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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 suppression. filtering
MLCC's	> 100 µF	ca. 10 kV	ca. 10 A/µF	85°C up to 200°C	EMI suppression. buffering. coupling

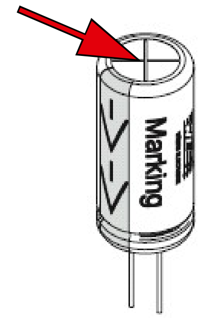
Aluminum Electrolytic Capacitors / Aluminum Polymer Capacitors

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



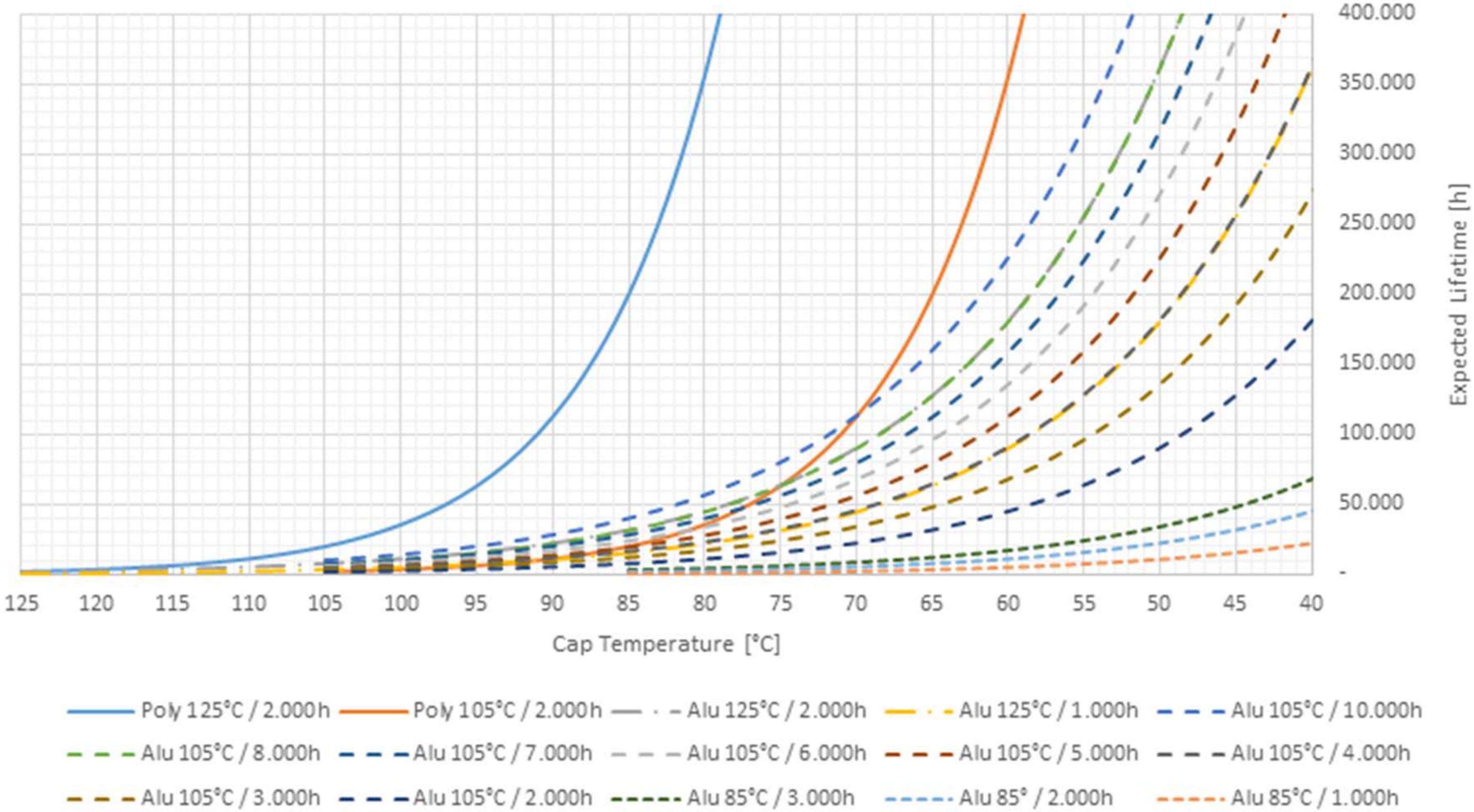
- **Aluminum Polymer Capacitor**
  - Smaller ESR than Aluminum-Cap >> higher allowable ripple current
  - No dry-out behavior like Aluminum-Cap (solid electrolytic)
  - Higher expected lifetime / load life
  - Limited in size (max. 10 x12 mm cans) and voltage (max. 200V)
  - Load life will be calculated 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 Useful 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.ΔC/C≤±20%; 2.DF≤2 times of the specified value; 3.LC≤specified value; 4.Capacitor without visible damage.	1.ΔC/C≤±40%; 2.DF≤4 times of the specified value; 3.LC≤specified value; 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

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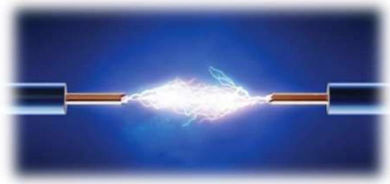
- The following factors mainly accelerate the aging behavior of an e-cap:
  - Temperature
    - electrolyte loss / dry out
    - leakage current >> oxide degradation



  - 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?

- **List of necessary parameters:**

  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_x=Actual operating temperature(℃) which the capacitor is used at.
  ΔT=An increase(deg) in core temperature produced by internal heating due to actual operating ripple current.
  ΔT_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

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_s(℃)	Delta To, ΔT_0(℃)	Rated Ripple Current, I_0(A)	Applied Ripple Current, High freq. (IH , A)	Applied Ripple Current, Low freq. (IL , A)	High Freq. Coeff. (Hz)	Low Freq. Coeff. (Hz)	Equivalent Rated Ripple Current, Ix(A)	Delta T, ΔT(℃)	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_s=Actual operating temperature(℃) which the capacitor is used at.

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

ΔT_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(℃)	ΔTo(℃)
85	10
105	5
125	5

Detailed Life estimation for Aluminum 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
ΔT (°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
ΔT_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 criteria for possible cost down at e-cap selection / dimensioning:

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

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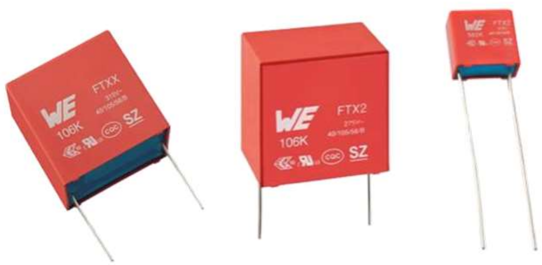
Film Capacitors show benefits in comparison to other cap types:

- 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 overstress. 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 ε_r >> only smaller capacitance values are possible**
  - **linear temperature 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 ε_r >> higher capacitance values are possible**
  - **not linear (and stronger distinct) temperature dependency**
  - **aging behavior**
  - **high voltage dependency**
  - **piezoelectric effects can result in microphonic effects**

What need to be considered at MLCC selection?

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- **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

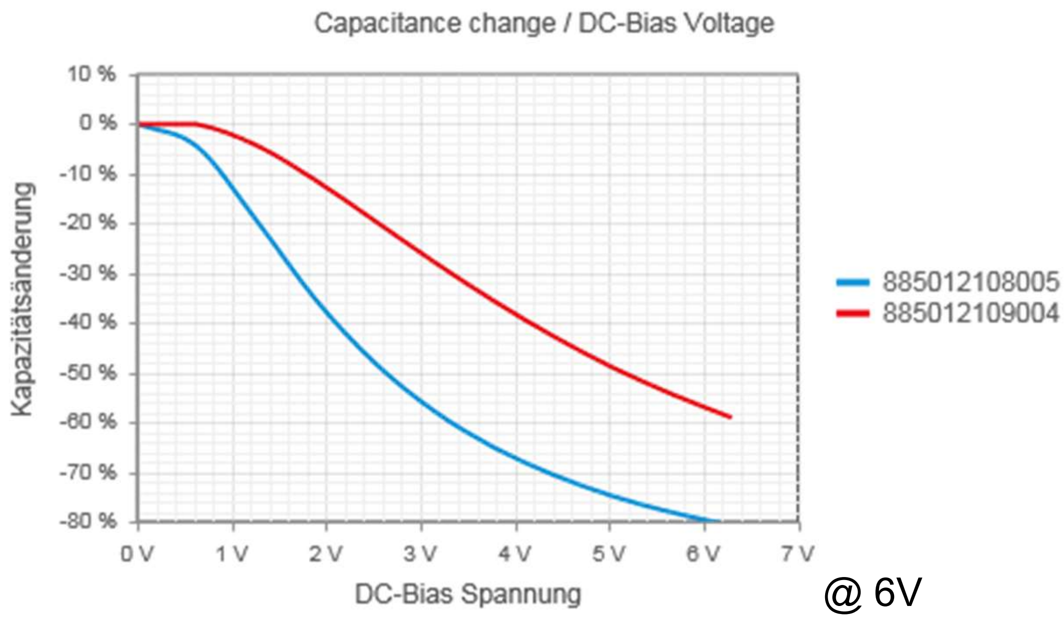
      >> check the manufacturer data to be able to assume occurring effects

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

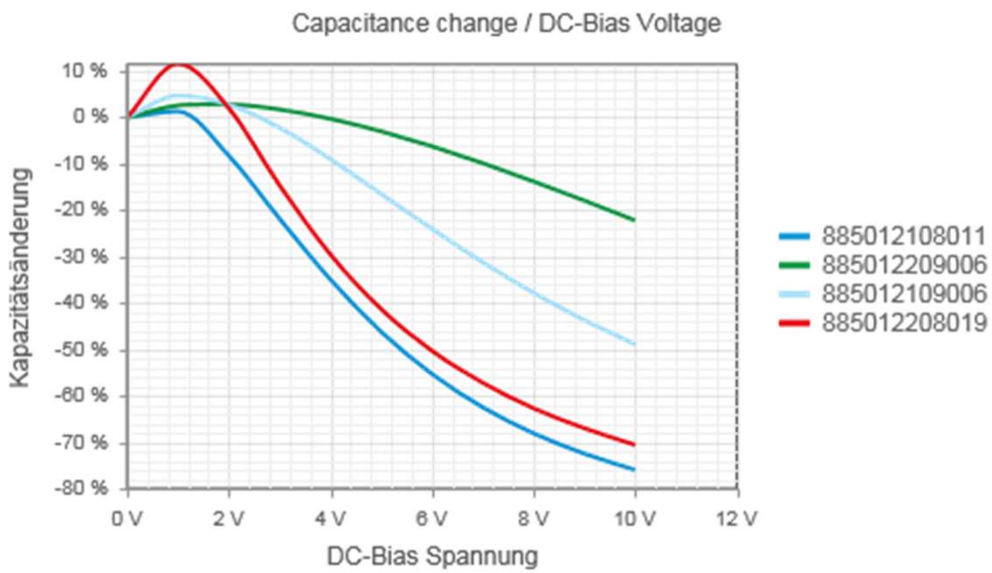


@ 6V

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

	Artikel-Nr.	Bauform	Typ	C ▲	ΔC(V$_{DC}$...	U_R	T_{max}
✔	885012108005	1206	X5R	100 µF	-79,6 %	6,30 V	85,0°C
✔	885012109004	1210	X5R	100 µF	-56,9 %	6,30 V	85,0°C

Example: Ceramic vs. DC Bias vs. Geometry



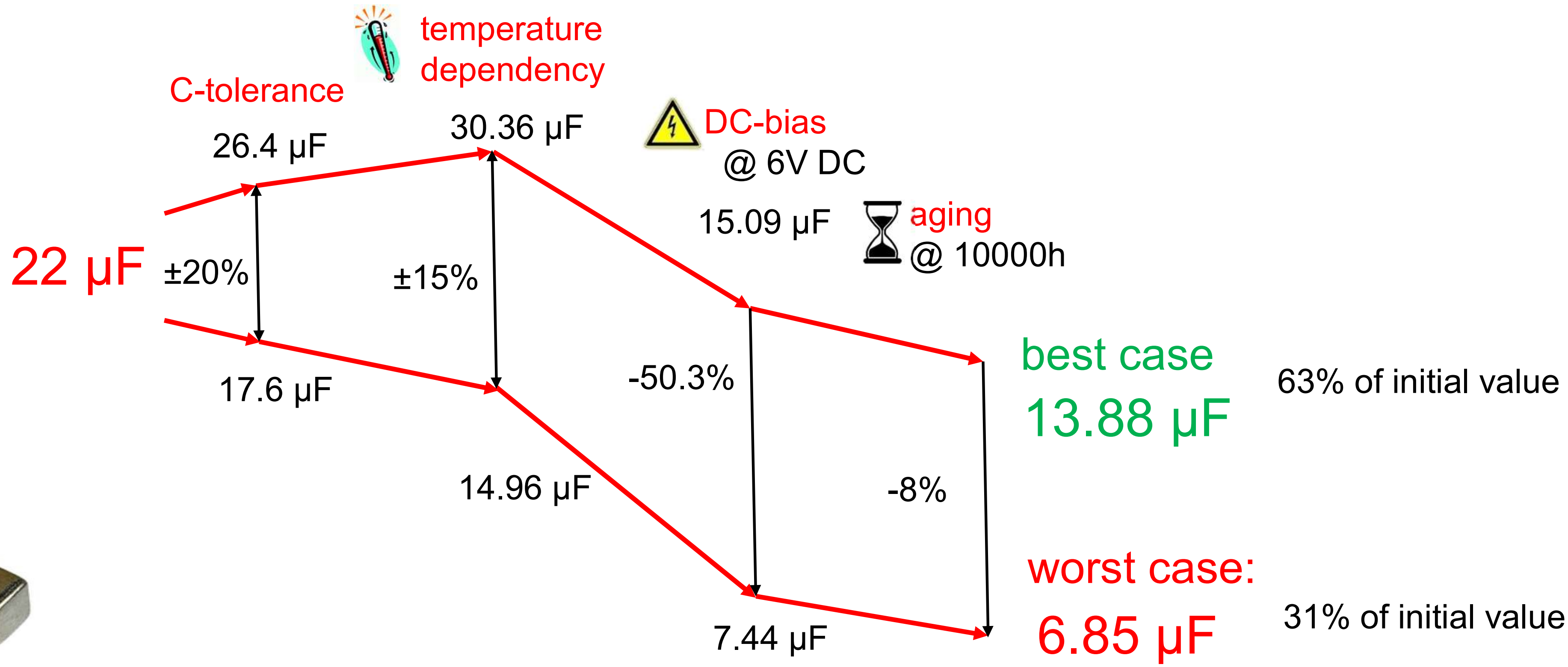
@ 6V

Filter: 22,0 µF ≤ C ≤ 22,0 µF | Bauform = 1206, 1210 | 10,0 V ≤ U_R ≤ 10,0 V

	Artikel-Nr.	Bauform	T...	C	$\Delta C(V_{DC\text{-}Bias}$...	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

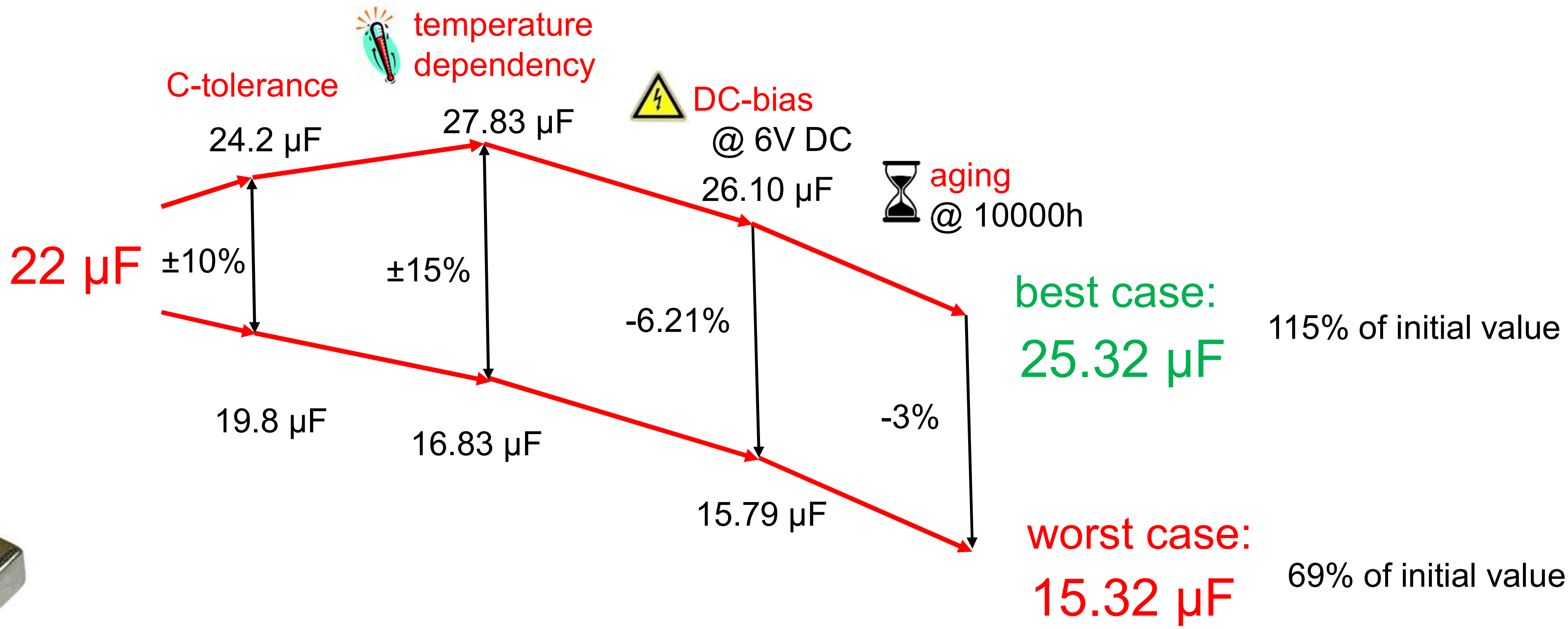
Example 1: How much capacitance do you really get?

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



Example 2: How much capacitance do you really get?

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



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

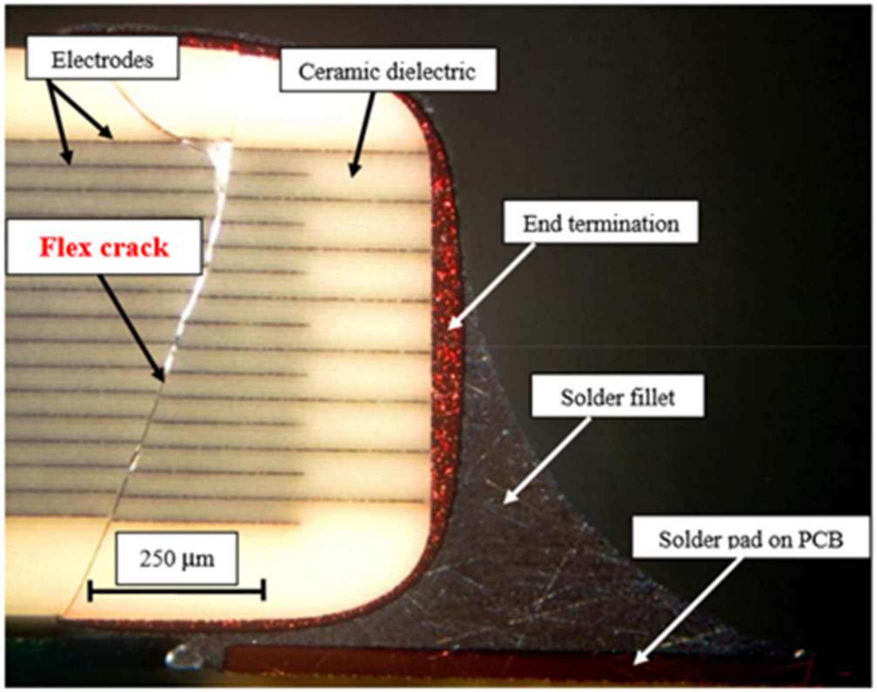
  - also this material structure is prone to piezoelectric effects and this can also result in microphonic effects

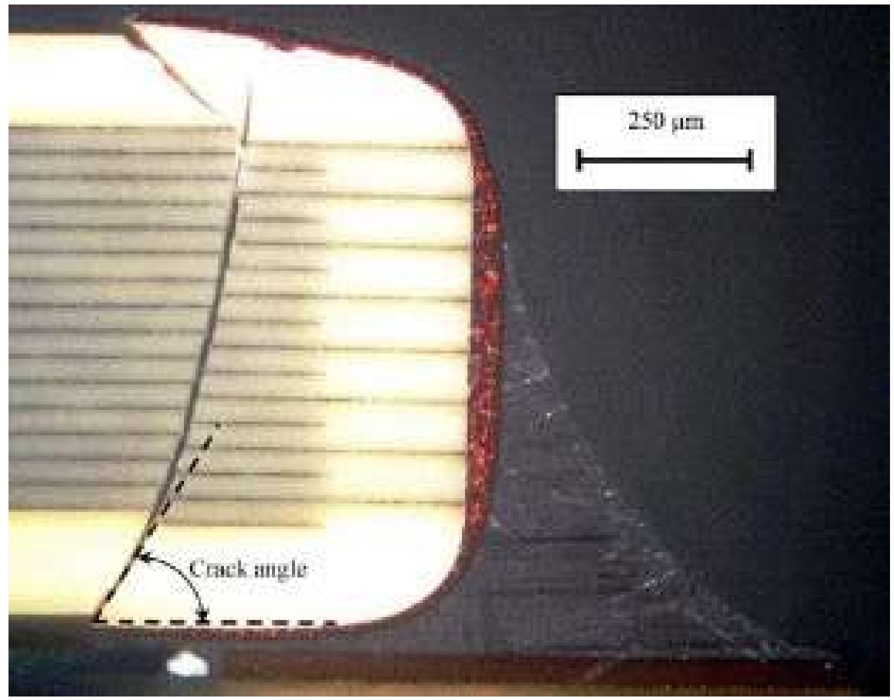
Piezoelectric Effects of class 2 MLCC‘s

- **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





Source: Calce / University of Maryland

MLCC - cracking

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- **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!