Capacitors in Switching Power Conversion

Wilmer Companioni
Technical Marketing Manager
Who Am I:
Recovering Engineer

BSEE: University of Florida
- 10+ years electronics design experience
  - Motorola
  - Blackberry
  - Freelance/Consulting
- 5+ years in sales/marketing
  - Manufacturer sales rep
  - KEMET last 4 years.

Old picture, back when I was young and pretty.
### Power Conversion Industry Trends:
*Let’s Make Things Harder*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>↓</td>
</tr>
<tr>
<td>Power</td>
<td>↑</td>
</tr>
<tr>
<td>Energy Density</td>
<td>↑</td>
</tr>
<tr>
<td>Frequency</td>
<td>↑</td>
</tr>
<tr>
<td>Temperature</td>
<td>↑</td>
</tr>
<tr>
<td>Voltage</td>
<td>↑</td>
</tr>
<tr>
<td>Cost</td>
<td>↓</td>
</tr>
</tbody>
</table>
Silicon Industry Response: Wide Band Gap Semiconductors

Especially attractive at 1.2+ kV

Cree SiC MOSFET Six-Pack Power Module

Source: P. Friedrichs & M. Buschkuhle, Infineon AG, Energetica India, May/June 2016
Battle of the Materials: 
SiC/GaN vs. Si

• Compared to Si, Wide Band Gap (WBG) IGBT and Power Modules:
  – Are smaller
  – Require less cooling
  – Are more energy efficient

<table>
<thead>
<tr>
<th>Conversion Efficiency</th>
<th>Si Based</th>
<th>WBG Based GaN or SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC to DC</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>AC to DC</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>DC to AC</td>
<td>96%</td>
<td>99%</td>
</tr>
</tbody>
</table>

*Source: Mouser Electronics, L. Culberson, 2016*

• Snubber and DC Link capacitors requirements for AC/DC conversions in high power inverters and converters will be reviewed
Battle of the Materials: 
*PP Film vs. MLCC*

- For DC-Link Capacitors:
  - Lower capacitance required promotes miniaturization due to:
    - Increasing switching frequency
    - Higher voltages

- Lower capacitance is within the range of MLCC.
  - But these need must be:
    - Extremely reliable
    - Over-temperature capable
    - Over-voltage capable
    - High current capable
    - Mechanically robust

- **PRO-TIP:** MLCC for effective switching noise suppression when placed close to WBG where cooling is limited.
WBG Revolution: Effects on The Capacitor

\[ C = \frac{P_{\text{load}}}{U_{\text{ripple}} \left( U_{\text{max}} - \frac{U_{\text{ripple}}}{2} \right) \cdot f_{\text{rectifier}}} \]
Ceramic Capacitors Choices:
Pairing with WBG Semi

<table>
<thead>
<tr>
<th>EIA Types</th>
<th>Dielectric</th>
<th>Class I</th>
<th>Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraelectric</td>
<td>CaZrO$_3$</td>
<td>X7R, X5R</td>
<td>BaTiO$_3$</td>
</tr>
<tr>
<td>Ferroelectric</td>
<td>BaTiO$_3$</td>
<td>C0G, C0H, U2J</td>
<td>C0G, C0H, U2J</td>
</tr>
</tbody>
</table>

*Film caps are great for DC but their temp limitation makes it a difficult choice for WBG*
Leadless Stacks
Packaged MLCC for Higher Capacitance Density

• Meet the need for increased capacitance in a given circuit board space in power applications.
• MLCC terminations are bonded together using Transient Liquid Phase Sintering.
• The Leadless Stacks are surface mounted on a circuit board using the same assembly processes as an MLCC.
What is TLPS?
- Low temperature reaction of low melting point metal or alloy with a high melting point metal or alloy to form a reacted metal matrix or alloy.
- Forms a metallurgical bond between 2 surfaces.
- Has high failure temperatures.
CTE Mismatch Comparison
Leadless Stacks vs. Leaded MLCC

Leadless Stack Mounted on Circuit Board
Small TLPS joint with low CTE mismatch

J-Lead Stack Mounted on Circuit Board
J-lead absorbs mismatch but CTE mismatch must be minimized

Mounting Solder
Circuit Board
Leadless Stacks 3640 0.22µF 500V MLCC

Form Factors & Materials

Circuit Board/Package

Termination

CuSn TLPS

Ni/Thin Au

Solder

0.88µF  0.44µF  0.22µF
U2J MLCC for 48V Power Applications
Leadless Stacks of 1812, 0.47µF, 50V

Minimize Power Dissipation at 300kHz:
- Low ESR \((P = I^2R)\)
- Smaller Circuit Area than MLCC

Low Power Loss Orientation combines low ESR with a smaller circuit area.
Leadless Stacks of 4 X 3640 0.22µF 500V
Stack Orientation; Horizontal vs. Vertical

Vertical Orientation has:
- Lower ESL
- Higher SRF
- Lower ESR
Leadless Packages of 4 X 3640 0.22µF 500V

Ripple Current Heating; Horizontal vs. Vertical

**Horizontal**

Heat dissipation into Cu board.

- **12A_{RMS} @ 140kHz WARMING UP**

**Vertical**

Heat dissipation in Air above.

- **34.9°C**
- **29.2°C**

**Vertical Orientation:**
- More even heating
- Lower Temp. @ Steady State ≈ - 5°C
Leadless Stacks of 3640 0.22μF 500V MLCC
Surface Mounted Performance

- Board Flexure is > 3mm similar to MLCC
- No Failures 0/50 through 1000 cycles -55 to +150°C

19.1MPa failure at 27.9kg > 15 x the 1.8kg minimum AEC Q200