Case Study:

Small size stack capacitors replace Aluminum Electrolytic Capacitors in SMPS

AVX Corporation

One AVX Blvd

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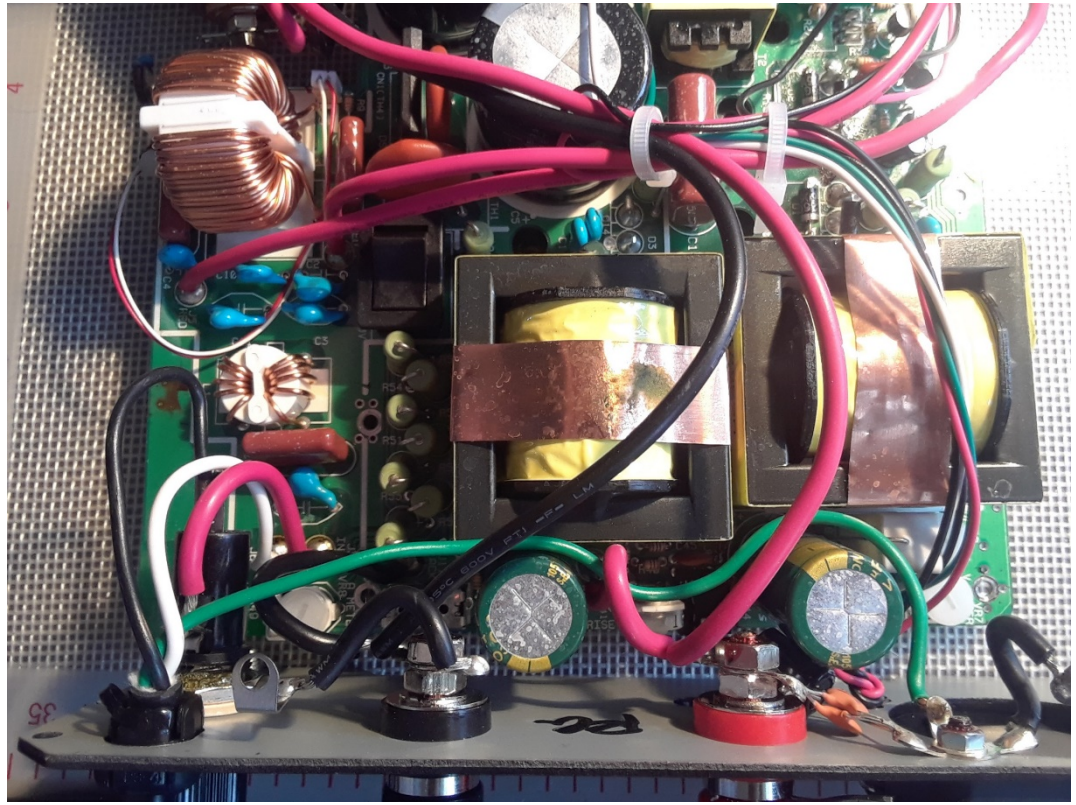
Outline

- 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

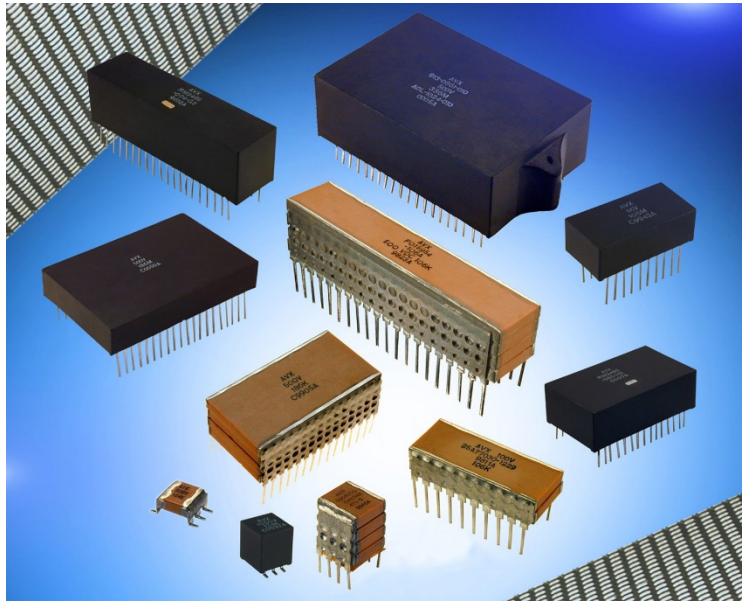


Aluminum Electrolytic vs. Stacked Ceramics

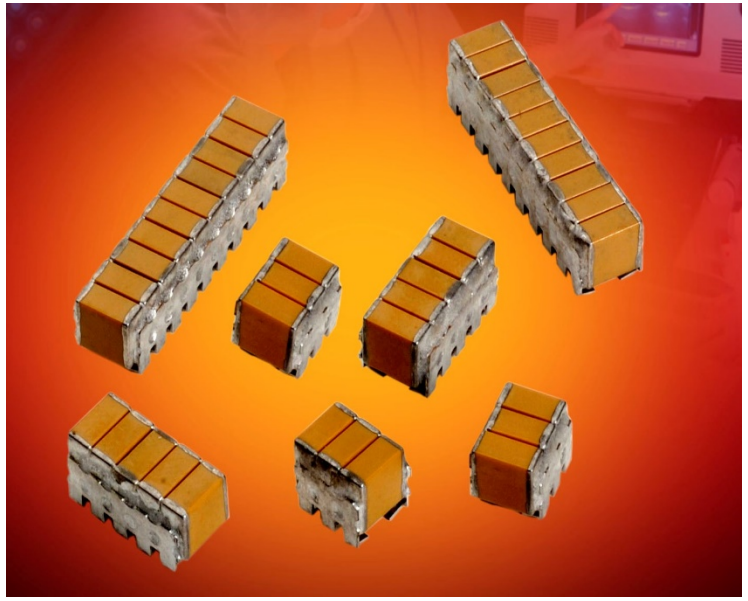
- Radial Aluminum Electrolytic compared to Stacked Capacitor
- Note: multiple stacked capacitor types now exist

Al Electrolytic

Horizontal Stacks



Vertical Stacks



Aluminum Electrolytic vs. Stacked Ceramics

Mechanical:

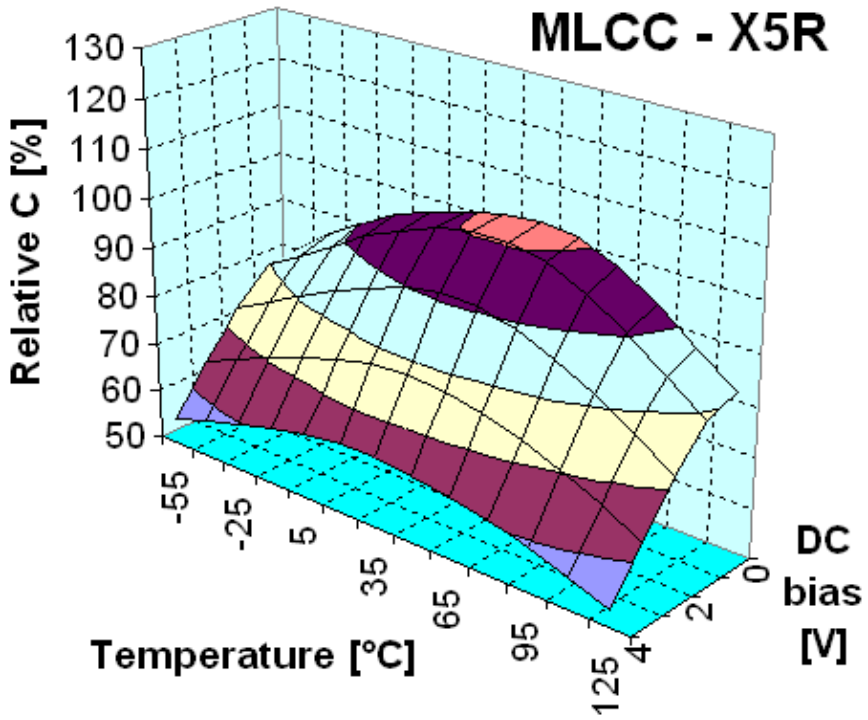
- Radial Aluminum Electrolytic compared to Stacked Capacitor (in this study)

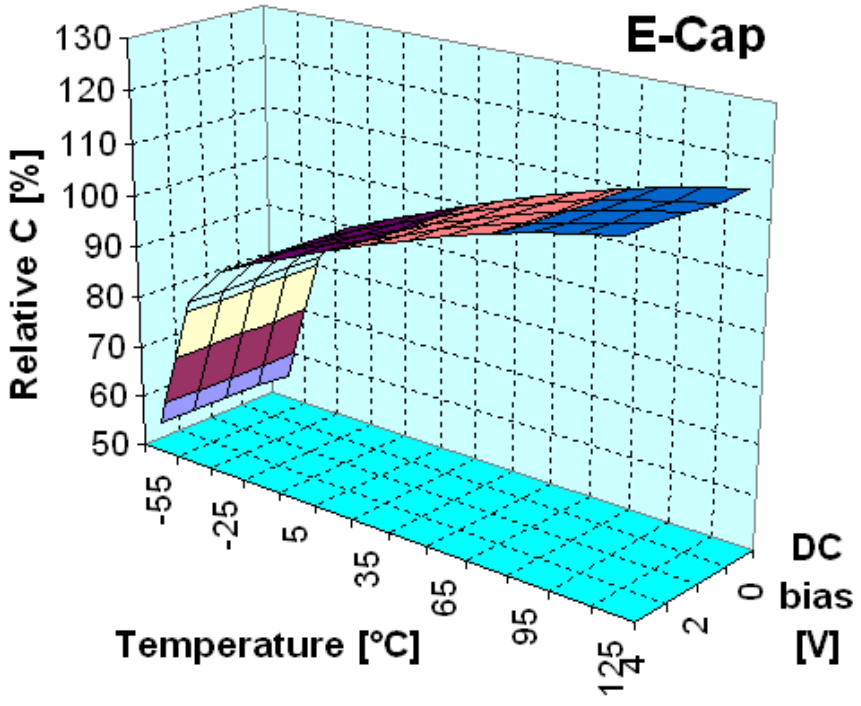
Parameter	Stacked Ceramic	Radial Electrolytic
Weight - grams	4.6	11.5
Volume - mm^3	1463	7600
Board Area (X-Y) - mm^2	217	211
Height - mm	6.75	36
Weight/µF - grams/µF	0.098	0.0035
Volume/µF - mm^3/µF	31.13	2.30

Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- Capacitance vs. Temperature vs. Bias

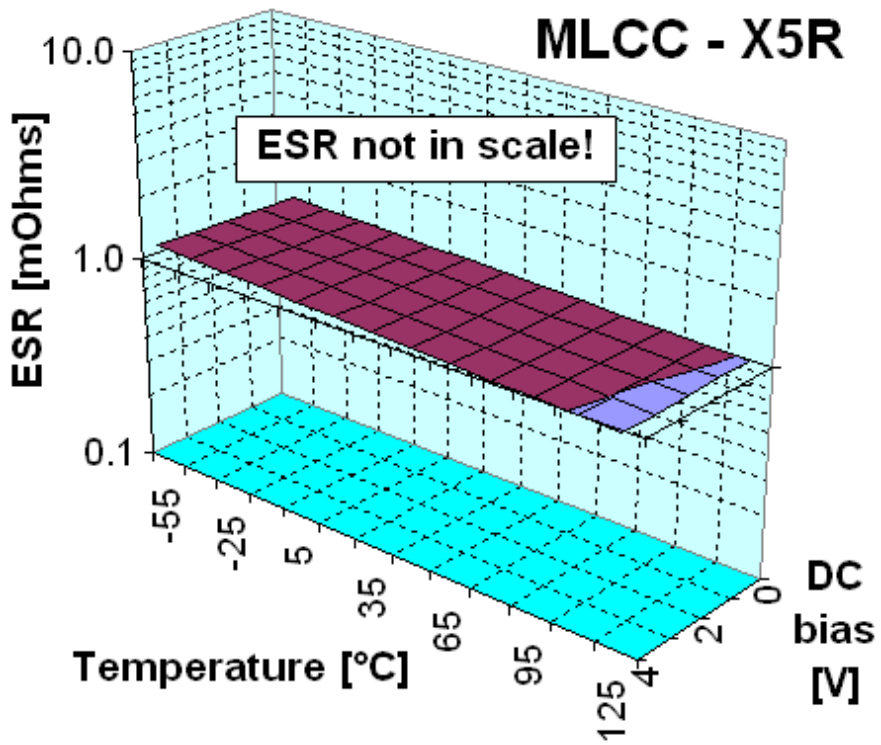


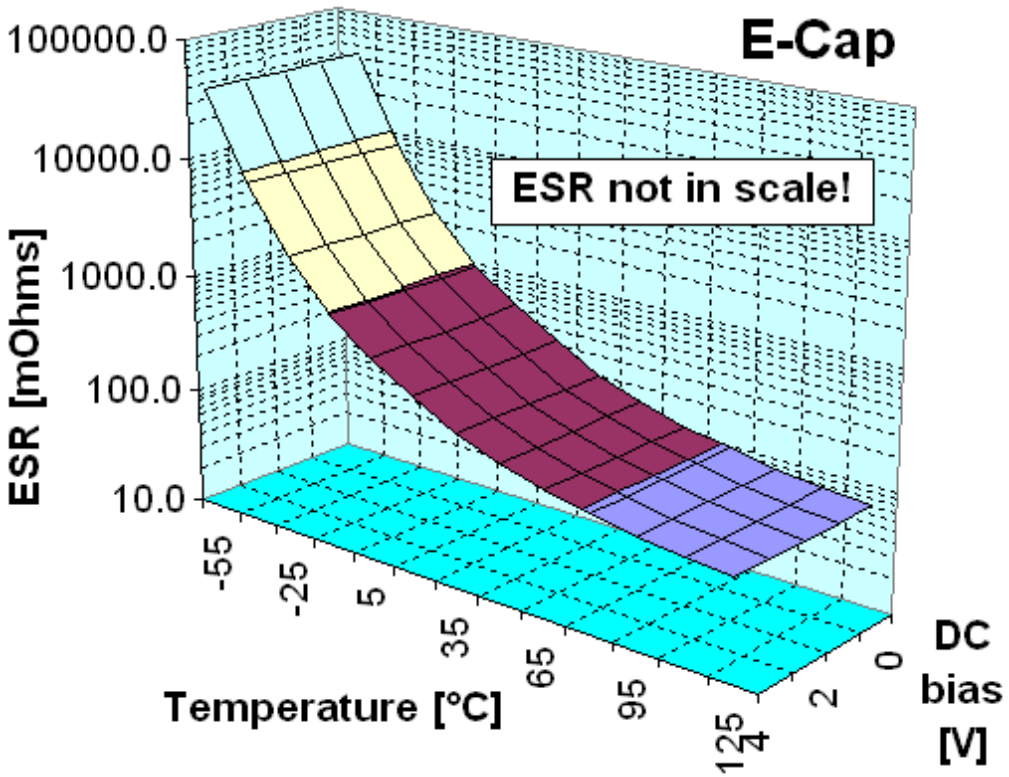


Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- ESR vs. Temperature

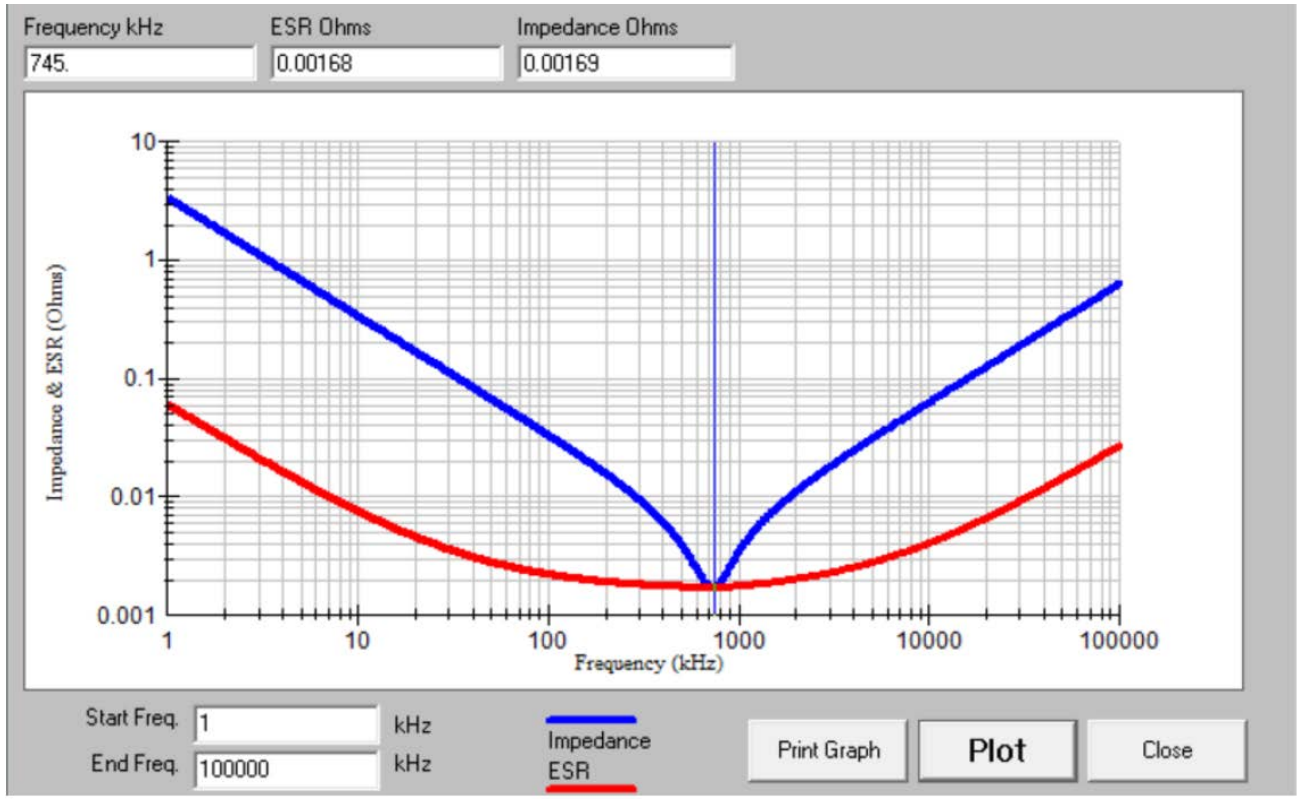




Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- Stacked MLCC Frequency response



Aluminum Electrolytic vs. Stacked Ceramics

Electrical:

- Stacked MLCC Frequency response

Typical ESR Performance (mΩ)

	Aluminum Electrolytic 100µF/50V	Low ESR Solid Tantalum 100µF/10V	Solid Aluminum Electrolytic 100µF/16V	MLCC SMPS 100µF/50V	MLCC SMPS 4.7µF/50V
ESR @ 10KHz	300	72	29	3	66
ESR @ 50KHz	285	67	22	2	23
ESR @ 100KHz	280	62	20	2.5	15
ESR @ 500KHz	265	56	18	4	8
ESR @ 1MHz	265	56	17	7	7.5
ESR @ 5MHz	335	72	17	12.5	8
ESR @ 10MHz	560	91	22	20	14

- 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 125ºC

		Max. Rated Voltage & Temperature (100% rated voltage, 125ºC)		Non-Standard Conditions (50% rated voltage, 50ºC)		
Product Type	**Lots Tested**	**Equivalent Device Hrs.**	**Failure Rate 1/**	**Equivalent Device Hrs.**	**Failure Rate 1/**	**Failure Rate (FITS**) 2/**
Product Reliability for Stacked SM-style 50V &100V Rated Capacitors 1/1/2013 - 1/1/2018	98	1.43E+07	0.03	1.14E+11	0.000003	0.03

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 (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.

$$Acc_V = \left(\frac{V_t}{V_u}\right)^3 \qquad Acc_t = 10^{\left(\frac{t_t - t_u}{25}\right)}$$

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 125ºC

		Max. Rated V &T (100% rated voltage, 125ºC)		Non-Standard Conditions (50% rated voltage, 50ºC)		
Product Type	**Lots Tested**	**Equivalent Device Hrs.**	**Failure Rate 1/**	**Equivalent Device Hrs.**	**Failure Rate 1/**	**Failure Rate (FITS**) 2/**
ST20 & ST12 TurboCap Products All voltage ratings combined	52	2.09E+06	0.19	1.68E+10	0.000023	0.23

MTBF	4.31E+09

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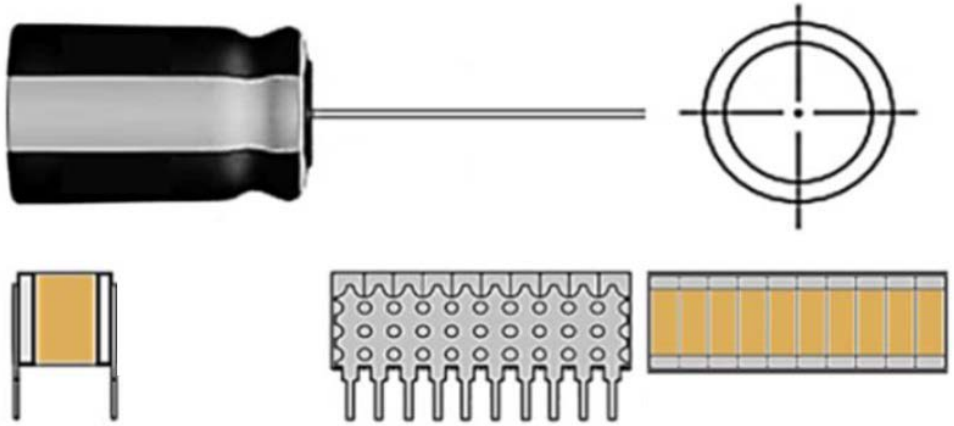
Test Description & Results

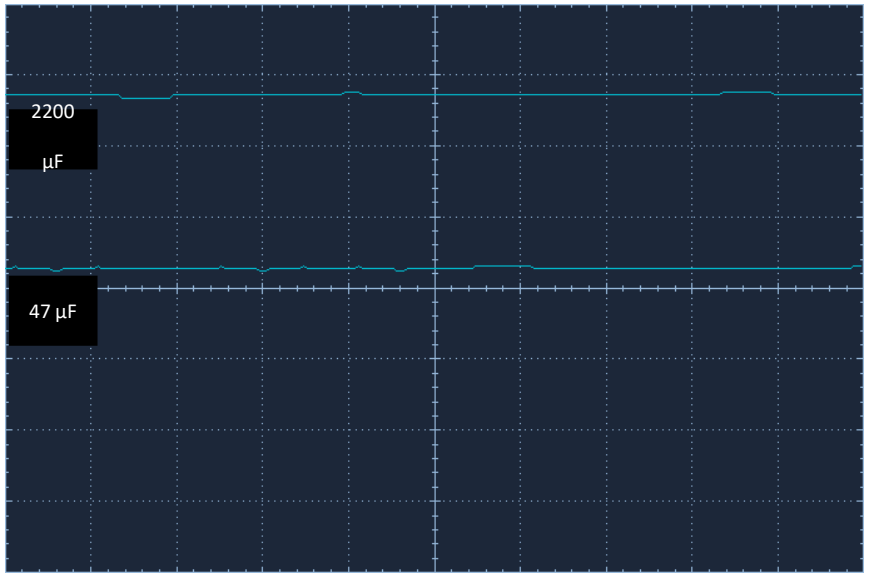
- Obtained closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of lower capacitance value
- Results:

Original vs. modified design	Test Case 1: Open Frame Switcher	Test Case 2: Closed Frame miniature switcher
Original radial electrolytic value	2200	3000
Stacked MLCC value	200	47
Supply load (Ohms)	3.3	5

Test Description & Results

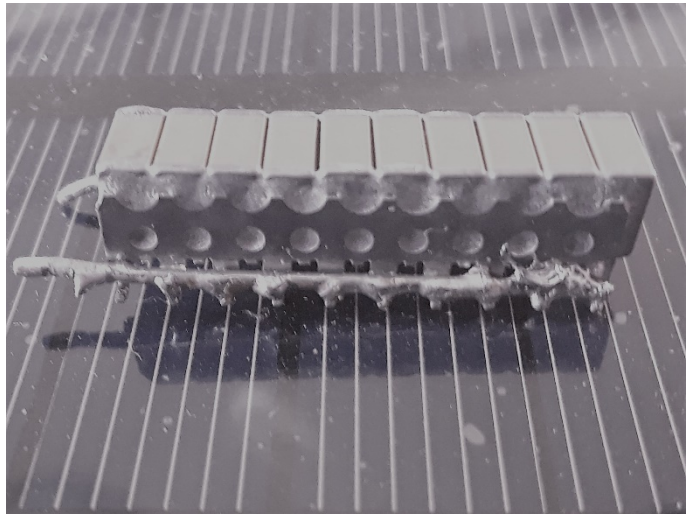
- Obtained closed frame and open frame switchers
- Measure ripple with original radial Electrolytic and replace with Stacked MLCCs of much lower capacitance value
- Results: closed frame relative comparison trace

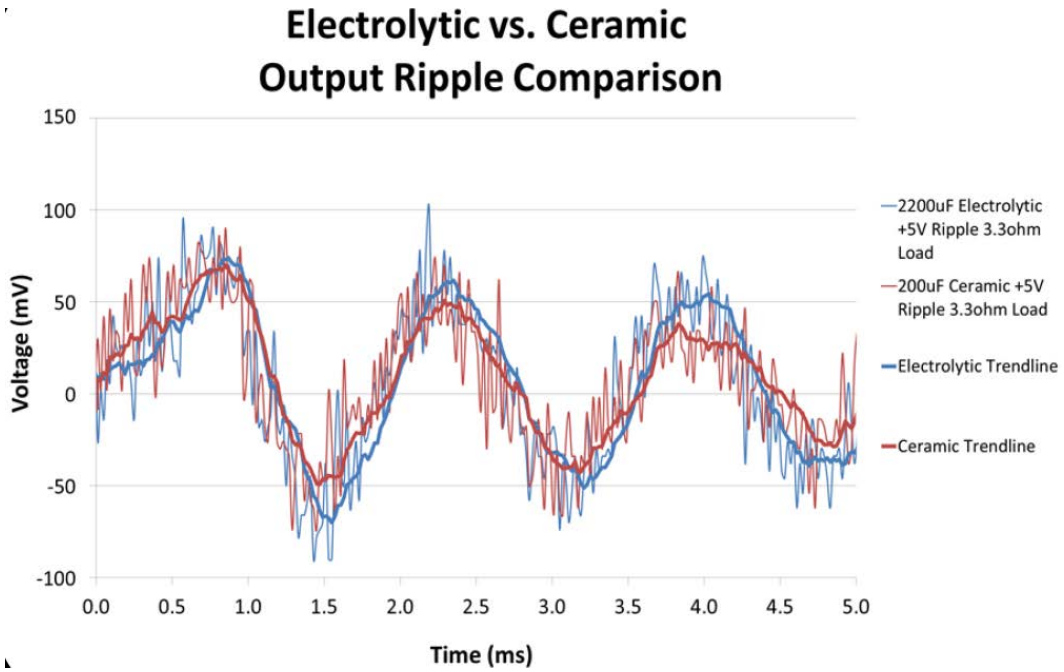




Test Description & Results

- 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





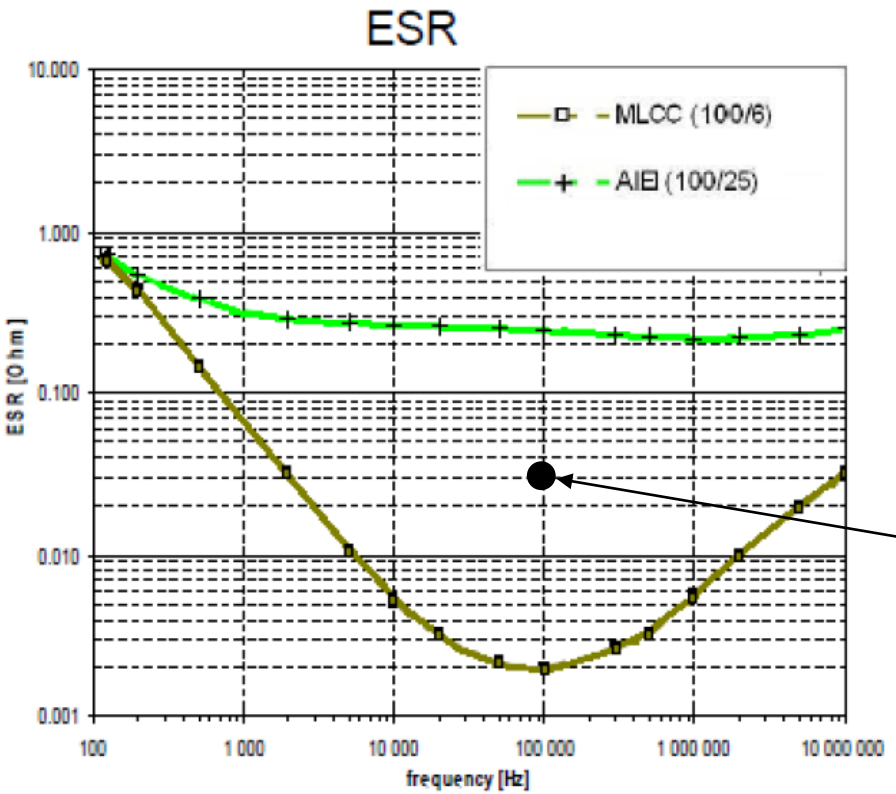
General Capacitor Selection Rules

- 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

General Capacitor Selection Rules

Why Stacked Ceramics perform so well in SMPS:

Example A: 100µF



Example C: 3300µF

Example B: 24µF

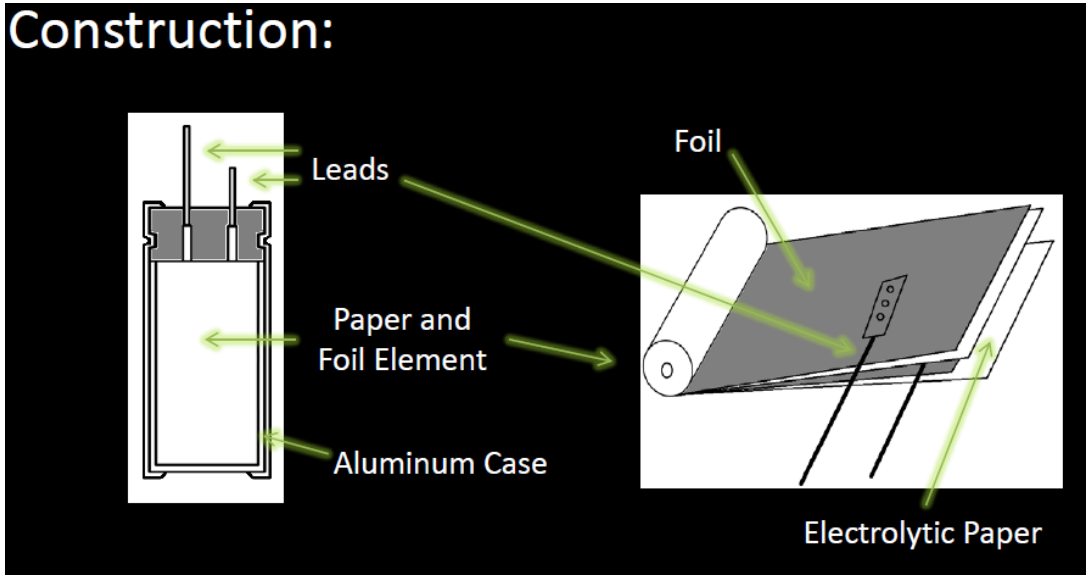
Typical ESR (mΩ)

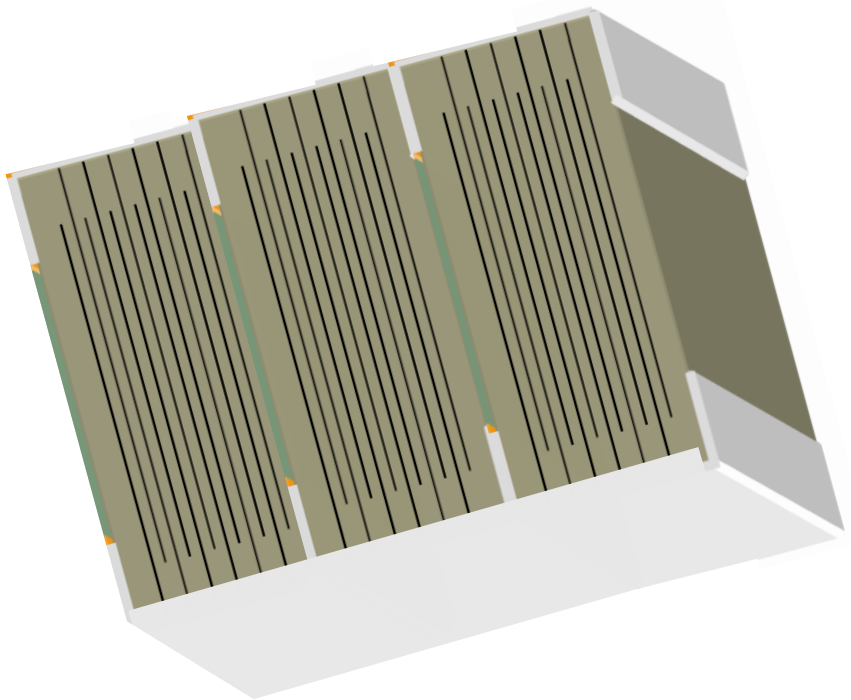
24 µF Performance

	Aluminum Electrolytic	Tantalum	MLC
ESR @ 50KHz	2,100	140	1
ESR @ 100KHz	2,000	125	1
ESR @ 500KHz	1,600	105	2.5
ESR @ 1MHz	1,500	105	5
ESR @ 5MHz	1,200	140	10
ESR @ 10MHz	1,700	190	14

General Capacitor Selection Rules

Lowered inductance:

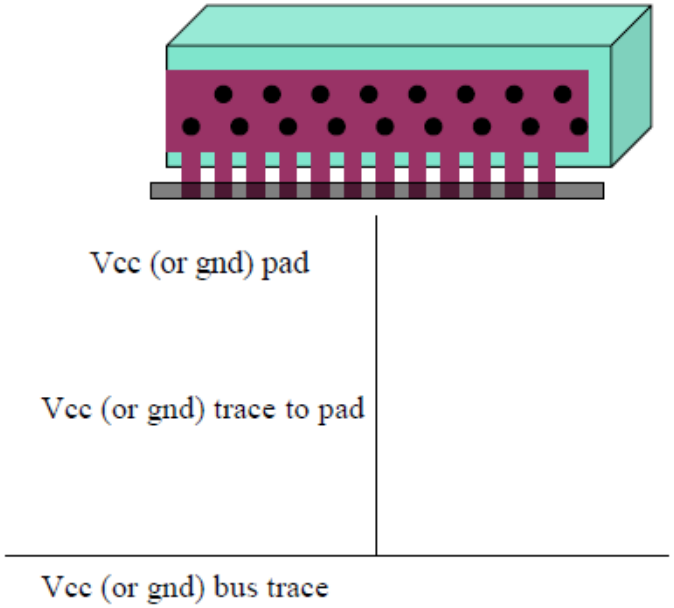




Alternate Board Implementation

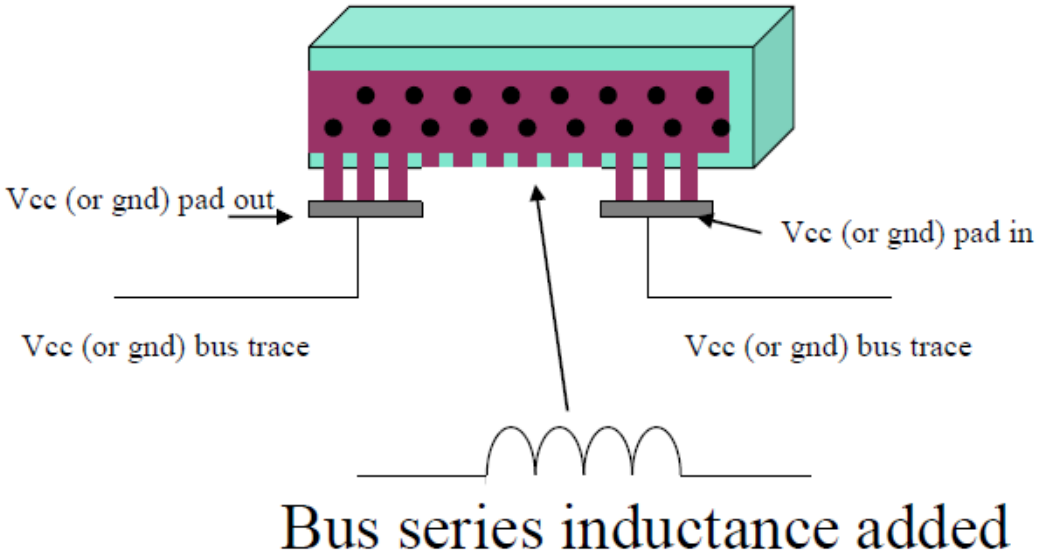
- Reduce Stacked cap parallel inductance and maximize series inductance:

STANDARD CONFIGURATION



LOW INDUCTANCE CONFIGURATION

Power is routed from the PCB trace up the lead frame



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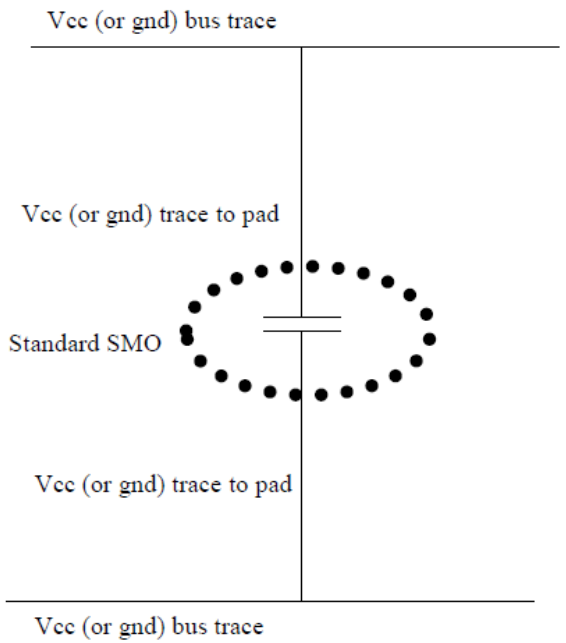

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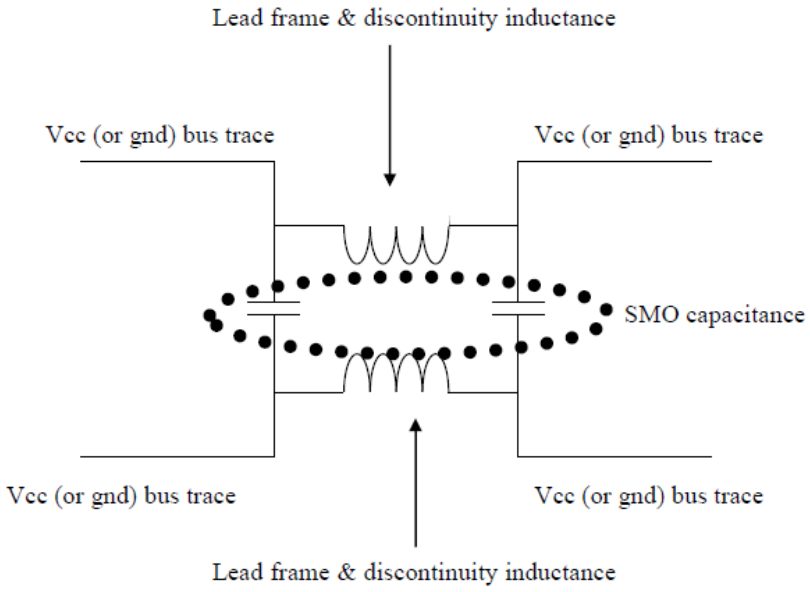

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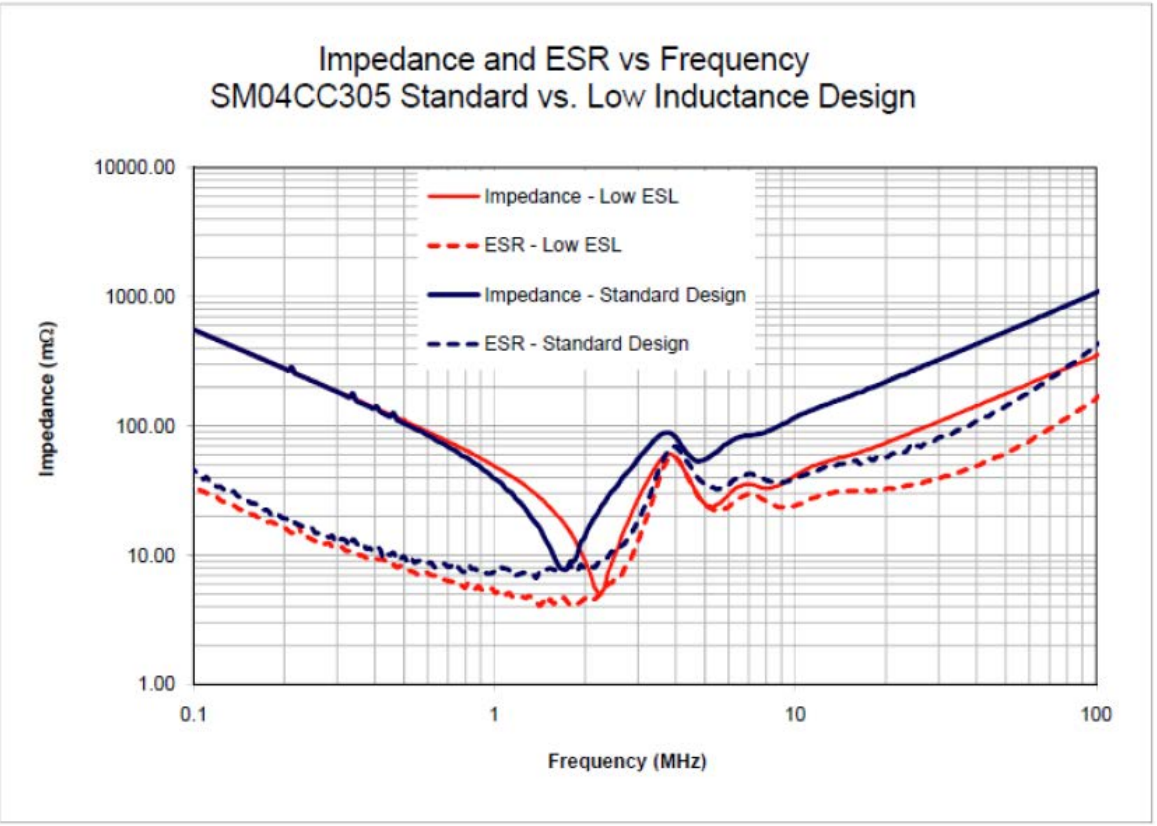

Self-Resonant Frequency = 2.3 MHz
ESR @ Self-Resonance = 5.10 mΩ
Self-Inductance = 1.54 nH
Capacitance = 3.10 µF

Self-Resonant Frequncy =1.7 MHz
ESR @ Self-Resonance = 7.66 mΩ
Self-Inductance = 2.83 nH
Capacitance = 3.1 µF

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