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
ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

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

Vertical Stacks

Horizontal Stacks
# 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 - cubic mm</td>
<td>1463</td>
<td>7600</td>
</tr>
<tr>
<td>Board Area (X-Y) – square mm</td>
<td>217</td>
<td>211</td>
</tr>
<tr>
<td>Height - mm</td>
<td>6.75</td>
<td>36</td>
</tr>
<tr>
<td>Weight/uf - grams/uf</td>
<td>0.098</td>
<td>0.0035</td>
</tr>
<tr>
<td>Volume/uf - cubic mm/uf</td>
<td>31.13</td>
<td>2.30</td>
</tr>
</tbody>
</table>
ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Electrical:
• Capacitance vs. Temperature vs. Bias
ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

**Electrical:**
- ESR vs. Temperature

![Graph 1: MLCC - X5R](image1.png)

![Graph 2: E-Cap](image2.png)
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

<table>
<thead>
<tr>
<th>Typical ESR Performance (mΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Electrolytic 100μF/50V</td>
</tr>
<tr>
<td>ESR @ 10KHz</td>
</tr>
<tr>
<td>ESR @ 50KHz</td>
</tr>
<tr>
<td>ESR @ 100KHz</td>
</tr>
<tr>
<td>ESR @ 500KHz</td>
</tr>
<tr>
<td>ESR @ 1MHz</td>
</tr>
<tr>
<td>ESR @ 5MHz</td>
</tr>
<tr>
<td>ESR @ 10MHz</td>
</tr>
</tbody>
</table>
## 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 (FITs**) 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>

**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 ($Acc_r$) = 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.

$$Acc_r = \left( \frac{t_t}{t_u} \right)^3 \quad Acc_t = 10^{(\frac{t_t}{20})}$$
**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>

| MTBF         | 4.31E+09    |

**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.

\[
Acc_T = \left( \frac{t_T}{t_U} \right)^3 \quad Acc_V = 10^{\left( \frac{V_T}{57} \right)}
\]
• 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>
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

2200uf
47 uf
TEST DESCRIPTION & RESULTS

- Obtained Closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of ~ 1/10 the capacitance value

Results: commercial grade open frame switcher
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 and 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
GENERAL CAPACITOR SELECTION RULES

Why stacked ceramics perform so well in SMPS:

Example A: 100uf

Example B: 24uf

Example C: 3300uf
GENERAL CAPACITOR SELECTION RULES

Lowered Inductance:

Construction:
- Leads
- Paper and Foil Element
- Aluminum Case
- Foil
- Electrolytic Paper
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
Reduce Stacked cap parallel inductance and maximize series inductance:

**ALTERNATE BOARD IMPLEMENTATION:**
ALTERNATE BOARD IMPLEMENTATION:

- **Impedance and ESR vs Frequency**
  - SM04CC305 Standard vs. Low Inductance Design

- **Graph Details**
  - Impedance - Low ESL
  - ESR @ Self-Resonance = 5.10 mΩ
  - Self-Inductance = 1.54 nH
  - Capacitance = 3.10 µF

- **Impedance - Standard Design**
  - Self-Resonant Frequency = 1.7 MHz
  - ESR @ Self-Resonance = 7.66 mΩ
  - Self-Inductance = 2.83 nH
  - Capacitance = 3.1 µF
SUMMARY:

• Mechanical & Electrical comparisons made:
  o AlEl has higher cap density but unstable across temp & frequency
  o Stacked MLCCs available in vertical or horizontal configuration
  o 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 & Electrical 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