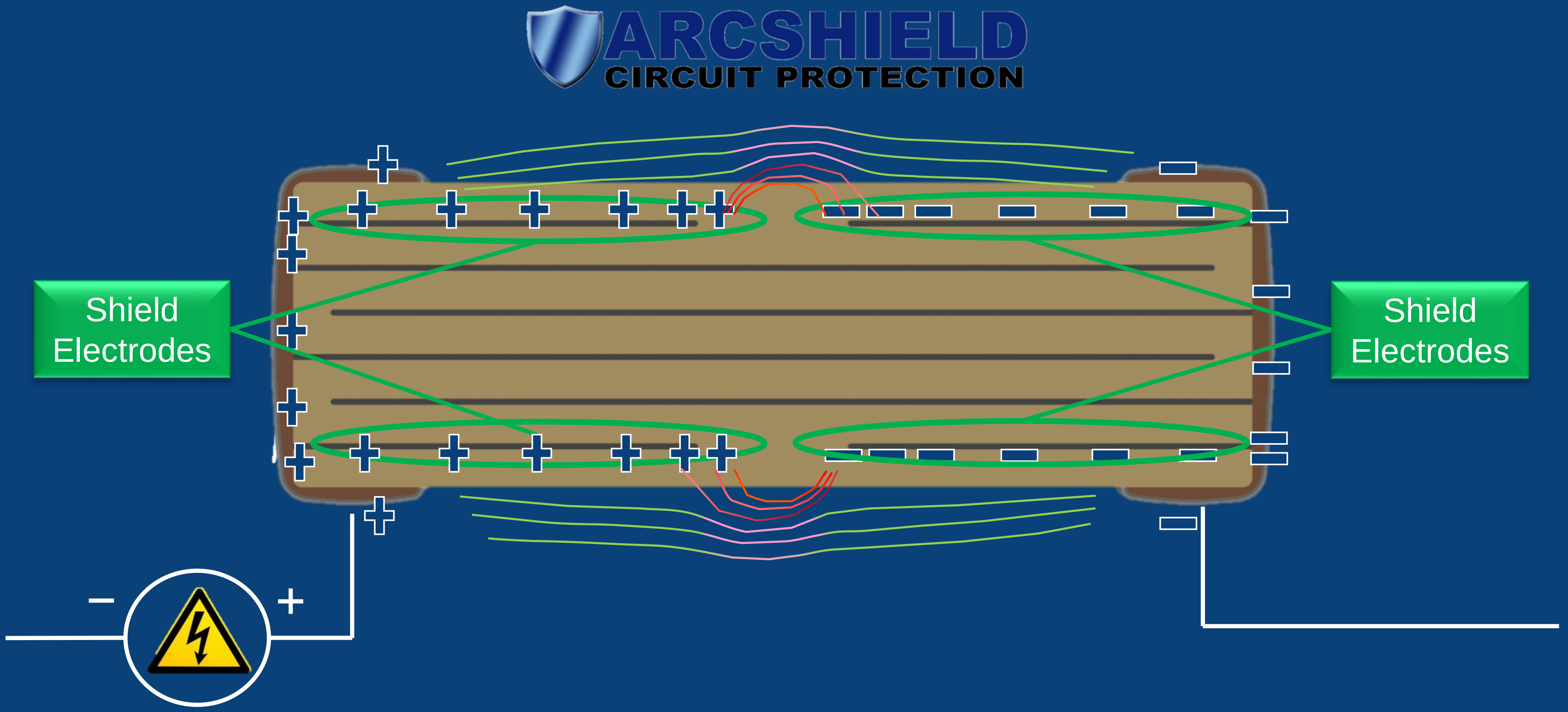
KEMET ArcShield Technology



Explanation of Shield Design

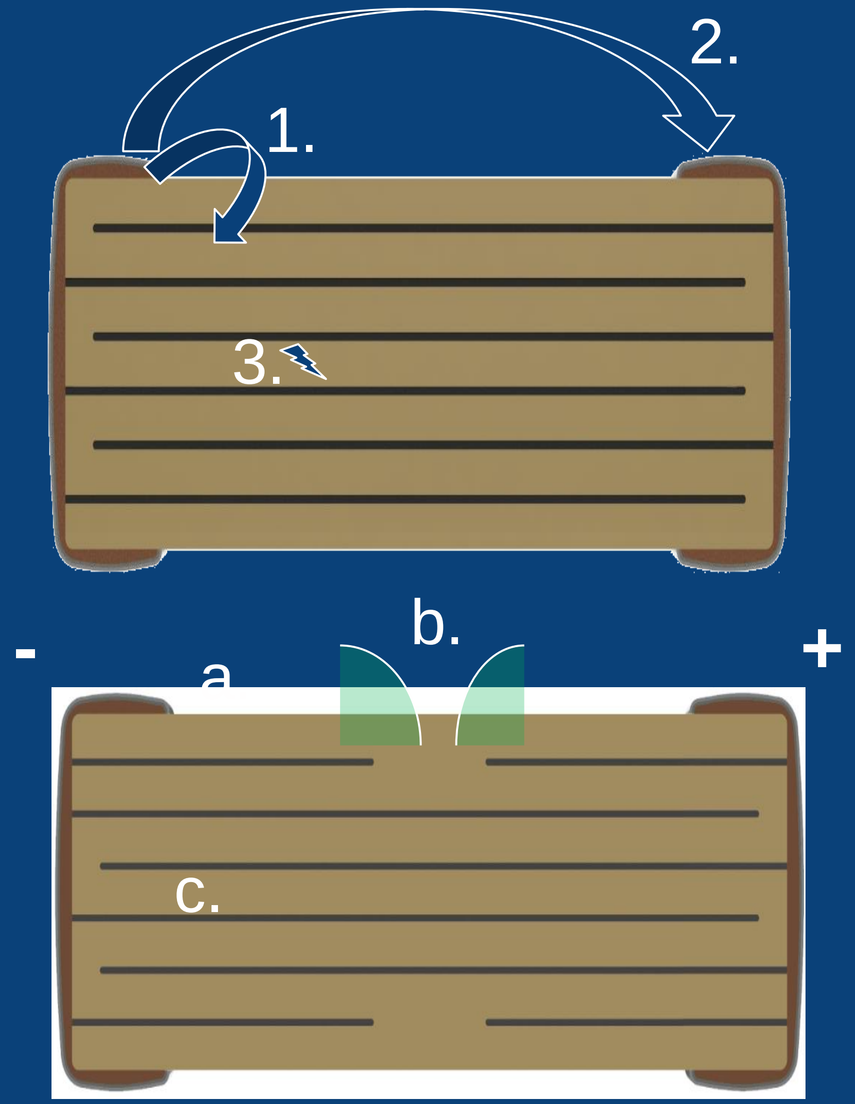
Designed for Higher Voltage

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.



The Mechanical Challenge

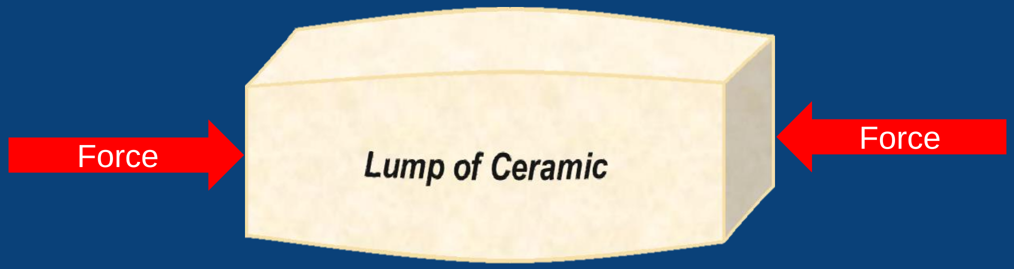
Ceramic Materials are Inherently Brittle

Ceramic Properties

- High chemical bond strength
- High Elastic Modulus
- Low Ductility
- Very Hard

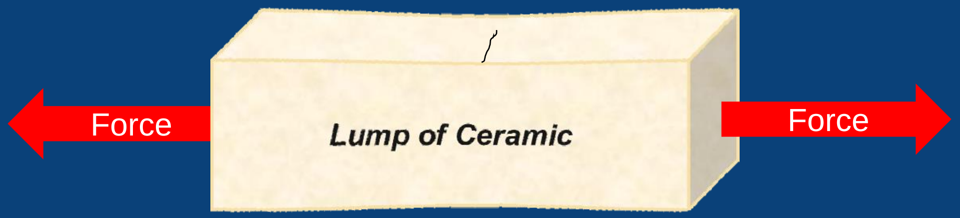
External Forces on Ceramic Material

Compression



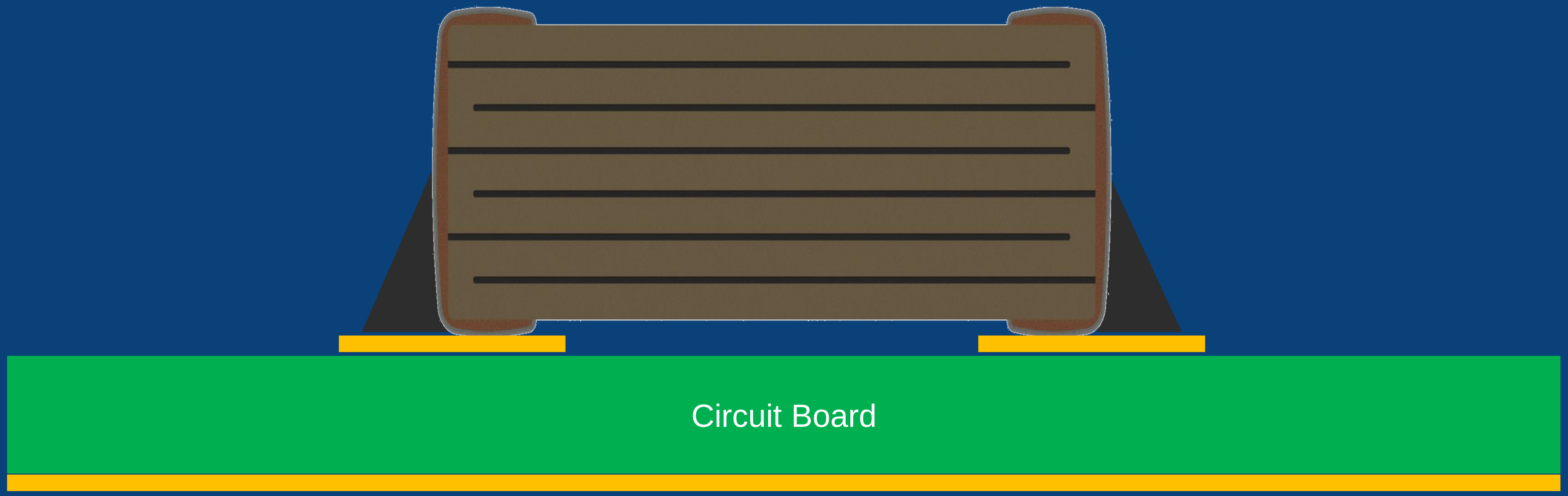
Strong under compression

Tension



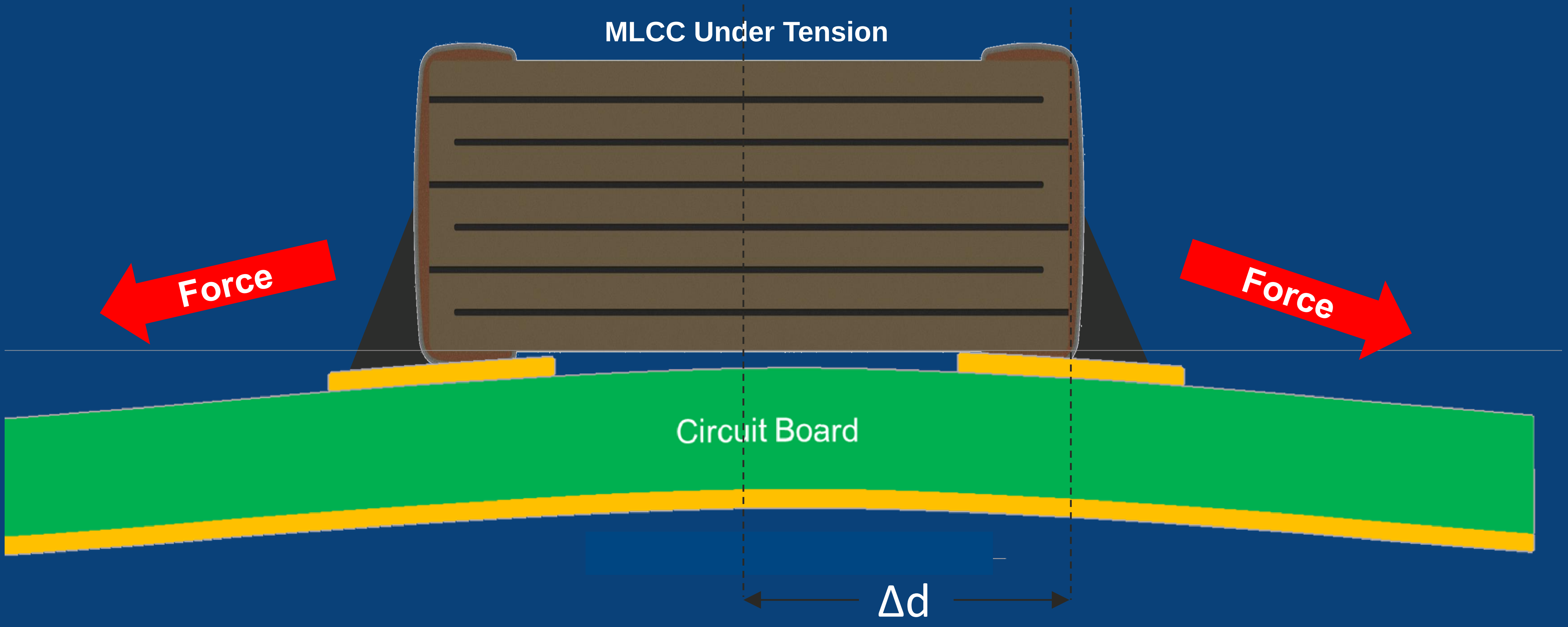
Weak under tension

Flex Cracking



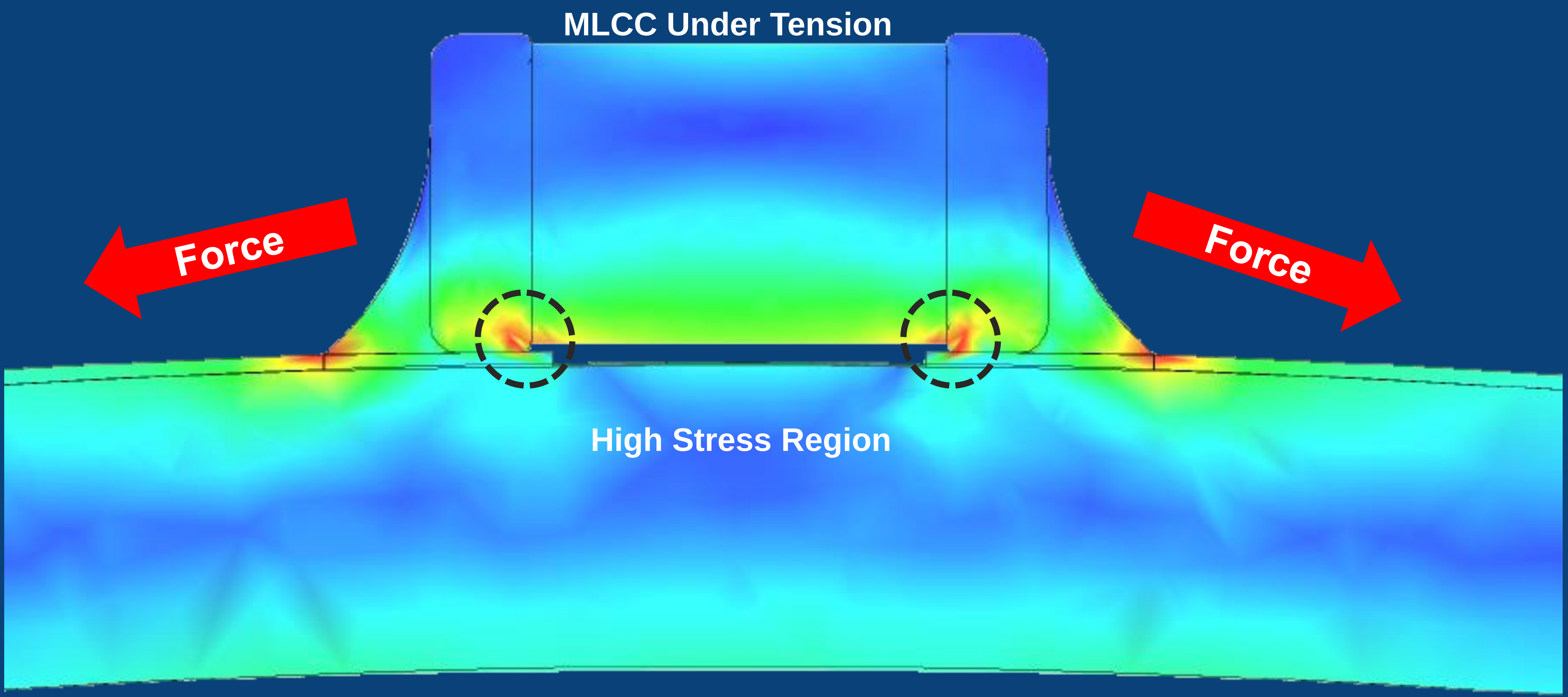
Flex Cracking

Convex Bend



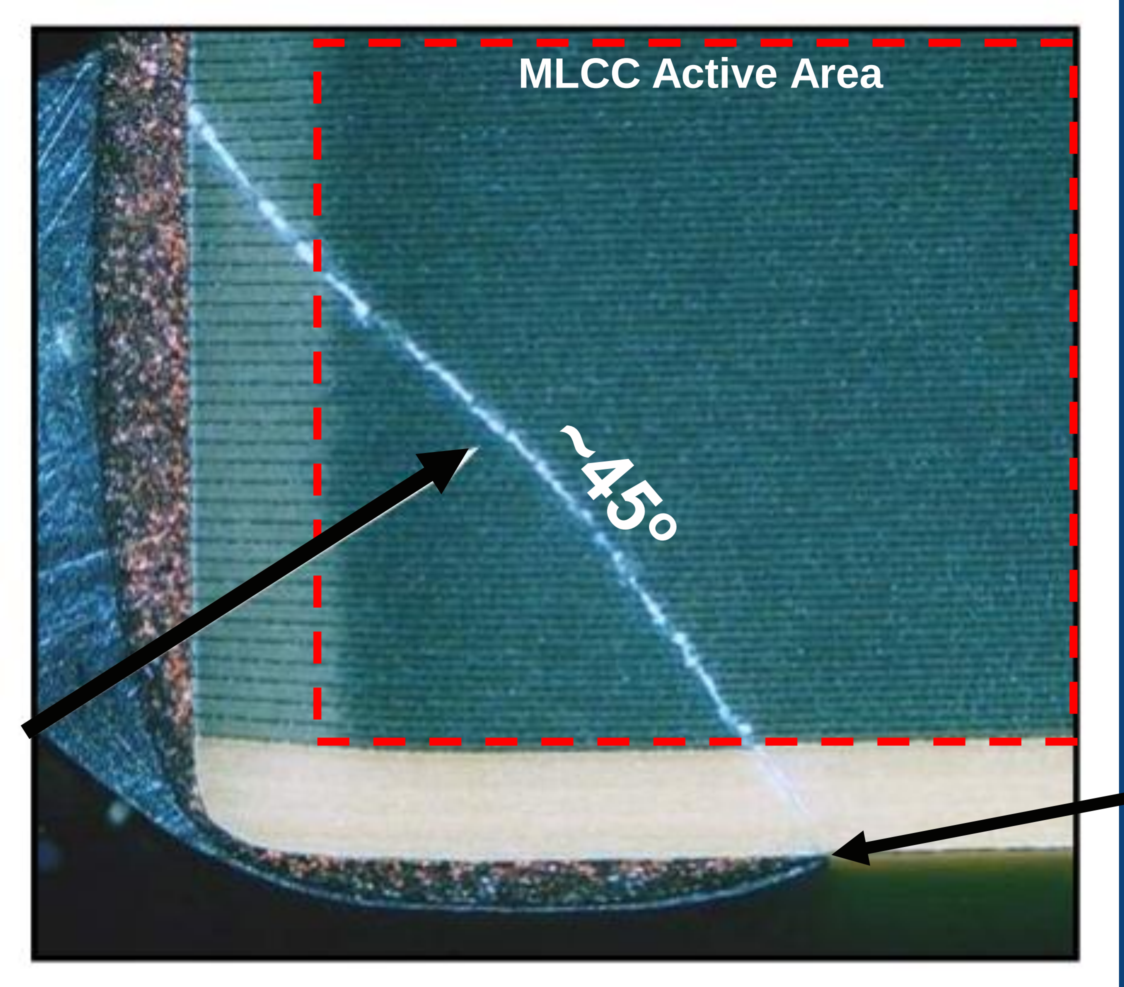
Flex Cracking

Excessive Bending



Finite Element Analysis

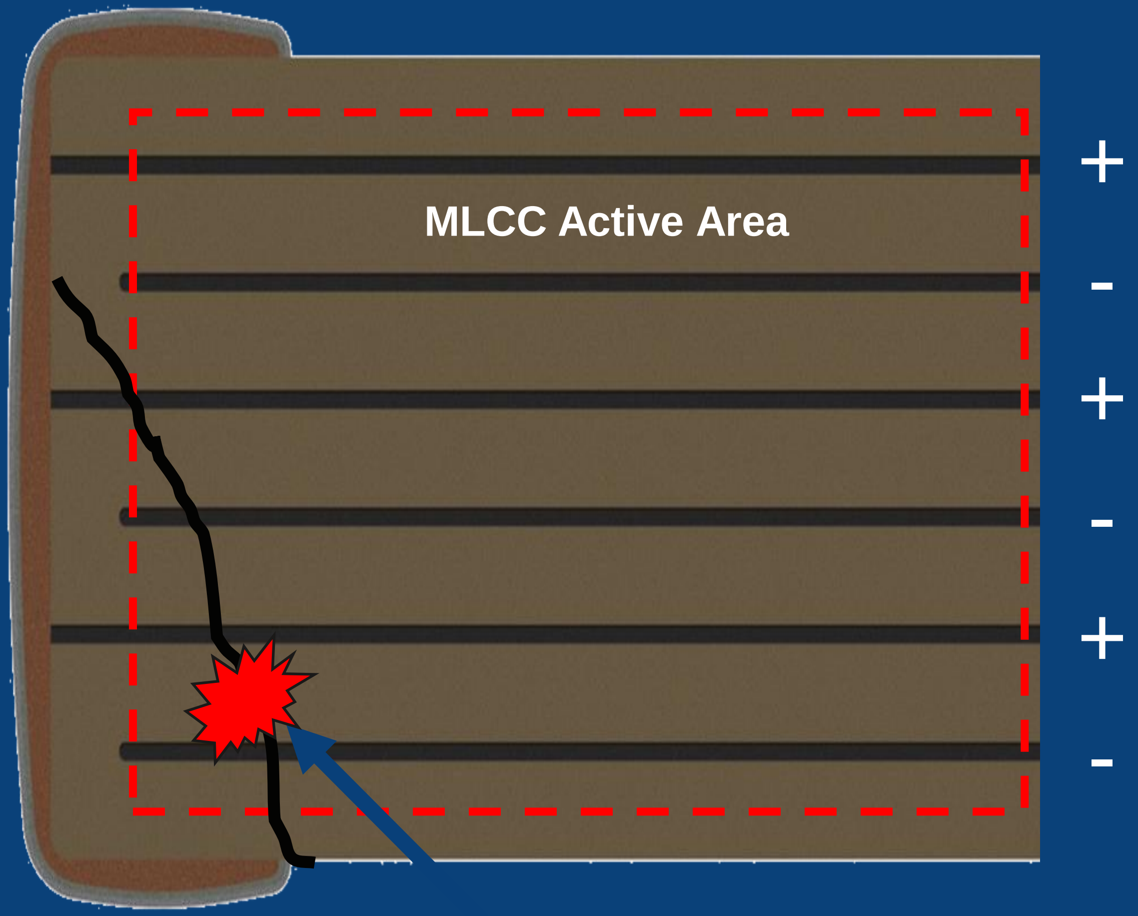
Flex Crack Signature



Flex crack signature

Starts here

Flex Crack Failures

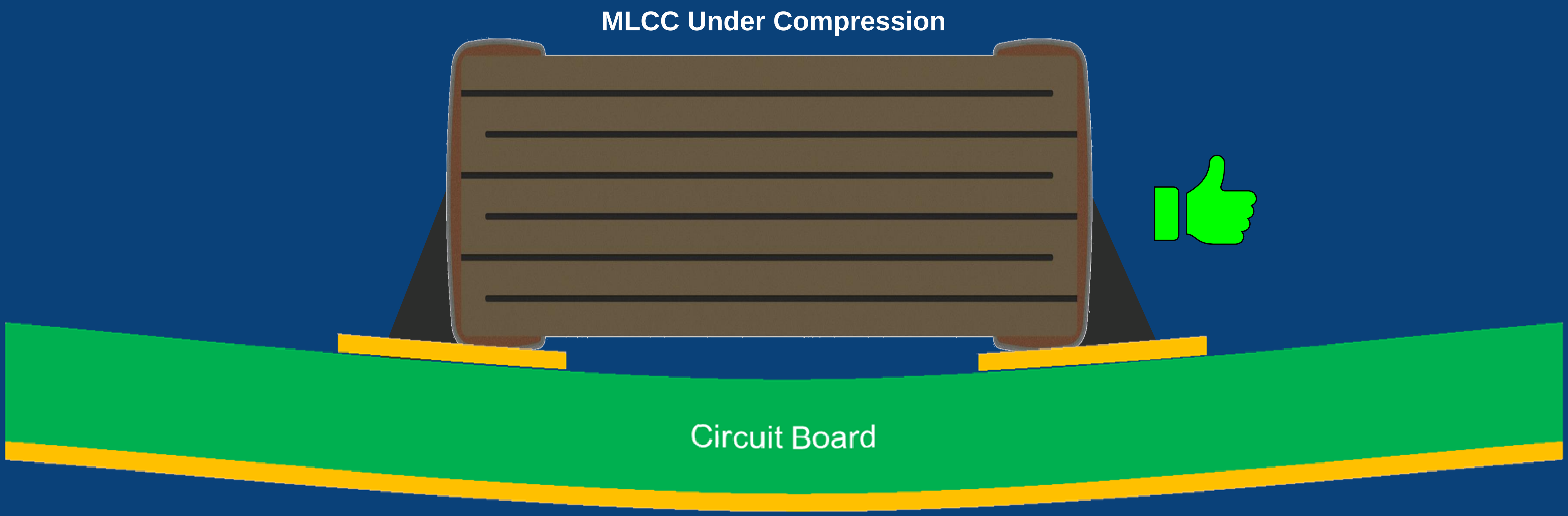


Opposing Electrodes

Note: Failure may be delayed

Flex Cracking

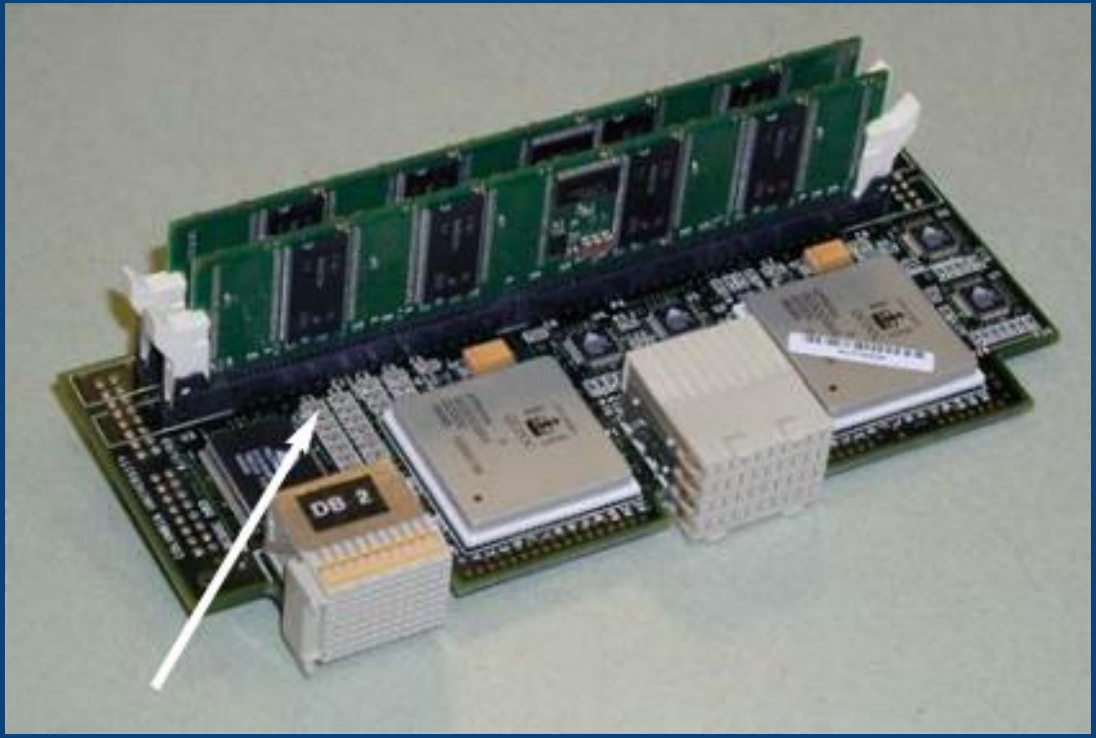
Concave Bend



Main Causes of Flex Cracks

Too Close to Connectors

KEMET BUILT INTO TOMORROW



Design Tips

- Mount MLCCs further away from connector if possible
- Better support near connector to reduce flexing

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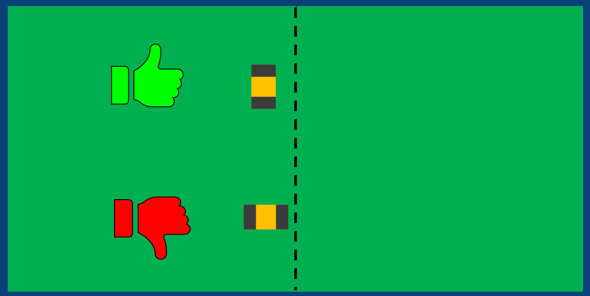
Main Causes of Flex Cracks

Board Singulation (Depanelization)

PCB Scribe Line

Scribe Line



Design Tips

- Avoid excessive bending techniques
- Mount MLCCs parallel to boards edge if close

Capacitor Mitigation Solutions

Level 1 Protection – Basic Level of Crack Protection

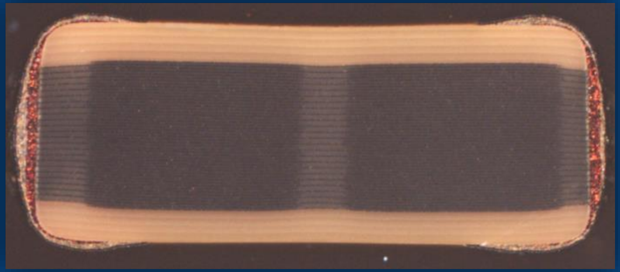
Floating Electrode

Pros

- Serial design
- Fails open

Cons

- Reduced capacitance in the same volume



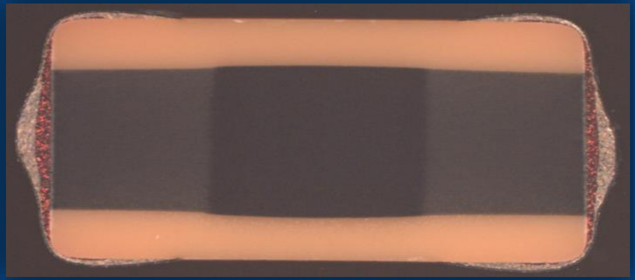
Open Mode

Pros

- Crack doesn't go through active area
- Fails open

Cons

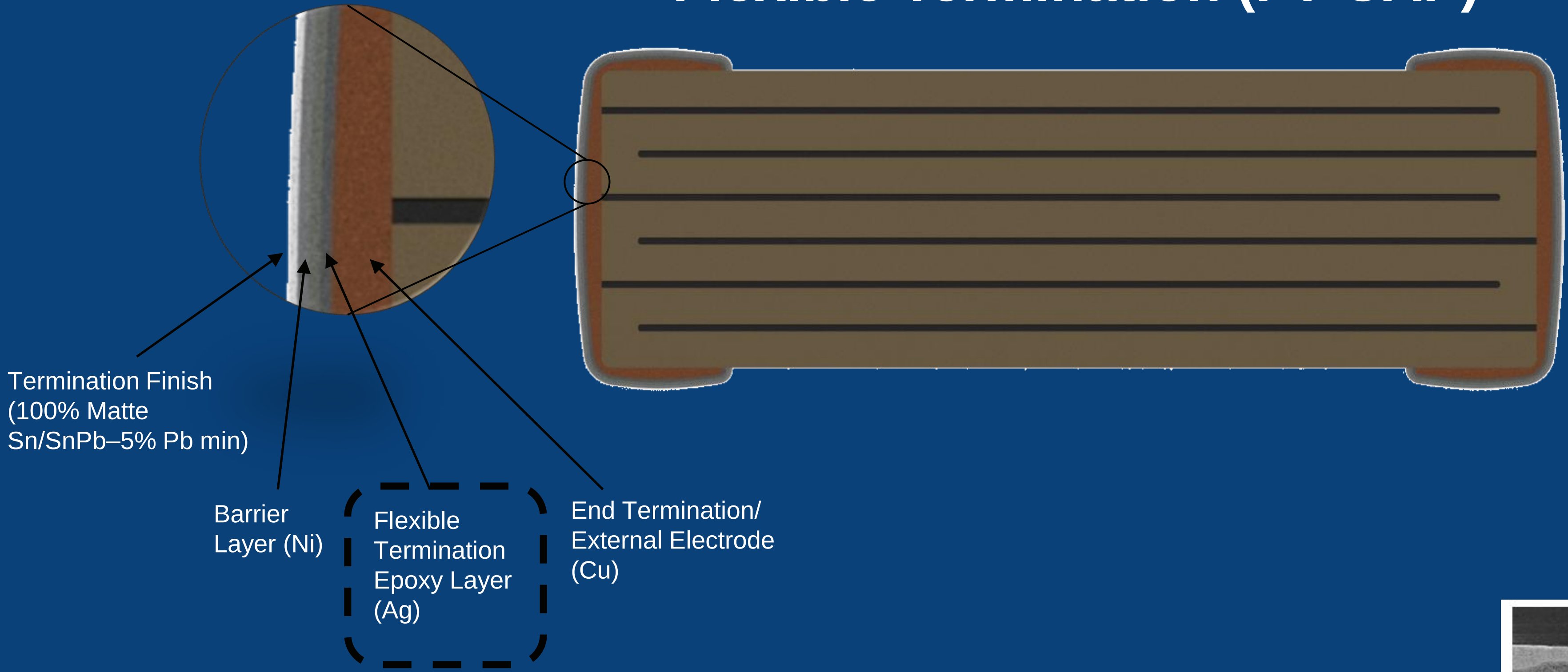
- Reduced capacitance in the same volume



Capacitor Mitigation Solutions

Level 2 Protection – Intermediate Level of Crack Protection

Flexible Termination (FT-CAP)

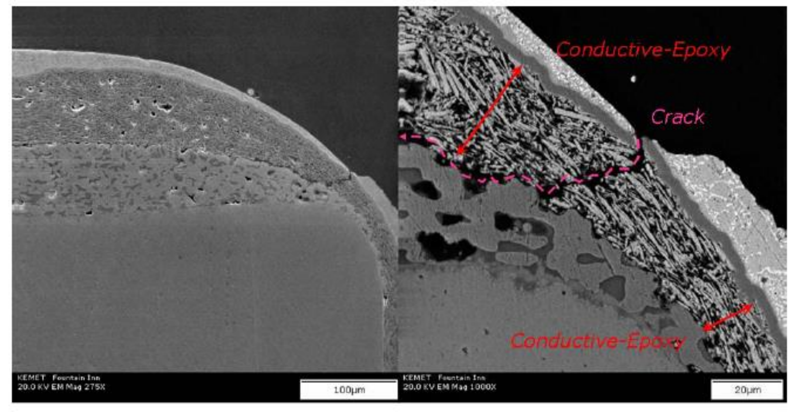


Pros

- Increased flex capability
- High volumetric efficiency

Cons

- Fail short



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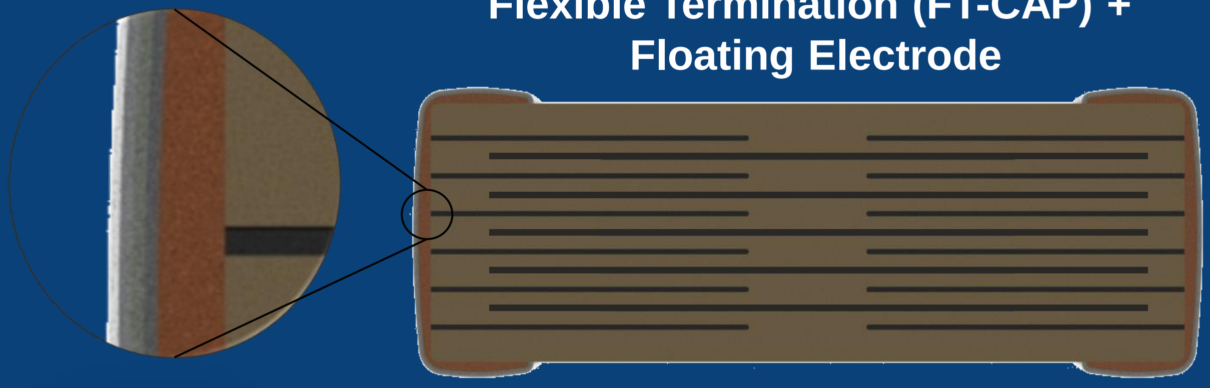
Capacitor Mitigation Solutions

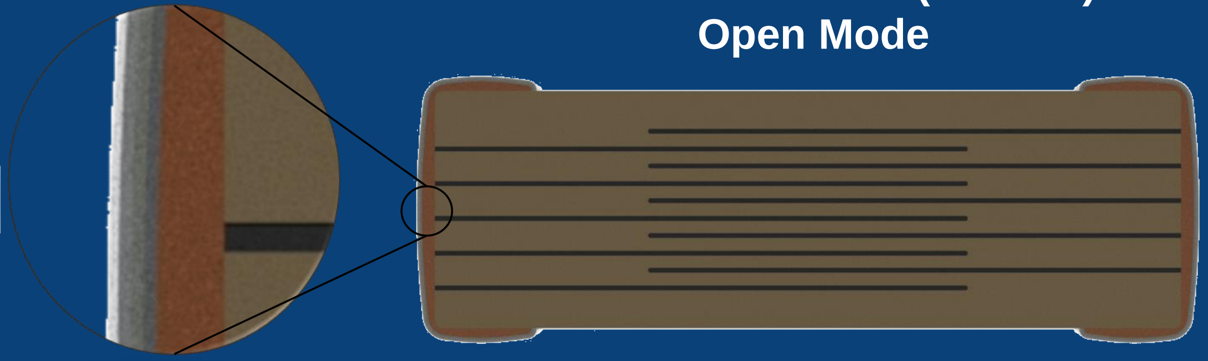
Level 3 Protection – High Level of Crack Protection (Hybrid Technology)

KEMET
BUILT INTO TOMORROW

Flexible Termination (FT-CAP) + Floating Electrode



Flexible Termination (FT-CAP) + Open Mode



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

Cons
- Reduced capacitance in the same volume

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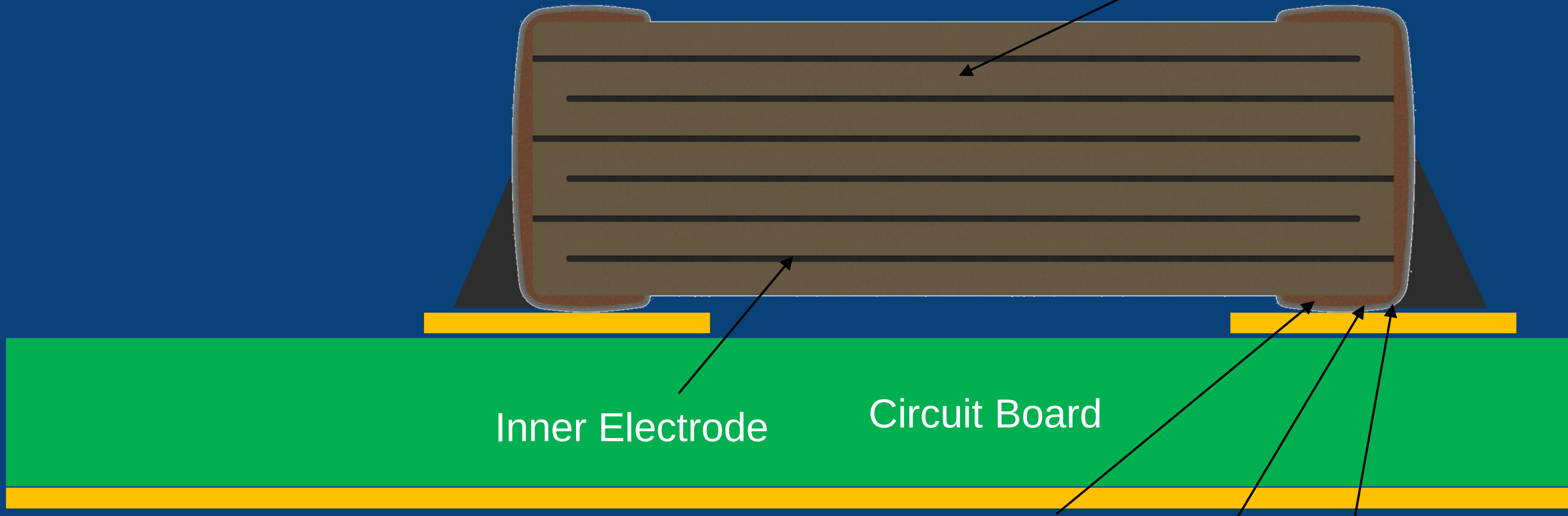
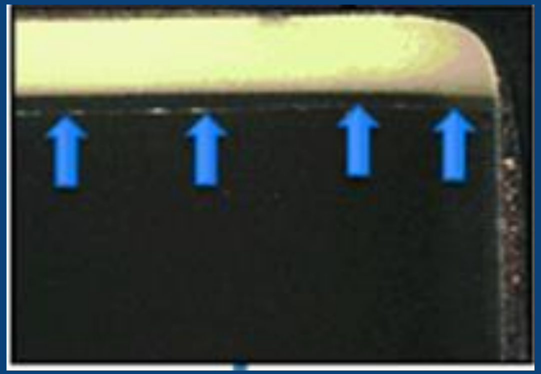
Thermal Shock

Why is it an issue?



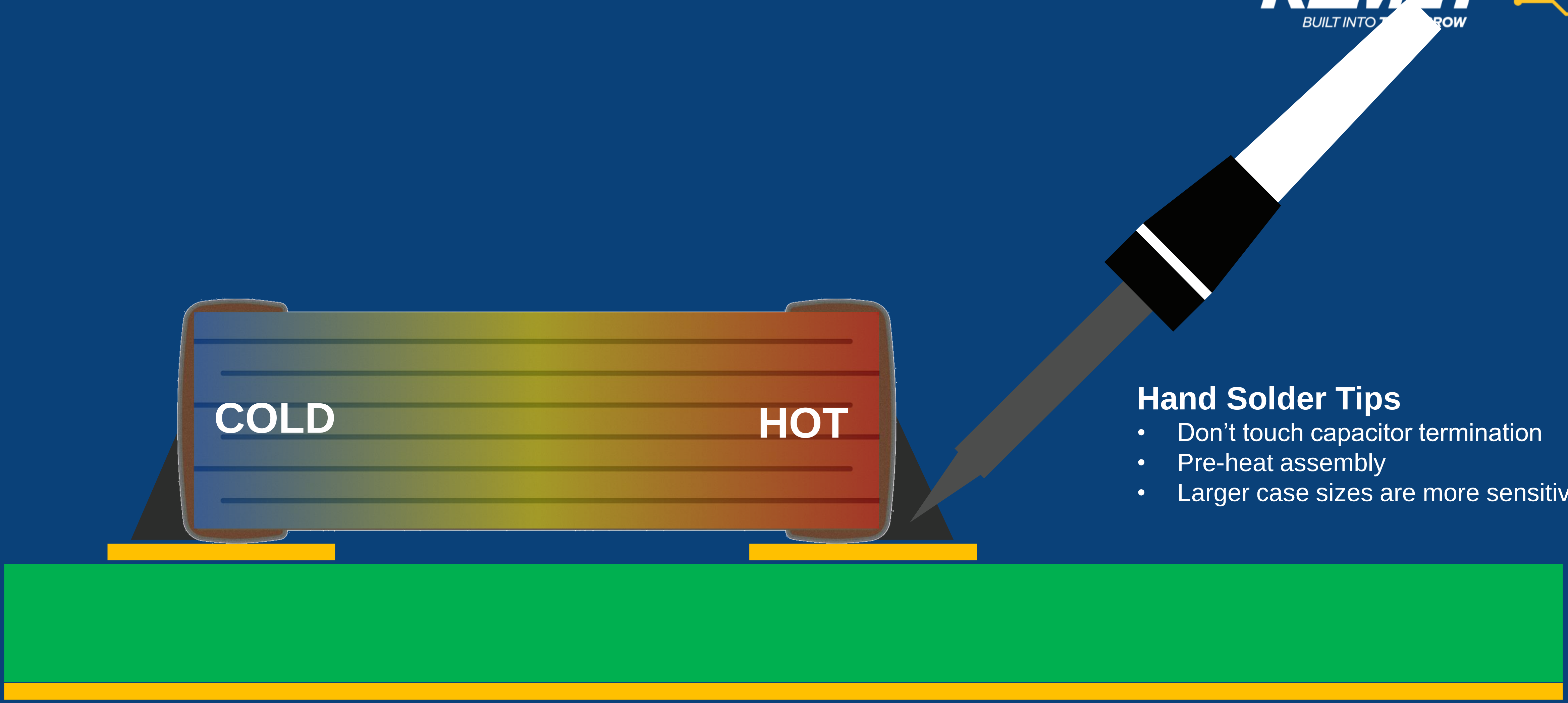


CTE – Coefficient of Thermal Expansion

Thermal Shock Cracks → CTE Mismatch

Thermal Shock

Causes – Hand Soldering



Hand Solder Tips

- Don’t touch capacitor termination
- Pre-heat assembly
- Larger case sizes are more sensitive

Internal Temperature Gradients

Uneven Expansion and Contraction

Thermal Shock

Causes – Solder Wave