Satisfied with MLCC Downsizing and Availability?
Let’s go behind the scenes of technology, their physics & alternatives

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Agenda

- The MLCC Downsizing Challenge
  - Why smaller is not necessarily better?
  - What challenges you need to overcome within the design stage

- The Physics behind MLCCs
  - Why is DC-Bias so critical
  - What is the “real” available capacitance

- Are their alternatives out there?
  - Introducing possible technologies for replacements
The Downsizing Challenge of MLCCs
Possible Disadvantages of Downsizing

- **Worse electrical stability / performance**
  - For class 2 ceramics X7R / X5R >> higher capacity loss due to DC bias

- **Assembly times are rising**
  - With smaller sizes positioning runs more slowly
  - In the future also several components need to be picked as replacement

- **Most of it has to be invested in new production equipment**
  - It may require new feeder benches, nozzles and pick & place machines

- **Re-design necessary**
  - Blocks engineering resources for new projects
  - Releases (such as e.g. UL) must be repeated
  - Changes in the manufacturing process needed
DC Bias Effect of Class 2 Ceramics is chip size related!

<table>
<thead>
<tr>
<th>Order Code</th>
<th>Series</th>
<th>Size</th>
<th>T...</th>
<th>C</th>
<th>Vr</th>
<th>$\Delta C(V_{DC-Bias})$ @12.5 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>885012206076</td>
<td>WCAP-CSGP</td>
<td>0603</td>
<td>X7R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>-51.6 %</td>
</tr>
<tr>
<td>885012106022</td>
<td>WCAP-CSGP</td>
<td>0603</td>
<td>X5R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>-69.8 %</td>
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<tr>
<td>885012207078</td>
<td>WCAP-CSGP</td>
<td>0605</td>
<td>X7R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>-32.3 %</td>
</tr>
<tr>
<td>885012107015</td>
<td>WCAP-CSGP</td>
<td>0805</td>
<td>X5R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>-33.4 %</td>
</tr>
<tr>
<td>885012208004</td>
<td>WCAP-CSGP</td>
<td>1206</td>
<td>X7R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>-7.31 %</td>
</tr>
<tr>
<td>885012209024</td>
<td>WCAP-CSGP</td>
<td>1210</td>
<td>X7R</td>
<td>1.00 $\mu$F</td>
<td>25.0 V</td>
<td>1.17 %</td>
</tr>
</tbody>
</table>
MLCCs are super products, but keep in mind their physics!
What need to be considered at MLCC selection?

### Class 1 (e.g.: NP0 = C0G)
- Mainly the C-tolerance need to be taken into account
- Depended on specific type no temperature dependence (e.g. C0G / NP0) or linear temperature dependence
- No further derating

  >> so this types provide stable and precise C-values

  >> for all applications where a fixed and stable C-value (e.g. clock) is needed the proper choice

### Class 2 (e.g.: X7R, X5R, Y5V)
- There are multiple effects with influence on given C-value:
  - C-tolerance (according to datasheet)
  - Non linear temperature dependence (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
Example: DC Bias vs. Geometry

![Graph showing capacitance change vs. DC bias voltage]

- At 6V, the capacitance change for 885012108005 is approximately -79.6%.
- The capacitance change for 885012109004 is approximately -56.9%.

<table>
<thead>
<tr>
<th>Artikel-Nr.</th>
<th>Bauform</th>
<th>Typ</th>
<th>C</th>
<th>ΔC(V_DC)</th>
<th>UR</th>
<th>Tmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>885012108005</td>
<td>1206</td>
<td>X5R</td>
<td>100 μF</td>
<td>-79.6%</td>
<td>6,30 V</td>
<td>85,0°C</td>
</tr>
<tr>
<td>885012109004</td>
<td>1210</td>
<td>X5R</td>
<td>100 μF</td>
<td>-56.9%</td>
<td>6,30 V</td>
<td>85,0°C</td>
</tr>
</tbody>
</table>
Example: **Ceramic vs. DC Bias vs. Geometry**

![Capacitance change vs. DC Bias Voltage graph](image)

- Capacitance change / DC-Bias Voltage
- DC Bias Voltage range: 0 V to 12 V
- Capacitance Change range: -80% to 10%

### Table

<table>
<thead>
<tr>
<th>Artikel-Nr.</th>
<th>Bauform</th>
<th>T</th>
<th>C (µF)</th>
<th>ΔC&lt;VCC-bias</th>
<th>UR</th>
<th>Tmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>885012208019</td>
<td>1206</td>
<td>X7R</td>
<td>22,0 µF</td>
<td>-50,3 %</td>
<td>10,0 V</td>
<td>125°C</td>
</tr>
<tr>
<td>885012209006</td>
<td>1210</td>
<td>X7R</td>
<td>22,0 µF</td>
<td>-6,21 %</td>
<td>10,0 V</td>
<td>125°C</td>
</tr>
<tr>
<td>885012108011</td>
<td>1206</td>
<td>X5R</td>
<td>22,0 µF</td>
<td>-55,3 %</td>
<td>10,0 V</td>
<td>85,0°C</td>
</tr>
<tr>
<td>885012109006</td>
<td>1210</td>
<td>X5R</td>
<td>22,0 µF</td>
<td>-24,0 %</td>
<td>10,0 V</td>
<td>85,0°C</td>
</tr>
</tbody>
</table>

@ 6V
Example 1: How much capacitance do you really get?

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

![Diagram showing capacitance variations under different conditions.]

- C-Tolerance: ±20%
  - 26.4 µF
  - 30.36 µF
- Temperature dependence: ±15%
  - 17.6 µF
  - 14.96 µF
- DC-bias @ 6V DC
  - 15.09 µF
- Aging @ 10000h
  - 13.88 µF
  - 6,85 µF
- Best case: 13.88 µF (63% of nominal value)
- Worst case: 6.85 µF (31% of nominal value)
Example 2: How much capacitance do you really get?

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

![Diagram of capacitance variations with annotations for C-tolerance, temperature dependence, DC-bias, and aging with best and worst case scenarios.](image-url)
Why is capacitance drift of class 2 MLCC‘s 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 Behaviour
  - Also this material structure is prone to piezoelectric effects and this can also result in microphonic effects
Piezoelectric Effects of class 2 MLCCs

- **Piezoelectric Effect**
  - Mechanical pressure on the capacitor or shock or vibration loads can cause voltage at the electrodes
  - Class 2 MLCCs 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

Electrodes
Ceramic dielectric

Flex crack
End termination
Solder fillet
Solder pad on PCB

250 μm

250 μm

Crack angle

Source: Calce / University of Maryland
MLCC - cracking

- What causes cracking?
  - Strong bending load or vibration on PCB level
    (can also occur during depaneling)
  - 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
Is there a proper alternative for MLCCs?

- **>1 µF – high capacitance**
  - Classic Aluminum E-Caps (like SMT V-Chips - also down to 3mm in size)
  - Aluminum Polymer E-Caps >> especially H-Chips
  - Tantalum - Capacitors

- **< 1 µF – low capacitance**
  - No real alternatives against conventional MLCCs
  - Film Caps could work, but are way too big / bulky
Conclusion for Class 2 MLCCs

- **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 <<

!!! Check for new designs smallest possible sizes !!! to stay up to date with market
Which alternatives can be considered?
Parallel Plate Capacitor

- Basic parts of a capacitor:
  1: Electrodes
  2: Dielectric material
  3: Distance between electrodes

>> These are the 3 main parameters to manipulate the capacitance!

How to calculate the capacitance?

\[ C = \varepsilon \frac{A}{d} = \varepsilon_0 \varepsilon_r \frac{W \times L}{d} \]
How to increase the capacitance?

- If you change the following parameters as described, the capacitance of the capacitor will be raised:

1) **Surface Area**
   the surface area of the two conductive plates which make up the capacitor
   >> the larger the area the greater the capacitance.

2) **Dielectric Material**
   the type of material which separates the two plates called the “dielectric”
   >> the higher the permittivity of the dielectric the greater the capacitance.

3) **Distance**
   the distance between the two plates
   >> the smaller the distance the greater the capacitance.

- In current development of capacitors these parameters are still in focus to increase the capacitance.
<table>
<thead>
<tr>
<th>Material</th>
<th>Relative Permittivity ($\varepsilon_r$) @ 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>vacuum</td>
<td>1</td>
</tr>
<tr>
<td>air (1bar)</td>
<td>1,00059</td>
</tr>
<tr>
<td>paper</td>
<td>1,6 ... 2</td>
</tr>
<tr>
<td>paraffin paper</td>
<td>2</td>
</tr>
<tr>
<td>polytetrafluoroethylene (Teflon)</td>
<td>2,1</td>
</tr>
<tr>
<td>polystyrene</td>
<td>2,3</td>
</tr>
<tr>
<td>polypropylene</td>
<td>2,5</td>
</tr>
<tr>
<td>polycarbonate</td>
<td>3</td>
</tr>
<tr>
<td>quartz</td>
<td>4,5</td>
</tr>
<tr>
<td>glass</td>
<td>5</td>
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<td>porcelain</td>
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<tr>
<td>calcite</td>
<td>6,5</td>
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<tr>
<td>aluminum oxide</td>
<td>9,3</td>
</tr>
<tr>
<td>tantalum pentoxide</td>
<td>26</td>
</tr>
<tr>
<td>niobium pentoxide</td>
<td>42</td>
</tr>
<tr>
<td>mica</td>
<td>58</td>
</tr>
<tr>
<td>epsilan</td>
<td>5000</td>
</tr>
<tr>
<td>Ceramic, Class 1</td>
<td>&gt;10 ... 500</td>
</tr>
<tr>
<td>Ceramic, Class 2</td>
<td>&gt;500 ... &gt; 10000</td>
</tr>
</tbody>
</table>

\[
\varepsilon = \varepsilon_0 \times \varepsilon_r
\]

\[
\varepsilon_0 = 8,8542 \times 10^{-12} \frac{A s}{V m}
\]

\[
= 8,8542 \times 10^{-14} \frac{F}{cm}
\]
Capacitor Types

- **Film Capacitors**
  - Paper Film Capacitor
  - Plastic Film Capacitor

- **Ceramic Capacitors**
  - Class 1
  - Class 2

- **Electrolytic Capacitors (E-Caps)**
  - Aluminum Electrolytic Capacitor
  - Tantalum Electrolytic Capacitor
  - Niobium Electrolytic Capacitor

- **Super Capacitors**
  - Electric Double Layer Capacitor
  - Pseudo Capacitor
  - Hybrid Capacitor

- **Mica Capacitors**
- **Glass Capacitors**
- **Rotary Capacitors**
- **Trimming Capacitors**
Why it’s tricky to find alternatives for MLCCs?
## Capacitor Technology Comparison

<table>
<thead>
<tr>
<th>capacitor type</th>
<th>max. possible capacitance</th>
<th>voltage range</th>
<th>max. permissible current</th>
<th>max. operating temperature</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Electrolytic Capacitor</td>
<td>&gt; 1F</td>
<td>ca. 600 V</td>
<td>ca. 0.05 A/µF</td>
<td>85°C up to 150°C</td>
<td>smoothing, buffering, DC Link</td>
</tr>
<tr>
<td>Film Capacitors</td>
<td>&gt; 8mF</td>
<td>ca. 3kV</td>
<td>ca. 3 A/µF</td>
<td>max. 110°C</td>
<td>DC Link, EMI suppression, filtering</td>
</tr>
<tr>
<td>MLCC’s</td>
<td>&gt; 100 µF</td>
<td>ca. 10 kV</td>
<td>ca. 10 A/µF</td>
<td>85°C up to 200°C</td>
<td>EMI suppression, buffering, coupling</td>
</tr>
</tbody>
</table>
What’s a proper alternatives against MLCC‘s?

- **>1 µF – high capacitance**
  - Classic Aluminum E-Caps (like SMT V-Chips - also down to 3mm in size)
  - Aluminum Polymer E-Caps >> especially H-Chips
  - Tantalum - Capacitors

- **< 1 µF – low capacitance**
  - No real alternatives against conventional MLCCs
  - Film Caps could work, but are way too big / bulky
What’s a proper alternatives against MLCC‘s?

- **Aluminum Polymer Capacitors – H-Chips**
  - H-Chip are interesting for
    - Miniaturization - possible to shrink by replacing MLCCs
    - Replacement for Tantalum- & MLCCs because:
      - >> no DC Bias Effect / no Voltage Derating
      - >> for low profile / height critical designs
  - Capacitance Range:
    - 15 µF - 560µF
  - Voltage Range:
    - 2V / 2,5 V / 4V / 6,3V

H-Chip vs. V-Chip
Impedance vs. Frequency

(typical sample curve)

- **Polymer H-Chip**
- **MLCCs (Class 2) without DC-Bias**
- **MLCCs (Class 2) with DC-Bias**
Capacitance Change vs. DC-Bias
Capacitance Change vs. Temperature

![Graph showing capacitance change vs. temperature for Polymer H-Chips and MLCCs (Class 2).]

- **Typical sample curve:**
- **Temperature in °C:** -55 to 105
- **Capacitance Change in % [ΔC / C]:** -20 to 20

- **Typical capacitance change over temperature for Polymer H-Chips:**
- **Max. allowed capacitance change over temperature for MLCCs like X7R or X5R ceramic:**

26.08.2019  |  eiCap  |  FPu
Let’s optimize your integration density

Save Space on your PCB

24 x MLCCs
- P/N: 885012107006 with 47 μF
- 24 x 47 μF = 1128 μF
- $V_R = 6.3 \text{ V(DC)}$
- Size 0805 $\rightarrow 2 \times 1.5 \text{ mm}$
- $C @ 6 \text{ V(DC)} = 216 \mu\text{F}$ due to DC - Bias
- $A = 255 \text{ mm}^2$

1 x H-Chip Aluminum Polymer Capacitors
- P/N: 875015119006 with 220 μF
- 1 x 220 μF = 220 μF
- $V_R = 6.3 \text{ V(DC)}$
- Size 2917 $\rightarrow 7.3 \times 4.3 \text{ mm}$
- $C @ 6 \text{ V(DC)} = 220 \mu\text{F}$
- $A = 44 \text{ mm}^2$
Many thanks for your attention!