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>ΔC(VDC-Bias) @12.5 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>8850122006076</td>
<td>WCAP-CSGP</td>
<td>0603</td>
<td>X7R</td>
<td>1.00 μF</td>
<td>25.0 V</td>
<td>-81.6 %</td>
</tr>
<tr>
<td>885012106022</td>
<td>WCAP-CSGP</td>
<td>0603</td>
<td>X5R</td>
<td>1.00 μF</td>
<td>25.0 V</td>
<td>-69.8 %</td>
</tr>
<tr>
<td>885012207078</td>
<td>WCAP-CSGP</td>
<td>0805</td>
<td>X7R</td>
<td>1.00 μF</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 μF</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 μF</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 μF</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

**Capacitance change / DC-Bias Voltage**

@ 6V

<table>
<thead>
<tr>
<th>Artikel-Nr.</th>
<th>Bauform</th>
<th>Typ</th>
<th>C</th>
<th>ΔC(VDC)</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 / DC-Bias Voltage graph](chart.png)

- **Capacitance Change** vs. **DC Bias Voltage**
- **Filter**: $22.0 \, \mu F \leq C \leq 22.0 \, \mu F$, Bauform = 1206, 1210, $10.0 \, V \leq U_R \leq 13.0 \, V$

<table>
<thead>
<tr>
<th>Artikel-Nr.</th>
<th>Bauform</th>
<th>T...</th>
<th>C</th>
<th>ΔC(VDC-Bias...)</th>
<th>U_R</th>
<th>T_{max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔️ 885012208019</td>
<td>1206</td>
<td></td>
<td>X7R</td>
<td>22,0 , \mu F</td>
<td>10,0 , V</td>
<td>125°C</td>
</tr>
<tr>
<td>✔️ 885012209006</td>
<td>1210</td>
<td></td>
<td>X7R</td>
<td>22,0 , \mu F</td>
<td>10,0 , V</td>
<td>125°C</td>
</tr>
<tr>
<td>✔️ 885012108011</td>
<td>1206</td>
<td></td>
<td>X5R</td>
<td>22,0 , \mu F</td>
<td>10,0 , V</td>
<td>85,0°C</td>
</tr>
<tr>
<td>✔️ 885012109006</td>
<td>1210</td>
<td></td>
<td>X5R</td>
<td>22,0 , \mu F</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

  - Temperature dependence
    - 22 µF
    - 26,4 µF
    - 30,36 µF

  - DC-bias @ 6V DC
    - 15,09 µF
    - Aging @ 10000h
    - 1,46 µF

  - Aging @ 10000h
    - 1,38 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 showing capacitance variation with temperature and DC-bias effects.]

- **C-Tolerance**: 24,2 µF (±10%)
- **Temperature Dependence**: 27,83 µF (±15%)
- **DC-bias @ 6V DC**: 26,10 µF (-6,21%)
- **Aging @ 10000h**: 15,79 µF (-3%)

**Best Case**: 25,32 µF (115% of nominal value)

**Worst Case**: 15,32 µF (69% of nominal value)
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

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
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.
## Talking about Permittivity

### Table: Relative Permittivity ($\varepsilon_r$) @ 20°C

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative Permittivity ($\varepsilon_r$)</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>
</tr>
<tr>
<td>porcelain</td>
<td>5</td>
</tr>
<tr>
<td>calcite</td>
<td>6.5</td>
</tr>
<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>epsilin</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>

### Equations:

$$\varepsilon = \varepsilon_0 \times \varepsilon_r$$

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

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

- Fixed Capacitance
  - 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
  - Mica Capacitors
    - Pseudo Capacitor
  - Glass Capacitors
    - Hybrid Capacitor

- Variable Capacitance
  - 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 / 10V / 16V / 25V
Impedance vs. Frequency

(typical sample curve)

- Red: Polymer H-Chip
- Gray: MLCCs (Class 2) without DC-Bias
- Black: MLCCs (Class 2) with DC-Bias
Capacitance Change vs. DC-Bias

Possible Capacitance Change for MLCC with Class 2 Ceramic

(typical sample curve)
Capacitance Change vs. Temperature

-55  -35  -15   5    15    25    45    65    85    105

Capacitance Change in % (ΔC / °C)

-20  -15  -10  -5    0    5     10     15     20

Temperature in °C

Red: Polymer H-Chip
Black: MLCCs (Class 2)

(typical sample curve)

Typical capacitance change over temperature for Polymer H-Chips.
Max. allowed capacitance change over temperature for MLCCs like X7R or X5R ceramic.
Let’s optimize your integration density

- **24 x MLCCs**
  - 885012107006 with 47µF
  - 24 x 47µF = 1128µF ($V_R = 6.3V$)
  - Size 0805 => 2mm x 1.5mm
  - C @ 6V(dc) = 216µF due to DC-Bias
  - A = 255mm²

- **1 x H-Chip Aluminum Polymer**
  - 875015119006 with 220µF
  - 1 x 220µF = 220µF ($V_R = 6.3V$)
  - Size 2917 => 7.3mm x 4.3mm
  - C @ 6V(dc) = 220µF
  - A = 44mm²
Why it’s tricky to find alternatives for MLCCs?
Many thanks for your attention!