Capacitor Solutions for Resonant Converter Applications

Eduardo Drehmer + Michael Cannon – TDK
Eduardo Drehmer
Director of Marketing
FILM Capacitors
✉️ Eduardo.drehmer@tdk-electronics.tdk.com

Background:
• Over 20 years experience with knowledge on Manufacturing, Quality and Application of Electronic Components.
• Responsible for Technical Marketing for Film Capacitors

Michael Cannon
Product Manager
Ceramic Capacitors
✉️ Michael.cannon@us.tdk.com

Background:
• Product manager at TDK Corporation of America (Lincolnshire, IL) with over 25 years’ experience with passive component applications.
• Contributing member of the Automotive Electronics Council (AEC) and chair of the EIA Ceramic Capacitor subcommittee.
• B.S. in Ceramic Engineering from the University of Illinois.
What’s resonance?

When an oscillating force is applied at a resonant frequency of a dynamical system, the system will oscillate at a higher amplitude than when the same force is applied at other, non-resonant frequencies.

[Halliday, Resnick & Walker 2005]

Good or bad?
Principles

Series RLC Circuit

Parallel RLC Circuit

Either side of resonance the voltage drop = $V_L - V_C$

At resonance the voltage drop equals zero

Either side of resonance the current = $I_L - I_C$

At resonance the reactive current is zero

At resonance $X_T = 0$

short circuit

At resonance $X_T = \alpha$

open circuit
Resonant converters characteristics

Resonant circuits are very sensitive to variations in impedances of their components and of the load they supply.
Applications

[Diagram showing DC and AC circuits]

[Image of a cell tower]

[Image of an Apple Watch and iPhone charging wirelessly]

[Logo of AC/DC band]
Wireless Power Transmission

WPT is a good example of opportunities for resonant coupled converters.
Capacitor Design considerations

Charging profile challenges
  - Variable voltage
  - Variable current
  - Variable frequency
  - Variable temperature

Physical challenges
  - PCB/volume constraints
  - Creepage and clearance requirements

Processing challenges
  - SMD vs. PTH technology
  - Soldering temperature
Capacitor Technologies

Aluminum Electrolytic Capacitors

Ceramic Capacitors

Film Capacitors
Aluminum Electrolytic Capacitor Characteristics
## Film Capacitor Characteristics

<table>
<thead>
<tr>
<th>Simple connection</th>
<th>Film and foil arrangements</th>
<th>Types</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td>MKP</td>
</tr>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td>MKT</td>
</tr>
<tr>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td>MKN</td>
</tr>
<tr>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td>EMI suppression capacitors</td>
</tr>
</tbody>
</table>

### Dielectric

<table>
<thead>
<tr>
<th>Dielectric constant ($\varepsilon_r$)</th>
<th>PP</th>
<th>PET</th>
<th>PEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>C drift with time ($I_x = \Delta C/C$)</td>
<td>%</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C temperature coefficient $\alpha_C$</td>
<td>$10^6K$</td>
<td>-250</td>
<td>+600</td>
</tr>
<tr>
<td>C humidity coefficient $\beta_C$ (50 ... 95%)</td>
<td>$10^6%$ r.h.</td>
<td>40 ... 100</td>
<td>500 ... 700</td>
</tr>
<tr>
<td>Dissipation factor (1 kHz)</td>
<td>0.0005</td>
<td>0.0050</td>
<td>0.0040</td>
</tr>
<tr>
<td>Time constant</td>
<td>s</td>
<td>100 000</td>
<td>25 000</td>
</tr>
<tr>
<td>Dielectric absorption</td>
<td>%</td>
<td>0.05</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Film Capacitor Performance
New Film Materials for improved thermal performance

Semi-crystalline BOPP
- Easy to process into films
- Temperature limitation

Amorphous cyclic olefin copolymer (COC)
- High temperature operation
- Not processable into thin films

Blended film
+ Improved temperature operation
+ Processable into thin films down to 3 µm
Ceramic capacitor construction/material

<table>
<thead>
<tr>
<th>No.</th>
<th>ELEMENTS</th>
<th>MATERIAL</th>
<th>CONVENTIONAL</th>
<th>BME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Class I</td>
<td>Class I</td>
</tr>
<tr>
<td>1</td>
<td>DIELECTRIC</td>
<td>TiO₂</td>
<td></td>
<td>Ca₂ZrO₃</td>
</tr>
<tr>
<td>2</td>
<td>ELECTRODE</td>
<td>Pd</td>
<td></td>
<td>Ni</td>
</tr>
<tr>
<td>3</td>
<td>TERMINATION</td>
<td>Ag or Ag/Pd</td>
<td></td>
<td>Cu</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Sn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Technology comparison: HiCV types
Technology comparison: HiCV capacitors
MLCC for Resonant / C0G

- Small size, High Capacitance
- High Rated Voltage (630Vdc, 1kVdc)
- High Operating Temperature: 125degC (and higher)
- High stability (C, ESR) over temp, frequency, voltage
- AEC-Q200 Compliance

C0G MLCC has better capacitance stability than any other type of capacitors!
MLCC for Resonant / C0G
ex. LLC converter (full bridge type)

LLC converter uses the PFM (pulse frequency modulation) method, which controls the switching frequency while maintaining a fixed pulse width. Therefore, the resonance capacitor requires superior characteristics.

**Little variation in capacitance and tanδ; optimal as a resonance capacitor**
Since LLC converters have a PFM power supply which uses LC resonance, transformers and resonance capacitors are both extremely important components. The following types of characteristics are required in resonance capacitors which are used in the LLC capacitors of onboard chargers.

*Characteristics required in resonance capacitors of LLC converters*

- **Superior temperature characteristics**
  Since the resonance capacitors are used in resonance circuits, it is extremely important that the capacitance change caused by temperature fluctuations is small.

- **Superior withstand voltage characteristics**
  LLC converters are power supplies appropriate for use with relatively high power. However, since larger voltage rectangular waves than those in general electronic devices are applied, high withstand voltage (rated voltage) is required.

- **Superior ESR characteristics**
  Since a large current flows in resonance circuits, superior ESR is required.

In the past, film capacitors were normally used as resonance capacitors in the LLC converters of onboard chargers. This was because film capacitors have a good balance of withstand voltage and relatively high capacitance. However, in recent years, MLCCs have been developed with characteristics that approach the region of film capacitors, and there is an increasing need for a replacement for film capacitors in automotive electronics.
MLCC for Resonant / C0G ex. Wireless power transfer

High-power resonance capacitors are an important component in magnetic resonance using wireless power transfer EV charging systems. This is because a high-accuracy resonance circuit with high withstand voltage is required for quick, efficient wireless transfer of a large amount of power.
Example MLCC combination

C=17.6nF  V=1.65kVrms  I=17Arms

1206/C0G/630V Series  1210/C0G/1kV Series

The 1000V MLCC has a 50% lower ESR than the 630V MLCC. This enables a significant reduction in the number of resonance capacitors necessary.

<table>
<thead>
<tr>
<th>Series</th>
<th>Parallel</th>
<th>Irms / pcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>12</td>
<td>1.42Arms</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>2.13Arms</td>
</tr>
</tbody>
</table>

Enables reduction of mounting area!
## On Board Charger + DC-DC Converter

<table>
<thead>
<tr>
<th>TDK Item</th>
<th>Board Qty</th>
<th>Function</th>
<th>TDK Item</th>
<th>Board Qty</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGA6N1C0G3A822J</td>
<td>36</td>
<td>LLC Resonant</td>
<td>CGA5L1X7R1E106K</td>
<td>120</td>
<td>Output Filter</td>
</tr>
<tr>
<td>CGA6P1C0G3A153J</td>
<td>12</td>
<td>Output Filter</td>
<td>CGA6L4C0G2J153J</td>
<td>20</td>
<td>TBD</td>
</tr>
</tbody>
</table>

**Diagram**

- **On Board Charger**
  - AC 100~240V
  - DC-DC Converter

- **DC-DC Converter**
  - 12V
  - Li Battery (400V)
Resonant Capacitor : C0G Mid Voltage Series

**Appearance**
- Automotive grade
- Based upon AEC-Q200

**Line UP**

<table>
<thead>
<tr>
<th>LW Size (mm)</th>
<th>T.C.</th>
<th>Capacitance Range (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3216 (1206)</td>
<td>C0G</td>
<td>630V 630V 630V 630V 630V</td>
</tr>
<tr>
<td>3225 (1210)</td>
<td>C0G</td>
<td>630V 630V 630V 630V 630V</td>
</tr>
<tr>
<td></td>
<td>C0G</td>
<td>1kV 1kV 1kV 1kV 1kV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LW Size (mm)</th>
<th>Visual</th>
<th>T.C.</th>
<th>Capacitance Range (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAA572</td>
<td>C0G</td>
<td>1kV</td>
<td>630V</td>
</tr>
<tr>
<td>CAA573</td>
<td>C0G</td>
<td>1kV</td>
<td>630V</td>
</tr>
</tbody>
</table>

**Example of use**
- Application: OBC, WPT, DC-DC Converter LLC circuit

**Resonant Capacitor**
- 3216mm 10nF 630V C0G
- 3225mm 22nF 1kV C0G

**In production**
- MLCC 1210-1,000V-22nF 2s10p TDK CGA6P1C0G3A223J
- Sample Ready, MP 2021
Design Considerations

Effects of inhomogeneous impedance and internal resonances

MLCC 1210-1,000V-22nF 2s10p

ESR / Heat value

<table>
<thead>
<tr>
<th>ESR</th>
<th>Heat value</th>
<th>Approx. 60% reduction</th>
<th>ESR</th>
<th>Heat value</th>
</tr>
</thead>
</table>

Effects of inhomogeneous impedance and internal resonances

Standard Power Capacitor

Internal Self-Heating on different frequencies

Winding 1

Winding 2

Current sharing (%)

Bottom winding

Top winding

Frequency [kHz]
Design Considerations

Lifetime characteristic variations

Simulation Tools
Design Considerations

Capacitors for DC-Link circuits

TDK is one of the world’s leading manufacturer of DC-Link capacitors. Explore our comprehensive portfolio by clicking on the application icons below.

On Board Charger for PHEV and BEV

<table>
<thead>
<tr>
<th>Key Characteristics</th>
<th>Aluminum Capacitors</th>
<th>Film Capacitors</th>
<th>MLCC</th>
<th>Caradlink</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>850 V</td>
<td>800 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remark</td>
<td>all values apply for a single element</td>
<td>for all 500 V types (not SP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Operational Temperature (ambient + self heating)</td>
<td>105 °C</td>
<td>125 °C</td>
<td>125 °C</td>
<td>110 °C</td>
</tr>
<tr>
<td></td>
<td>120 °C</td>
<td>135 °C</td>
<td>135 °C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>135 °C</td>
<td>150 °C</td>
<td>150 °C</td>
<td></td>
</tr>
<tr>
<td>Max. Ripple Current Capability, 101 kHz, 85 °C</td>
<td>4.91 A (120 Hz, 85 °C)</td>
<td>3.5 ... 100 A (85 °C, 25 kHz)</td>
<td>2.0 ... 2.5 A</td>
<td>11 ... 47 A</td>
</tr>
<tr>
<td></td>
<td>3.93 A (120 Hz, 85 °C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Design Considerations

Regulatory Approvals and EMI requirements
Thank you