Class 1 Ceramic MLCC Technologies for Higher Power Density Applications

APEC 2019 Industry Session
OLEV
The Online Electric Vehicle
Enabling Technologies

Wide Bandgap (WBG) Semiconductors

The BIG 3 for WBG
- Higher Voltages
- Higher Frequencies
- Higher Temperatures

Power (W)

Frequency (Hz)

SiC

Si

GaN

Switch Tank Converters (STC)
98.92% Conversion Efficiency at 650W
48V instead of 12V
Capacitors to replace bulky magnetics
## Typical Capacitor Applications

### Snubber
- High dV/dT
- High ripple currents
- High voltages
- High temperatures (150°C)
- Low Inductance

### DC-LINK
- High ripple currents
- High voltages
- High temperatures (150°C)
- High frequencies

### Resonant
- High ripple current
- Low to high voltages
- Capacitance stability

### Capacitor Attributes
- Low loss
- High ripple current
- Low inductance
- High voltage
- High temperature
- Stable Capacitance over operation conditions
- High mechanical stability
Class 1 or Class 2?
Class 1 vs Class 2 BME MLCCs

Ceramic Dielectric
Class 1 - CaZrO$_3$
Class 2 - BaTiO$_3$

Termination (External Electrode, Cu)

Barrier Layer (Plated Ni)

Internal Electrode (Ni)

Plated Sn finish for Solderability

\[ C = \frac{\varepsilon_0 K A (n - 1)}{d} \]
Class 1 vs Class 2 BME MLCCs
Stability vs Temperature
Class 2 MLCCs
Capacitance Stability vs Voltage

Cap Change vs. DC Bias
X7R 1210 4.7uF 50V

-80% -70% -60% -50% -40% -30% -20% -10% 0%
0 10 20 30 40 50
DC Voltage (V)

Cap Change vs. AC Bias
X7R 1210 4.7uF 50V

-10.0% -5.0% 0.0% 5.0% 10.0%
0 0.5 1 1.5 2 2.5 3
Vrms

Cubic crystal (Temp. > Curie)
Tetragonal crystal (Temp. < Curie)

Ba²⁺ O²⁻ Ti⁴⁺
Class 1
Capacitance Stability vs DC and AC Voltage

Capacitance Change vs DC Bias
C0G 3640 220nF 500V

No change with DC voltage

Capacitance Change vs DC Bias
C0G 3640 220nF 500V

No change with AC voltage
Class 2 X7R MLCCs
Capacitance Stability vs Time (Aging)

Solder Process

Nominal Capacitance Tolerance

Reference

8,777 Hr = 1 Yr
87,770 Hr = 10 Yr
Class 1 MLCCs
Capacitance Stability vs Time (Aging)

No change with Time

Percentage Nominal vs Time Post Heat (Hours)
Class 1 vs Class 2 MLCCs

AC Characteristics

Class 2 BaTiO$_3$
Ferroelectric

Ferroelectric dipoles in *domains* align with the AC Field

Domain wall heating

Class 1 CaZrO$_3$
Paraelectric

Paraelectric dipoles align with AC field

No domains, so
No Domain wall heating
Class 1 vs Class 2 MLCCs

Loss Characteristics

**ESR**

Class 2 X7R versus Class 1 C0G/U2J

<table>
<thead>
<tr>
<th>Type</th>
<th>Typical 100kHz ESR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1 C0G/U2J</td>
<td>11.4 mOhms</td>
</tr>
<tr>
<td>Class 2 X7R</td>
<td>650 mOhms</td>
</tr>
</tbody>
</table>

DF Limit @1kHz
- Class 1 C0G: <0.1%
- Class 2 X7R: <3.5%
BME C0G and BME U2J both show high current carrying capability. Temperature rise <14°C up to ripple current of 10 A_{rms}.
C0G 3640 220nF 500V

Electrical Performance

Impedance

- |Z| (Ohms)
- >10MHz

ESR

- ESR (Ohms)
- <4mOhms
C0G 3640 220nF 500V

Ripple Current
Continuous

KC-LINK Ripple Current
Operating Voltage: 0 VDC

KC-LINK Ripple Current
Operating Voltage: 400 VDC

R_{th} = 15°C/W

Frequency (kHz)

Ripple Current (Arms)
KEMET KONNEKT Technology

- KONNEKT™ is a new packaging technology for electronic components patented by KEMET.

- TLPS is reacted metal matrix that forms a metallurgical bond between 2 surfaces, in this case, 2 MLCCs

- KEMET’s initial offer includes KONNEKT™ U2J SMD which offers bulk capacitance with extremely high ripple current capability.
More Cap, Same Footprint!

- Leadless multi-chip solution designed for high-efficiency and high-density power applications.

- KONNEKT™ U2J capacitors enable a low-loss, low-inductance package capable of handling extremely high ripple currents.

- KONNEKT™ enables extended cap ranges with 50V rating suitable for 48V DC-DC power supply applications.
KONNEKT™ U2J: Low-loss benefits

- U2J 1812 1.4uF thermal imaging, top view
- Low-Loss orientation provides benefits over standard orientation
  - Lower ESR
  - Lower Thermal Resistance
  - Lower Inductance

![Diagram showing thermal imaging and power loss comparison between traditional and low power loss orientations]

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Mounting Configuration</th>
<th>Typical ESR at 25°C, 100 kHz</th>
<th>Typical ESL at 25°C</th>
<th>100 kHz</th>
<th>200 kHz</th>
<th>300 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1812</td>
<td>Standard</td>
<td>1.15 mΩ</td>
<td>1.1 nH</td>
<td>12.0</td>
<td>12.0</td>
<td>11.5</td>
</tr>
<tr>
<td>1812</td>
<td>Low Loss</td>
<td>0.77 mΩ</td>
<td>0.45 nH</td>
<td>18.0</td>
<td>18.0</td>
<td>15.0</td>
</tr>
<tr>
<td>1812 1.4 uF</td>
<td>Standard</td>
<td>1.3 mΩ</td>
<td>1.6 nH</td>
<td>11.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>1812 1.4 uF</td>
<td>Low Loss</td>
<td>0.35 mΩ</td>
<td>0.4 nH</td>
<td>20.0</td>
<td>34.0</td>
<td>31.0</td>
</tr>
</tbody>
</table>
KONNEKT™ U2J: Typical Impedance and ESR

1812 940nF 50V

Impedance (Ohms)

- Standard
- Low-Loss

High SRF

1.15 mΩ

0.77 mΩ

1812 1.4μF 50V

Impedance (Ohms)

- Standard
- Low-Loss

High SRF

1.30 mΩ

0.35 mΩ

ESR (mOhms)

1812 940nF 50V

1.00

10.00

100.00

1,000.00

Frequency (kHz)

1 10

100 1,000 10,000 100,000

ESR (mOhms)

1812 1.4μF 50V

1.00

10.00

100.00

1,000.00

Frequency (kHz)

1 10

100 1,000 10,000 100,000

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Ripple current measurements performed at 85°C with a peak capacitor temperature of 95°C.
Samples mounted to heat sink with no forced air cooling. Maximum ambient and self heating cannot exceed 125°C.
Mechanical Robustness

- MLCC & Leadless Stacks of 1812, 0.47µF, 50V are qualified to AEC-Q200 Rev D
- The Modulus of Rupture of C0G and U2J is very high leading to excellent board flexure performance
- No loss of Shear Strength has been detected after long term exposure to harsh environments
- High MOR negates the need for lead frames improving ESR and ESL
KONNEKT for High Power Density

16x4 Array
Total Capacitance: 800nF
Max Current: 240 Arms at 200 kHz
Total Area: 11310 mm² or 17.5 in²

4x4 Array
Total Capacitance: 800nF
Max Current: 240 Arms at 200 kHz
Total Area: 2900 mm² or 4.6 in²
Summary

- Today’s high-power applications require high performance capacitance solutions for improving efficiencies and high power densities.
- Class 1 MLCC dielectrics have excellent loss, inductance, and capacitance stability characteristics making them a prime candidate for snubber, DC-LINK, and resonant applications.
- When combined with KEMET KONNEKT™ these class 1 dielectrics can further increase power densities by increasing capacitance in the same footprint and maximizing current handling capability.