Case Study:

Small size stack capacitors replace Aluminum Electrolytic Capacitors in SMPS

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Outline

- Project Description
- Comparison Aluminum Electrolytic vs. Stacked Ceramics
- Test Description & Results
- Capacitor Selection Rules Given
- Alternate Board Implementation Discussed
- Summary
Project Description

- Look for smaller size, higher reliability capacitors for switchers
- Determine performance of output caps in a switching power supply:
  - Weight
  - Volume
  - Board area
  - Reliability
  - Electrical performance
- Find optimization options

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Aluminum Electrolytic vs. Stacked Ceramics

- Radial Aluminum Electrolytic compared to Stacked Capacitor
- Note: multiple stacked capacitor types now exist
Aluminum Electrolytic vs. Stacked Ceramics

Mechanical:

- Radial Aluminum Electrolytic compared to Stacked Capacitor (in this study)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stacked Ceramic</th>
<th>Radial Electrolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight - grams</td>
<td>4.6</td>
<td>11.5</td>
</tr>
<tr>
<td>Volume - mm³</td>
<td>1463</td>
<td>7600</td>
</tr>
<tr>
<td>Board Area (X-Y) - mm²</td>
<td>217</td>
<td>211</td>
</tr>
<tr>
<td>Height - mm</td>
<td>6.75</td>
<td>36</td>
</tr>
<tr>
<td>Weight/µF - grams/µF</td>
<td>0.098</td>
<td>0.0035</td>
</tr>
<tr>
<td>Volume/µF - mm³/µF</td>
<td>31.13</td>
<td>2.30</td>
</tr>
</tbody>
</table>
Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- Capacitance vs. Temperature vs. Bias

![MLCC - X5R](image1)

![E-Cap](image2)
Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- ESR vs. Temperature

[Graphs showing ESR vs. Temperature for MLCC - X5R and E-Cap]
Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- Stacked MLCC Frequency response
Aluminum Electrolytic vs. Stacked Ceramics

Electrical:
- Stacked MLCC Frequency response

Reliability:
- MIL PRF 49470/1
- MIL PRF 49470/2
- DSCC 87106
- DSCC 88011
## Horizontal Stacked Ceramic Capacitor Reliability

**PRODUCT:** SMPS, 50 & 100V RATED CAPACITORS

**TEST CONDITIONS:** DATA BASED ON 1000 OR 2000 HOURS LIFE TESTING AT 200% RATED VOLTAGE AND 125°C

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Lots Tested</th>
<th>Equivalent Device Hrs.</th>
<th>Failure Rate 1/</th>
<th>Equivalent Device Hrs.</th>
<th>Failure Rate 1/</th>
<th>Failure Rate (FIT’s^2) 2/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Reliability for Stacked SM-style 50V &amp; 100V Rated Capacitors 1/1/2013 - 1/1/2018</td>
<td>98</td>
<td>1.43E+07</td>
<td>0.03</td>
<td>1.14E+11</td>
<td>0.000003</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**MTBF** 2.94E+10

**NOTES:**
1/ FAILURE RATES ARE CALCULATED IN PERCENT PER 1000 HOURS AT 90% CONFIDENCE LEVEL
2/ 1 FIT = 1 FAILURE IN 10 E+9 HOURS AT 90% CONFIDENCE LEVEL (PPM/1000 hours)

Total Acceleration (Accτ) = Temperature Acceleration (Acct) x Voltage Acceleration (AccV)

Where:
- \( V_t = \) Test Voltage
- \( V_u = \) Use Voltage
- \( t_t = \) Test Temp.
- \( t_u = \) Use Temp.

\[
Accτ = \left( \frac{t_u}{t_t} \right)^{3.9} \quad Accτ = 10^{\left( \frac{t_u}{t_t} \right)^{3.9}}
\]
Vertical Stacked Ceramic Capacitor Reliability

PRODUCT: TURBOCAP PRODUCT (ST20 AND ST12) – ALL VOLTAGE RATINGS COMBINED

TEST CONDITIONS: DATA BASED ON LIFE TESTING AT 150% RATED VOLTAGE AND 125°C

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Lots Tested</th>
<th>Equivalent Device Hrs.</th>
<th>Failure Rate 1/</th>
<th>Equivalent Device Hrs.</th>
<th>Failure Rate 1/</th>
<th>Failure Rate (FITs)** 2/</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST20 &amp; ST12 TurboCap Products All voltage ratings combined</td>
<td>52</td>
<td>2.09E+06</td>
<td>0.19</td>
<td>1.68E+10</td>
<td>0.000023</td>
<td>0.23</td>
</tr>
</tbody>
</table>

NOTES:
1/ FAILURE RATES ARE CALCULATED IN PERCENT PER 1000 HOURS AT 90% CONFIDENCE LEVEL
2/ 1 FIT = 1 FAILURE IN 10 E+9 HOURS AT 90% CONFIDENCE LEVEL (PPM/1000 hours)

Total Acceleration (\(Acc_T\)) = Temperature Acceleration (\(Acc_T\)) x Voltage Acceleration (\(Acc_V\))

Where:
\(V_T = \) Test Voltage \(V_u = \) Use Voltage \(t_T = \) Test Temp. \(t_u = \) Use Temp.

\[Acc_V = \left(\frac{V_T}{V_u}\right)^3 \quad Acc_T = 10^{\left(\frac{t_T-t_u}{22}\right)}\]
Test Description & Results

- Obtained closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of lower capacitance value
- Results:

<table>
<thead>
<tr>
<th>Original vs. modified design</th>
<th>Test Case 1: Open Frame Switcher</th>
<th>Test Case 2: Closed Frame miniature switcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original radial electrolytic value</td>
<td>2200</td>
<td>3000</td>
</tr>
<tr>
<td>Stacked MLCC value</td>
<td>200</td>
<td>47</td>
</tr>
<tr>
<td>Supply load (Ohms)</td>
<td>3.3</td>
<td>5</td>
</tr>
</tbody>
</table>

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Test Description & Results

- Obtained closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of much lower capacitance value

Results: closed frame relative comparison trace

2200 µF
47 µF

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Test Description & Results

- Obtained closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of $\sim \frac{1}{10}$ the capacitance value
- Results: commercial grade open frame switcher

![Image of MLCCs and Electrolytic Capacitors]

![Graph comparing Electrolytic vs. Ceramic Output Ripple]

[http://www.avx.com]
General Capacitor Selection Rules

- Aluminum Electrolytic work as evidenced by commercially available switchers
- When smaller sized solutions are needed consider low inductance Stacked MLCCs
- Two options are available within Stacked MLCCs – horizontal & vertical sacked parts:
  - Horizontal have larger cap value & voltages
  - Vertical have lower value, voltages & inductance
- Manufactures simulation software aides in device selection:
  - ESR/Z vs F, Temp Rise vs F, Max current vs. F, max Ripple Voltage vs. F, Phase Angle vs. F

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General Capacitor Selection Rules

Why Stacked Ceramics perform so well in SMPS:

Example A: 100µF

Example B: 24µF

Example C: 3300µF
General Capacitor Selection Rules

Lowered inductance:

Construction:
- Leads
- Paper and Foil Element
- Aluminum Case
- Foil
- Electrolytic Paper
Alternate Board Implementation

- Reduce Stacked cap parallel inductance and maximize series inductance:

**STANDARD CONFIGURATION**

- Vcc (or gnd) pad
- Vcc (or gnd) trace to pad
- Vcc (or gnd) bus trace

**LOW INDUCTANCE CONFIGURATION**

- Power is routed from the PCB trace up the lead frame
- Vcc (or gnd) pad out
- Vcc (or gnd) bus trace
- Vcc (or gnd) pad in

Bus series inductance added
Alternate Board Implementation

- Reduce Stacked cap parallel inductance and maximize series inductance:

  **STANDARD CONFIGURATION**
  - Vcc (or gnd) bus trace
  - Vcc (or gnd) trace to pad
  - Standard SMO
  - Vcc (or gnd) trace to pad
  - Vcc (or gnd) bus trace

  **LOW INDUCTANCE CONFIGURATION**
  - Lead frame & discontinuity inductance
  - Vcc (or gnd) bus trace
  - SMO capacitance
  - Vcc (or gnd) bus trace
  - Lead frame & discontinuity inductance
  - Vcc (or gnd) bus trace
Alternate Board Implementation
Summary

➤ Mechanical & Electrical comparisons made:
  - Aluminum Electrolytic has higher cap density but unstable across temp & frequency
  - Stacked MLCCs available in vertical or horizontal configuration
  - Stacked Caps – low ESR, capacitance stability depends upon dielectric

➤ Depending upon the switcher – smaller capacitance stacked MLCCs can effectively replace larger value Electrolytic Capacitor. Physical advantages captured.

➤ Mounting of stacked capacitors effects capacitors frequency response

➤ Next steps are to create a custom switcher where optimized stacked implementation can be achieved