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**webinar:**
# How to select the proper capacitor for your design?

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# How to select the proper capacitor for your design?

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***Content:***

- The approach of the seminar is to provide you the wright criteria to support you with capacitor selection for your particular design. The criteria and effects, which are import to keep in mind for the proper selection, are the basic topics of this seminar as well as selection criteria and advices for the following capacitor technologies:

- **Aluminum Electrolytic Capacitors / Aluminum Polymer Capacitors**
  - **Design In – rules and advices**
  - **Life estimation – criteria and calculation**
  - **Possibilities for cost down**
- **Film Capacitors**
  - **Why film capacitors are needed for particular applications**
  - **Which criteria and aging behaviors need to be taken into account for product selection**
- **MLCC's**
  - **Proper selection and dimensioning based on dependencies and tolerances**
  - **DC Bias effect and how to deal with it**
  - **Microphonic effect / cracking**

# Capacitor Type Comparison

| capacitor type | max. possible capacitance | | voltage range | | max. permissible current | | max. operating temperature | | Applications |
|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Electrolytic Capacitor** | > 1F | 🟢 | ca. 600 V | 🔴 | ca. 0,05 A/µF | 🔴 | 85°C up to 150°C | 🟡 | smoothing, buffering, DC Link |
| **Film Capacitors** | > 8mF | 🟡 | ca. 3kV | 🟡 | ca. 3 A/µF | 🟡 | max. 110°C | 🔴 | DC Link, EMI suppresion, filtering |
| **MLCC's** | > 100 µF | 🔴 | ca. 10 kV | 🟢 | ca. 10 A/µF | 🟢 | 85°C up to 200°C | 🟢 | EMI suppression, buffering, coupling |

# Aluminum Electrolytic Capacitors / Aluminum Polymer Capacitors

# Comparison:
# Aluminum Polymer / Aluminum-Electrolytic Capacitors

- **Aluminum Electrolytic Capacitor**
  - **Higher voltage ratings available (up to 600V)**
  - **cheaper pricing (@ same capacitance and voltage rating)**
  - **Better leakage current behavior than Polymer**
  - **Load life will be calculated as following:**

$$L_x = L_{nom} * 2^{\frac{T_0 - T_a}{10}}$$

vent

- **Aluminum Polymer Capacitor**
  - **Smaller ESR than Aluminum-Cap   >> higher allowable ripple current**
  - **No dry-out behavior like Aluminum-Cap (solid electrolytic)**
  - **Higher expected lifetime / load life**
  - **Limited in size (max. 10 x12 mm cans) and voltage (max. 200V)**
  - **Load life will be calculated as following:**

$$L_x = L_{nom} * 10^{\frac{T_0 - T_a}{20}}$$

no vent

$L_x$ = expected lifetime; $T_0$ = upper temperature limit ; $T_a$ =temperature of capacitor

# Comparison of expected life:
# Aluminum Electrolytic vs. Aluminum Polymer Capacitor
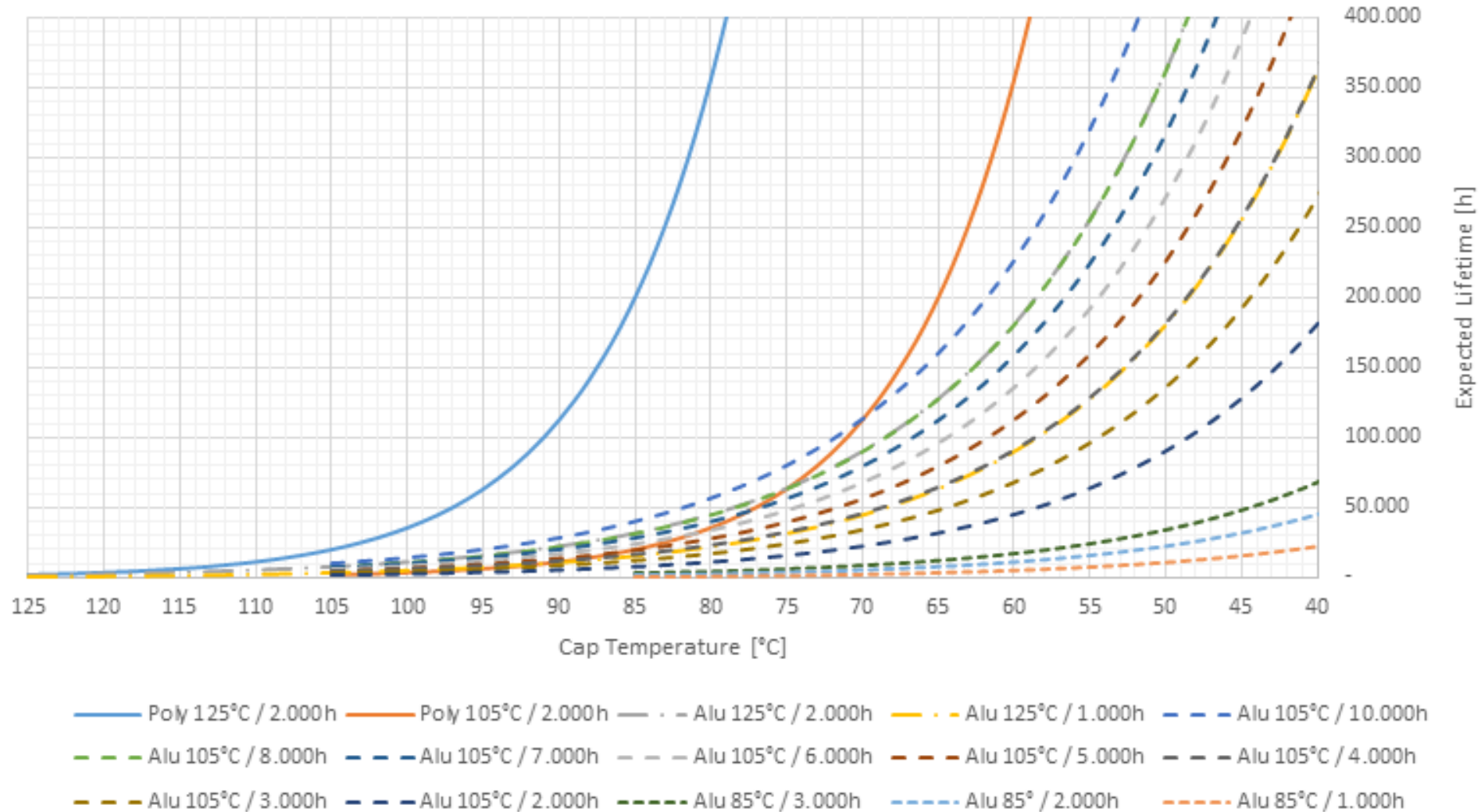
# What describes Endurance, Load Life and Usefull Life?

# Endurance and Useful Life as example with WCAP-AIG8 series

| WE Matchcode | WCAP-AIG8 | |
|---|---|---|
| Life | Endurance | Useful life |
| Time | 2000 h | 4000 h |
| Test condition | 85°C, $V_R$, $I_R$ | 85°C, $V_R$, $I_R$ |
| Requirements | 1.$\Delta C/C \leq \pm 20\%$;<br>2.DF≤2 times of the specified value;<br>3.LC≤specified value;<br>4.Capacitor without visible damage. | 1.$\Delta C/C \leq \pm 40\%$;<br>2.DF≤4 times of the specified value;<br>3.LC≤specified value;<br>4.Capacitor without visible damage. |

- It is necessary to check this for each manufacturer because it is not standardized!

- Not the specification of the manufacturer finally determines the lifetime, it will be the dimensioning and selection of the proper capacitor for your design

  >> How much capacitance drift is acceptable and still the application running properly? <<

# Major Factors for Aging of E-Caps

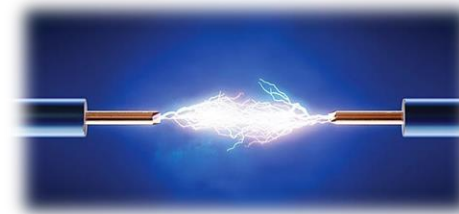- **The following fatcors mainly accelarate the aging behavior of an e-cap:**

  – **Temperature**
    - **electrolyte loss / dry out**
    - **leakage current >> oxide degradation**

  – **Ripple Current**
    - **self heating >> electrolyte loss / dry out**

  – **Voltage**
    - **leakage current >> oxide degradation**

  **These effects result in:**

  **>> capacitance decrease**

  **>> increase of ESR**

# Which parameters are necessary for a lifetime calculation?

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- **List of necessary parameters:**

    $L_x$=Life expectancy(hours).

    $L_0$=Assured lifetime(hours).This has been prescribed in the catalogs or product specifications.

    $T_0$=Maximum rated operating temperature(°C) of the capacitor.

    $T_a$=Actual operating temperature(°C) which the capacitor is used at.

    $\Delta T$=An increase(deg) in core temperature produced by internal heating due to actual operating ripple current.

    $\Delta T_0$=Inside temperature increase of capacitor by permissible ripple current at the maximum operating temperature
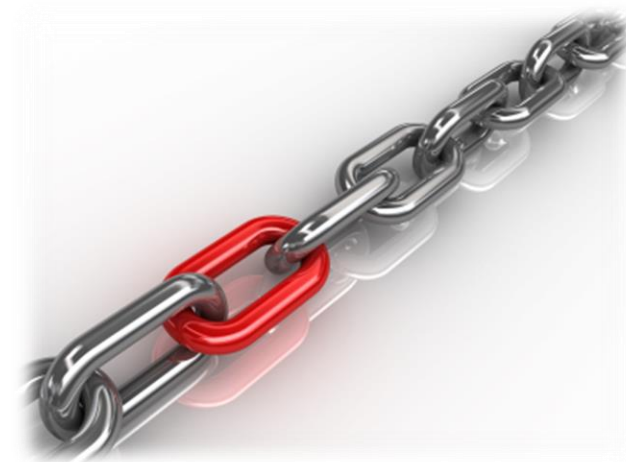
    $I_0$=Rated maximum permissible ripple current(Arms).

    $I_x$=Operating ripple current(Arms) actually flowing into a capacitors.

    $V_x$=Actual Applied Voltage

    $V_0$=Rated Voltage

**>> ΔT and ΔT0 will be assumed, if not known or possible to measure**

# Lifetime Calculation based on customer input

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## Expected Lifetime Calculation

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一、 Lifetime calculation

| Reference Designator | Load Condition | Part number | Rated Voltage(V) | Matchcode | Capacitance(uF) | Size D*L (mm) | Base lifetime of capacitor, $L_0$(Hours) | Maximum rated category temperature of capacitor, $T_0$(℃) | Actual Surface temperature of Capacitor, $T_a$(℃) | Delta To, $\Delta T_0$(℃) | Rated Ripple Current, $I_0$(A) | Applied Ripple Current, High freq. ($I_H$, A) | Applied Ripple Current, Low freq. ($I_L$, A) | High Freq. Coeff. (Hz) | Low Freq. Coeff. (Hz) | Equivalent Rated Ripple Current, Ix(A) | Delta T, $\Delta T$(℃) | Kripple | Estimated Lifetime, $L_x$(Hours) | Estimated Lifetime, $L_x$(years) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WE | | 865080649013 | 50 | WCAP-ASLI | 47 | 8X6.5 | 2000 | 105 | 60 | 5 | 0.24 | 0.20 | 0 | 1 | 1 | 0.20 | 3.47 | 1.236 | 55930 | 6.38 |

二、 Remarks

## Lx = Lo * 2^((To-Ts)/10) * Kripple

| Kripple | Products | |
|---|---|---|
| | Styles | Matchcodes |
| $2^{\frac{-\Delta T}{10}}$ | THT | WCAP-ATG8 |
| $2^{\frac{\Delta T_0 - \Delta T}{5}}$ | SMD | WCAP-AS5H,WCAP-ASLP,WCAP-ASLU,WCAP-ASLI,WCAP-ASLL |
| | THT | WCAP-ATG5(≤100V),WCAP-ATLI,WCAP-AT5H(≤100V),WCAP-ATUL,WCAP-ATLL,WCAP-AT1H(≤100V),WCAP-ATET |

$$\Delta T = \Delta T_o * (I_x / I_o)^2$$

Lx=Life expectancy(hours).

$L_0$=Assured lifetime(hours),This has been prescribed in the catalogs or product specifications.

$T_0$=Maximum rated operating temperature(℃) of the capacitor.

$T_a$=Actual operating temperature(℃) which the capacitor is used at.

$\Delta T$=An increase(deg) in core temperature produced by internal heating due to actual operating ripple current.

$\Delta T_0$=Inside temperature increase of capacitor by permissible ripple current at the maximum operating temperature

$I_0$=Rated maximum permissible ripple current(Arms).

$I_x$=Operating ripple current(Arms) actually flowing into a capacitors.

| To(℃) | $\Delta To$(℃) |
|---|---|
| 85 | 10 |
| 105 | 5 |
| 125 | 5 |

# Detailed Life estimation for Aluminium Polymer Capacitors

$$L_X = L_0 \times 10^{(T_0 - T_X)/20}$$

Where,

| | | |
|---|---|---|
| $L_X$ (Hrs) | =Life expectance in actual use |
| $L_0$ (Hrs) | =Life time |
| $T_0$ (105°C) | =Maximum operating temperature (105°C) |
| $T_X$ (°C) | =Temperature of capacitor in actual use |

$$T_X = T + \Delta T$$

$T$ (°C) = Ambient temperature
$\Delta T$ (°C) = Generating temperature

$$\Delta T = (I / I_0)^2 \times \Delta T_0$$

$I$ (A rms) = Ripple current in actual use
$I_0$ (A rms) = Maximum permissible ripple current
$\Delta T_0$ (°C) = Generated temperature value by maximum permissible ripple current
[Aluminum Can Type: About 20°C, Molded Chip Type: About 10°C ]

# Cost down possibilities for E-Caps

**Most effective criterias for possible cost down at e-cap selection / dimensioning:**

- **Rated Voltage**
  - **Aluminum Electrolyte Cap >> applied voltage should be arround 70% of rated voltage**
  - **Aluminium Polymer Cap >> applied voltage should be arround 90% of rated voltage**

- **Endurance**
  - **Reduce on a min necessary level by lifetime calculation**
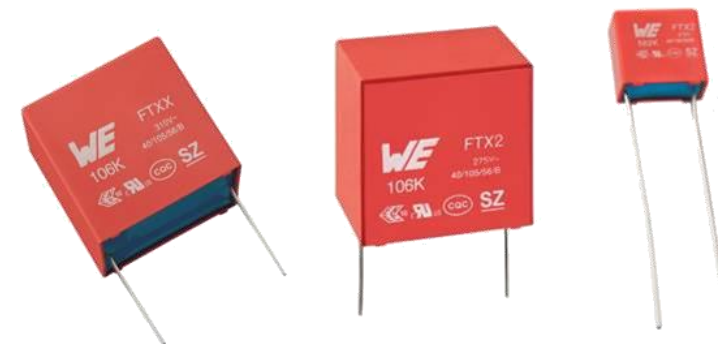
- **Max. Temperature**
  - **Dimensioning based on ambient condition and self heating**

**>> beside of capacitance per volume and special mounting types,
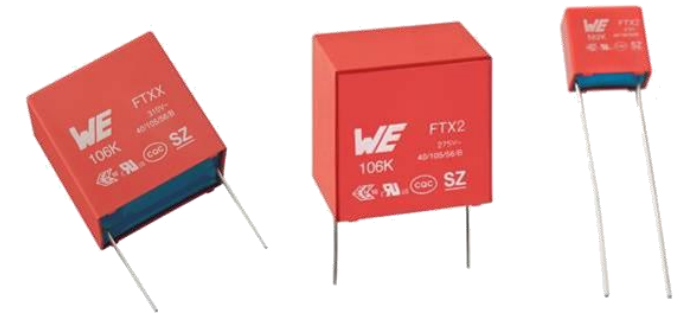these three factors are the main drivers for a possible cost down**

# Film Capacitors

# Why Film Capacitors are still needed for some special applications

**Film Capacitors show benefits in comparison to other cap types:**

- **no DC-Bias behavior**

- **can carry high current flow**

- **pretty good for long term usage and high lifetime**

**Keep in mind for Film Caps:**

- **Capacitance / volume ratio is less good as MLCC's and e-caps**

- **Temperature range up to max. 110°C**
  **>> don't oversterstress, base film / dielectric will get damaged**

- **Just a small range of SMT options are available**

- **types with coating or boxing can be prone to defects within high humidity as ambient condition**
  **>> the plastic film is hygroscopic and can absorb moisture >> short circuits and capacitance loss can happen**

# MLCC's
## Multilayer Ceramic Chip Capacitor's

# MLCC - Classification

- **Class 1 ceramics** (e.g.: NP0 = C0G)
  - built with **titanium oxide**
  - low relative permittivity $\varepsilon_r$ >> only smaller capacitance values are possible
  - linear tempartue dependency
  - minimum aging behavior
  - low (down to none) voltage dependency

- **Class 2 ceramics** (e.g.: X7R, X5R, Y5V)
  - built with **barium titanate**
  - higher relative permittivity $\varepsilon_r$ >> higher capacitance values are possible
  - not linear (and stronger distinct) temperature dependency
  - aging behavior
  - high voltage dependency
  - piezoelectric effects can result in microphonic effetcs

# What need to be considered at MLCC selection?

- **class 1:**
  - mainly the **C-tolerance** need to be taken into account
  - depended on specific type **no temperature dependency** (e.g. C0G / NP0) **or linear temperature dependency**
  - no further deratings
    - >> so this types provide stable and precis C-values
    - >> for applications with fixed and stable c-values (e.g. clock) the proper choice

- **class 2:**
  - There are multiple effects with influence on given C-value:
    - **C-tolerance** (according to datasheet)
    - **non linear temperature dependency** (manufacturer specific, related to material mix / construction)
    - **DC-bias** (manufacturer specific, related to material mix / construction)
    - **aging behavior**
      - >> the capacitance value of datasheet will be different with in an running application
      - >> check the manufacturer data to be able to assume occurring effects
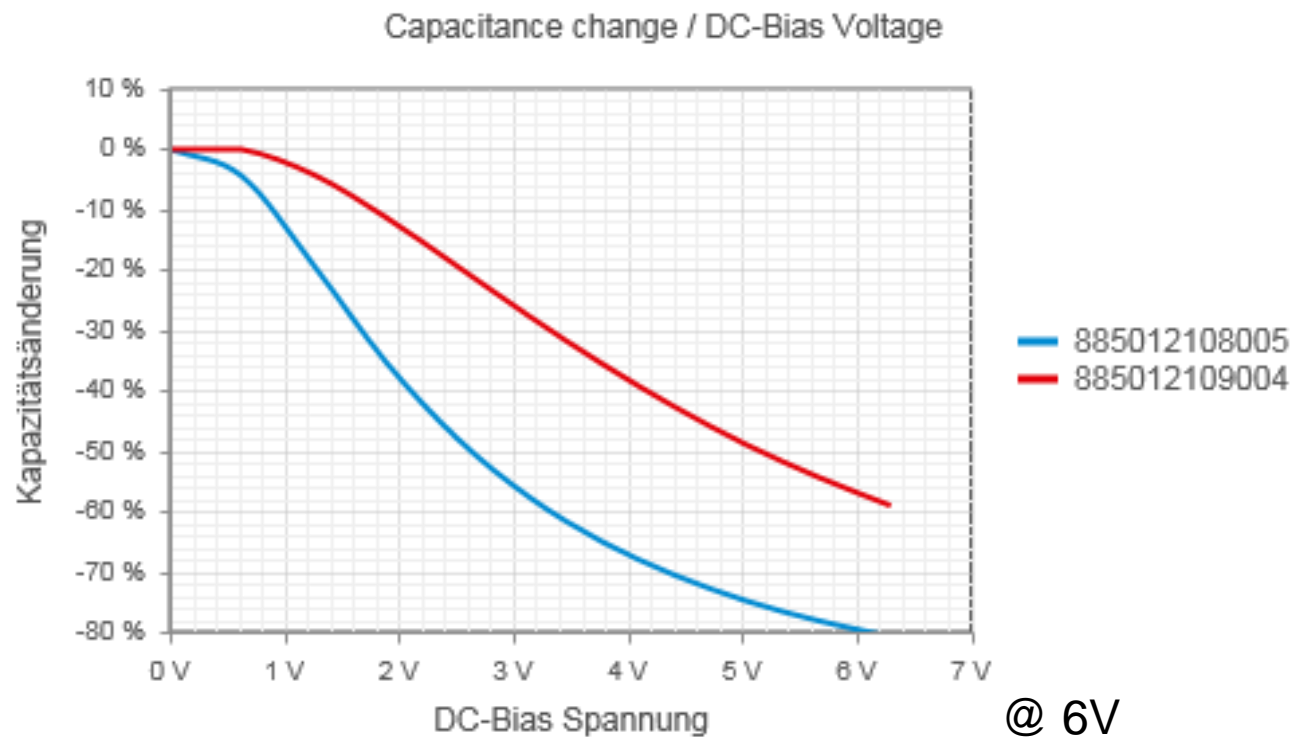
# Class 2 – MLCC's

- **Coding of class 2 ceramics according to EIA-RS-198:**

| EIA-RS-198 coding for class 2 ceramic capacitors | | | | | |
|---|---|---|---|---|---|
| **1st character** | | **2nd character** | | **3rd character** | |
| Letter | Lower temperature limit | Number | Upper temperature limit | Letter | Capacitance change over the permissible temperature range |
| X | −55 °C | 2 | +45 °C | A | ±1.0% |
| Y | −30 °C | 4 | +65 °C | B | ±1.5% |
| Z | +10 °C | 5 | +85 °C | C | ±2.2% |
| | | 6 | +105 °C | D | +3.3% |
| | | 7 | +125 °C | E | +4.7% |
| | | 8 | +150 °C | F | +7.5% |
| | | 9 | +200 °C | P | ±10% |
| | | | | R | ±15% |
| | | | | S | ±22% |
| | | | | T | +22/−33% |
| | | | | U | +22/−56% |
| | | | | V | +22/−82% |

# Example: DC Bias vs. Geometry



Capacitance change / DC-Bias Voltage

— 885012108005
— 885012109004

@ 6V

| | Artikel-Nr. | Bauform | Typ | C ▲ | ΔC(V_DC...) | U_R | T_max |
|---|---|---|---|---|---|---|---|
| ✔ | 885012108005 | 1206 | X5R | 100 µF | -79,6 % | 6,30 V | 85,0ºC |
| ✔ | 885012109004 | 1210 | X5R | 100 µF | -56,9 % | 6,30 V | 85,0ºC |

Filter: 100 µF ≤ C ≤ 100 µF ✖  Bauform = 1206, 1210 ✖  6,30 V ≤ U_R ≤ 6,30 V ✖

# Example: Ceramic vs. DC Bias vs. Geometry



Capacitance change / DC-Bias Voltage

— 885012108011
— 885012209006
— 885012109006
— 885012208019

@ 6V
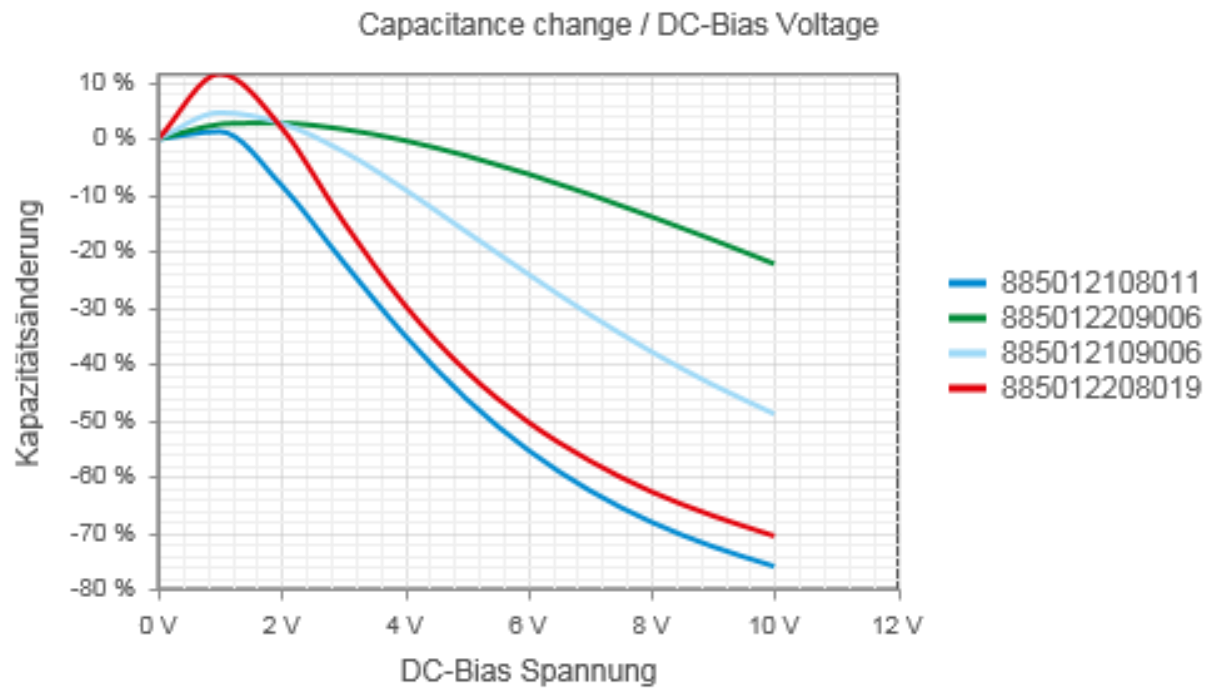
| Filter: | 22,0 µF ≤ C ≤ 22,0 µF ✖ | Bauform = 1206, 1210 ✖ | 10,0 V ≤ $U_R$ ≤ 10,0 V ✖ | | | | |
|---|---|---|---|---|---|---|
| | Artikel-Nr. | Bauform | T... ▼ | C | ΔC($V_{DC\text{-}Bias}$...) | $U_R$ | $T_{max}$ |
| ✔ | 885012208019 | 1206 | X7R | 22,0 µF | -50,3 % | 10,0 V | 125°C |
| ✔ | 885012209006 | 1210 | X7R | 22,0 µF | -6,21 % | 10,0 V | 125°C |
| ✔ | 885012108011 | 1206 | X5R | 22,0 µF | -55,3 % | 10,0 V | 85,0°C |
| ✔ | 885012109006 | 1210 | X5R | 22,0 µF | -24,0 % | 10,0 V | 85,0°C |

# Example 1: How much capacitance do you really get?

- **885012108011:** 22µF / X5R / 1206 / 20% @ 6V DC

C-tolerance

temperature dependency

DC-bias @ 6V DC

aging @ 10000h

26,4 µF

30,36 µF

15,09 µF

22 µF  ±20%  ±15%  -50,3%

best case
63% of initial value
13,88 µF

17,6 µF

14,96 µF

-8%

worst case:
31% of initial value
6,85 µF

7,44 µF
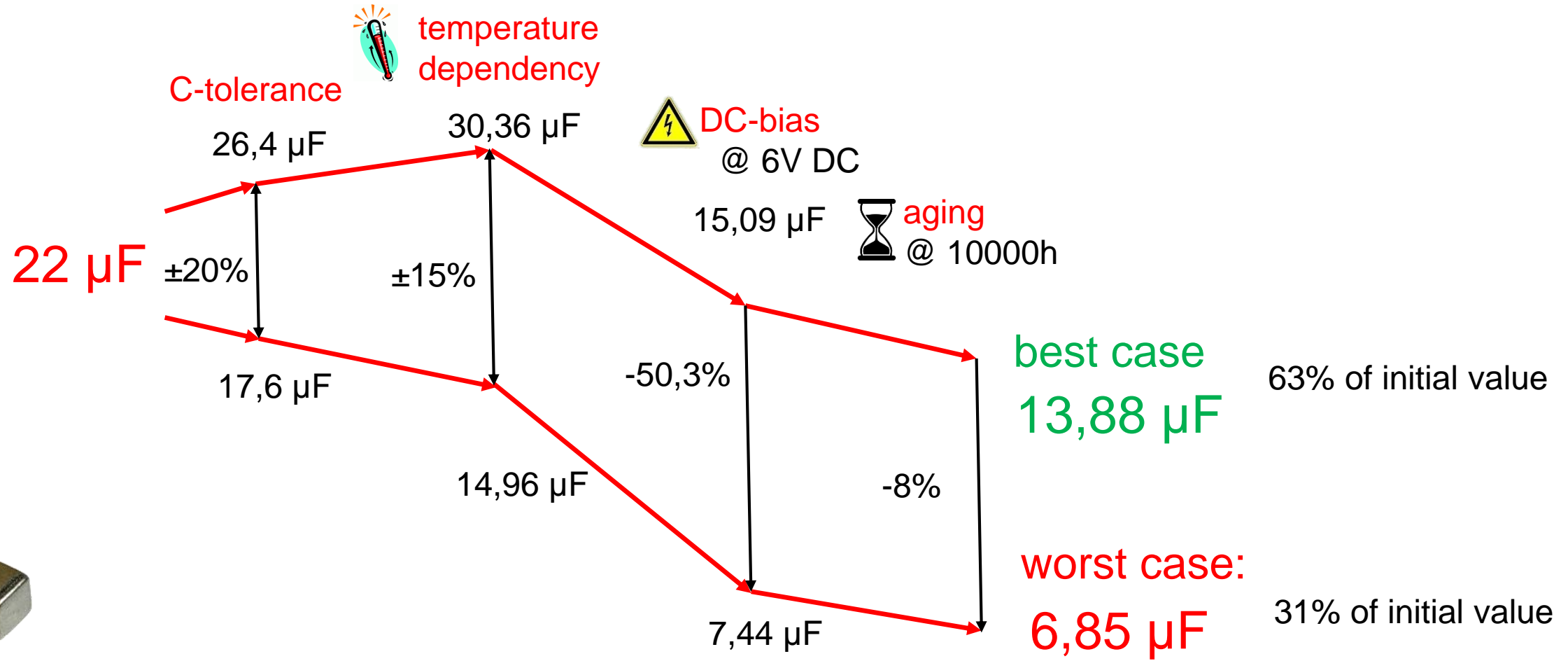
# Example 2: How much capacitance do you really get?

- **885012109006: 22µF / X7R / 1210 / 10 @ 6V DC**



C-tolerance

temperature dependency

DC-bias @ 6V DC

aging @ 10000h

24,2 µF

27,83 µF

26,10 µF

22 µF   ±10%    ±15%

-6,21%

best case: 25,32 µF

115% of initial value

19,8 µF

16,83 µF

-3%

15,79 µF

worst case: 15,32 µF

69% of initial value
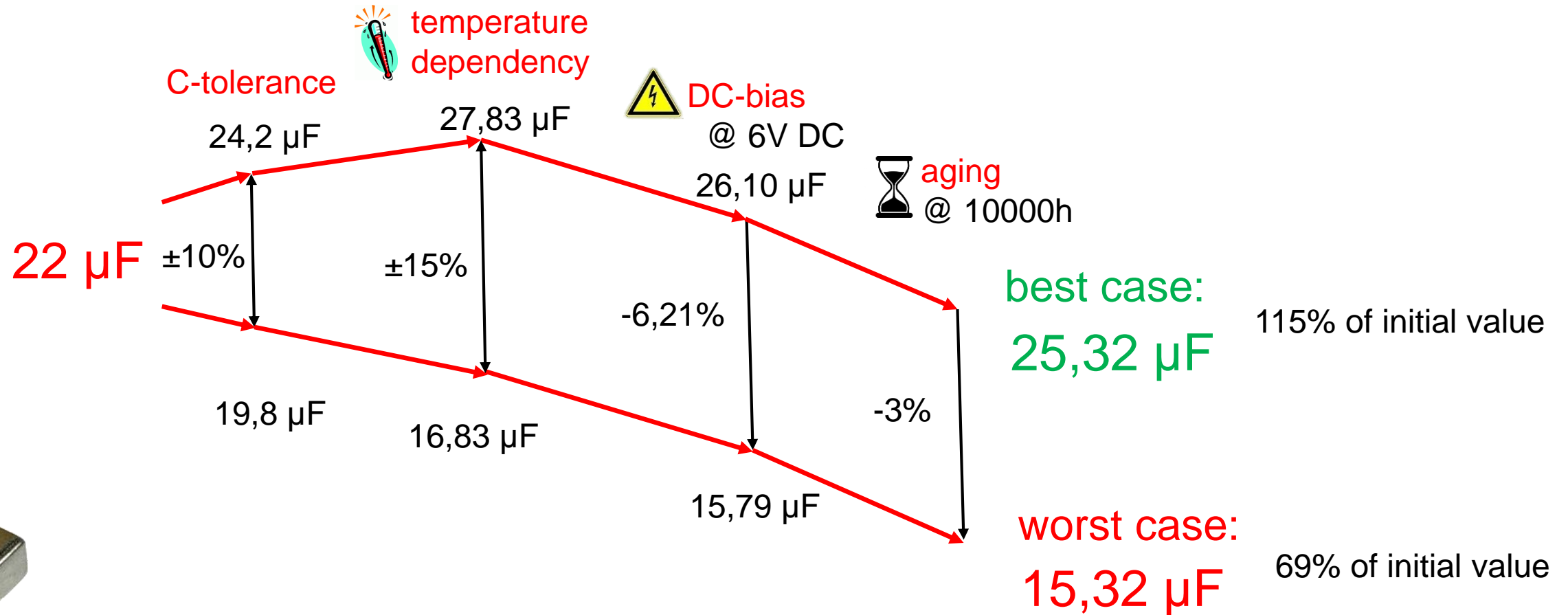
# Why is the capacitance of class 2 MLCC's drifting that strong?

■ **class 2 ceramics use
barium titanate as base material:**

– **this material is ferroelectric and this is the reason for such a strong capacitance dependency:**
  - **capacitance vs. temperature**
  - **DC-bias - dependency of capacitance against DC voltage**
  - **aging behavior**

– **also this material structure is prone to piezoelectric effects and this can also result in microphonic effects**

# Piezoelectric Effects of class 2 MLCC's

- **Piezoelectric Effect**
  - mechanical pressure on the capacitor or shock or vibration loads can cause voltage at the electrodes

  - class 2 MLCC's therefore shouldn't be used in sensitive analog signal paths e.g. amplifier circuits
    - mechanical vibrations generate voltage swings in the small mV range up to approx. 10 mV

- **Microphonic Effect / Noise (inverse piezoelectric effect)**
  - due to the reversibility of the piezoelectric effect, at high AC load, a partially audible sound radiation can occur via the capacitor and the printed circuit board
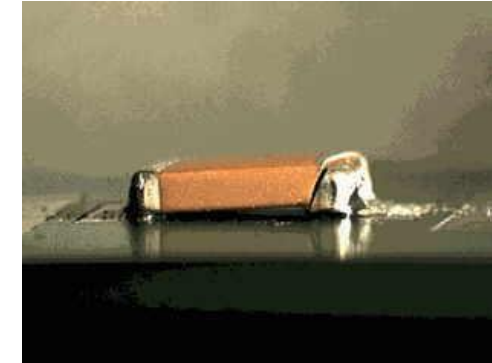
# MLCC - cracking
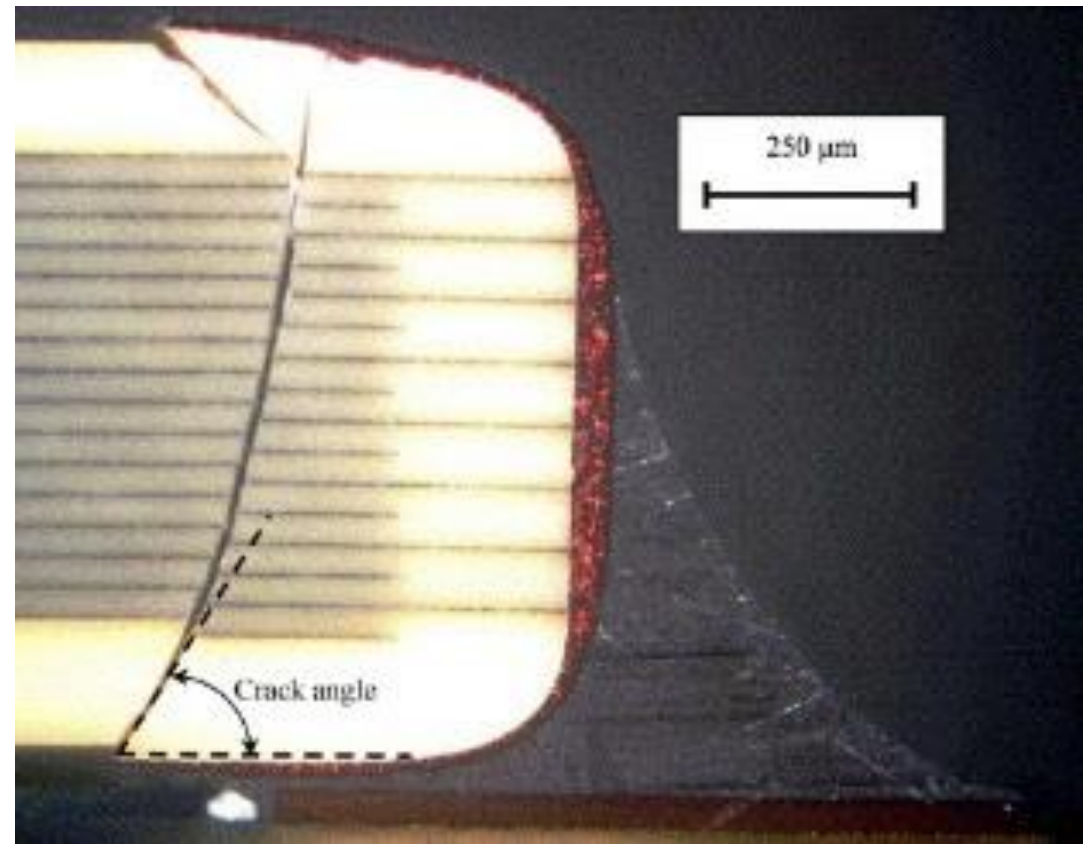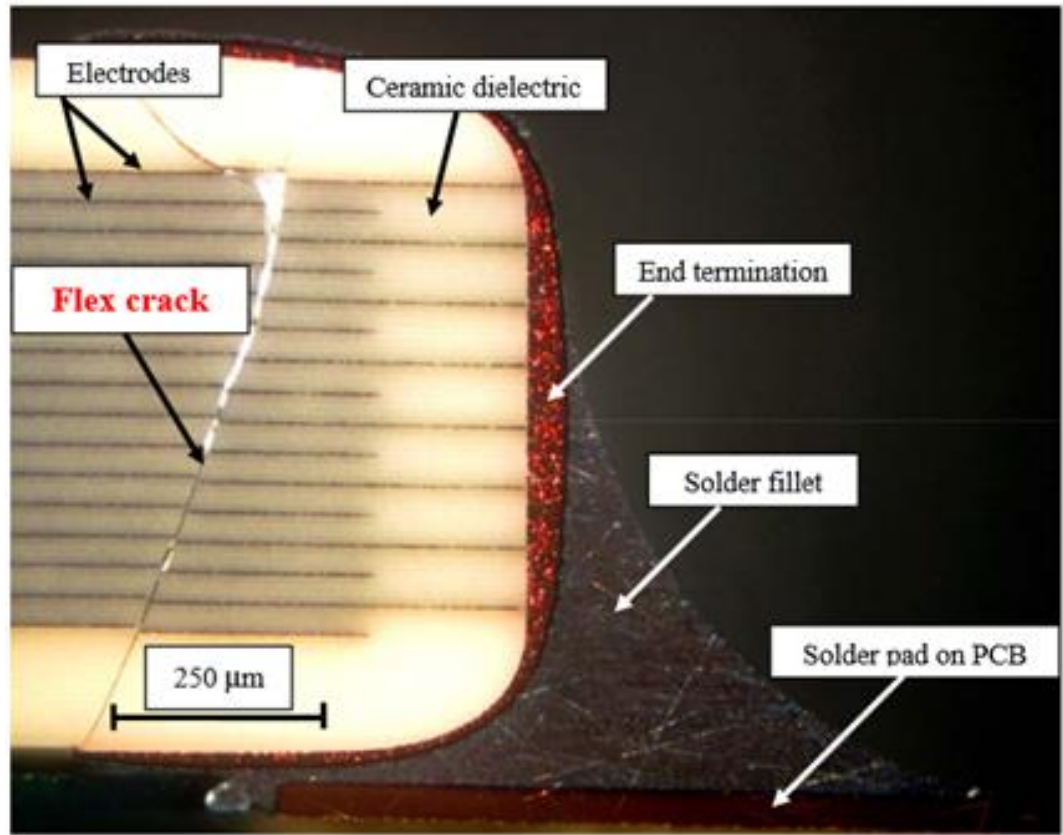
# MLCC - cracking

- **What causes cracking?**

  – **strong bending load or vibration on PCB level
    (can also occur during depanelling)**

  – **mechanical forces at plug-in connections or press-fit zones**

  – **unequal solder deposit amount >> strong mechanical stress at cool down**

  – **inconsistently heating of ceramic body >> especially problematic at manual soldering**


  **>> as bigger the size as more prone the MLCC is to cracking <<**

Source: Calce / University of Maryland

# conclusion for class 2 MLCC's

- **DC Bias effect**
  - choose rated voltage with enough buffer to applied voltage to still get sufficient capacitance values


- **reduce mechanical stress to a minimum** (also applicable for class 1)
  - can result in cracking and hard to detect defects and electrical failures


- **piezoelectric effects and possible microphonic effects**


- **integration density  vs. capacitance yield**
  - miniaturization can result in big capacitance loss depending on ceramic and size selection
    - \>\> keep in mind for new designs when shrinking existing circuits

# Thanks for your attention!