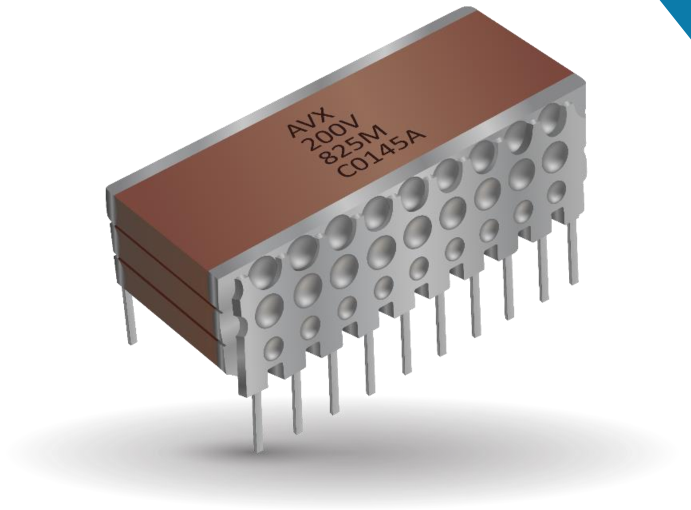
CASE STUDY:

SMALL SIZE STACK CAPACITORS REPLACE ALUMINUM ELECTROLYTIC CAPACITORS IN SMPS



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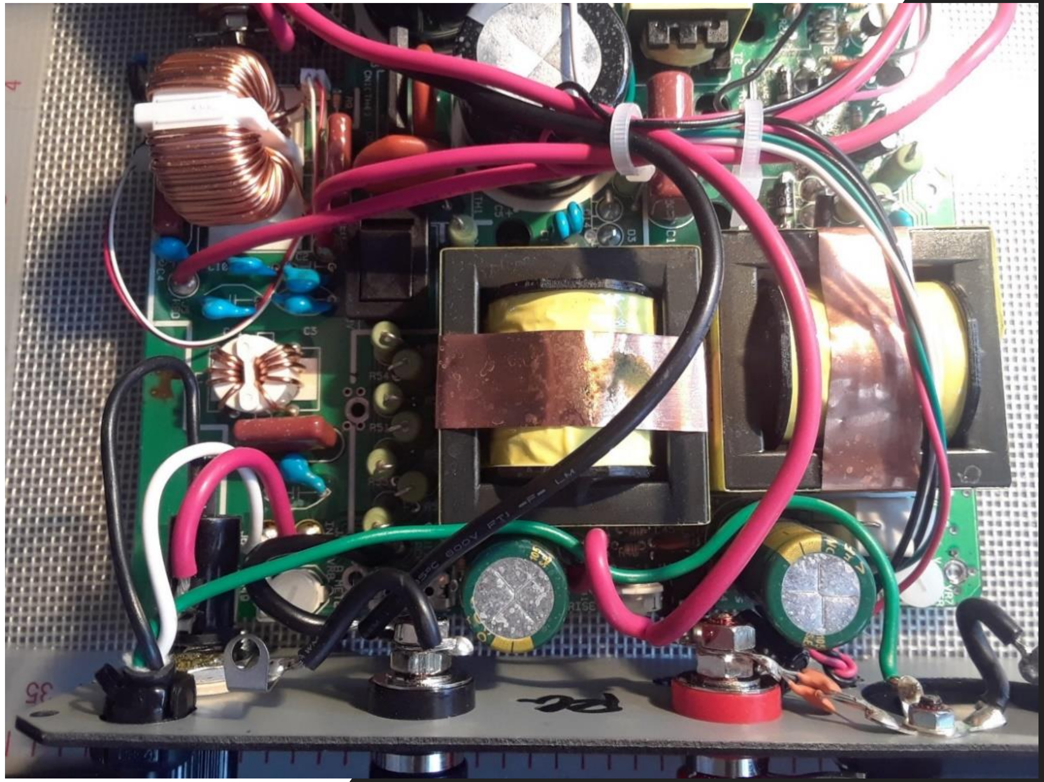
OUTLINE:

- Project description
- Comparison Aluminum Electrolytic vs. Stacked Ceramics
- Test description & results
- Capacitor selection rules given
- Alternate board implementation discussed
- Summary

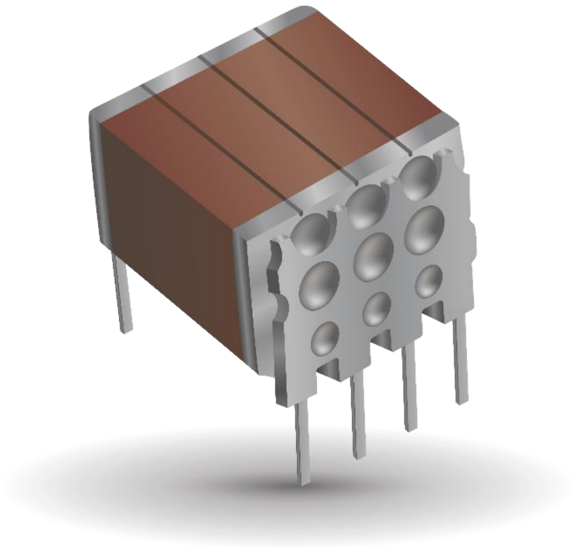
PROJECT DESCRIPTION:

- 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

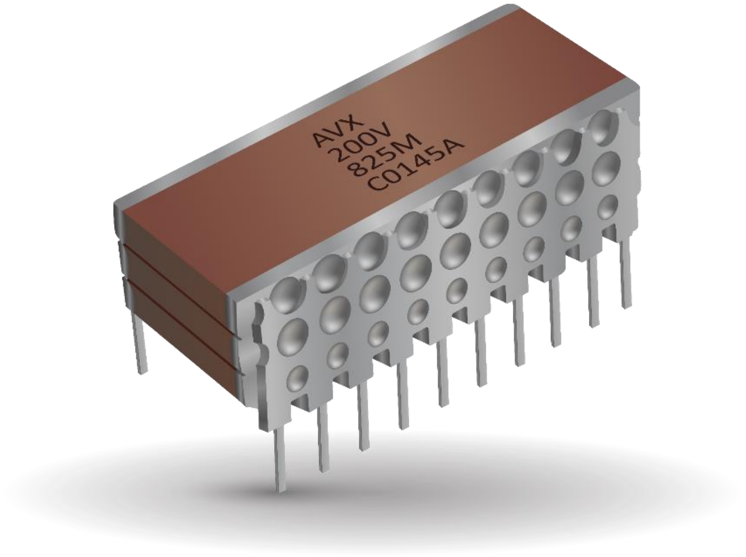


ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

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



Vertical Stacks



Horizontal Stacks

ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Mechanical:

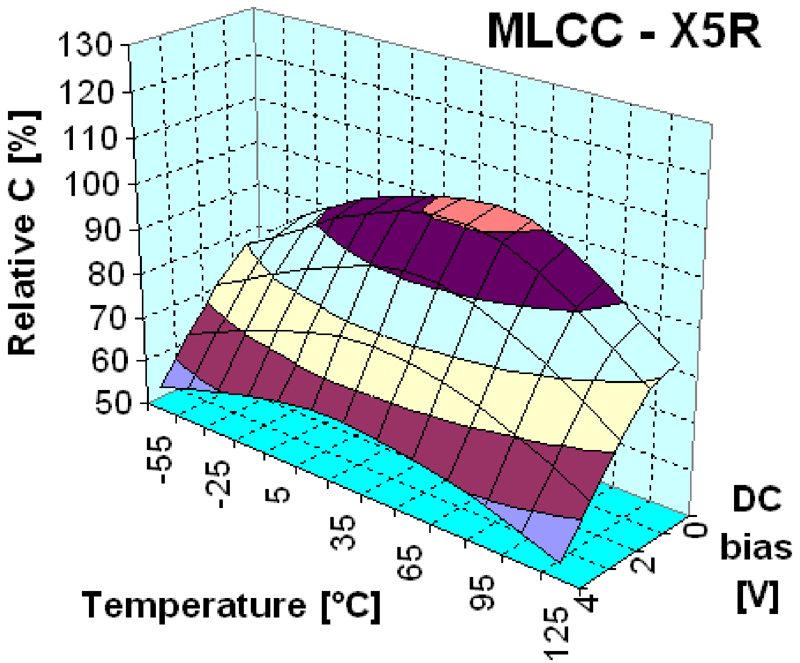
- Radial Aluminum Electrolytic compared to Stacked Capacitor (in this study)

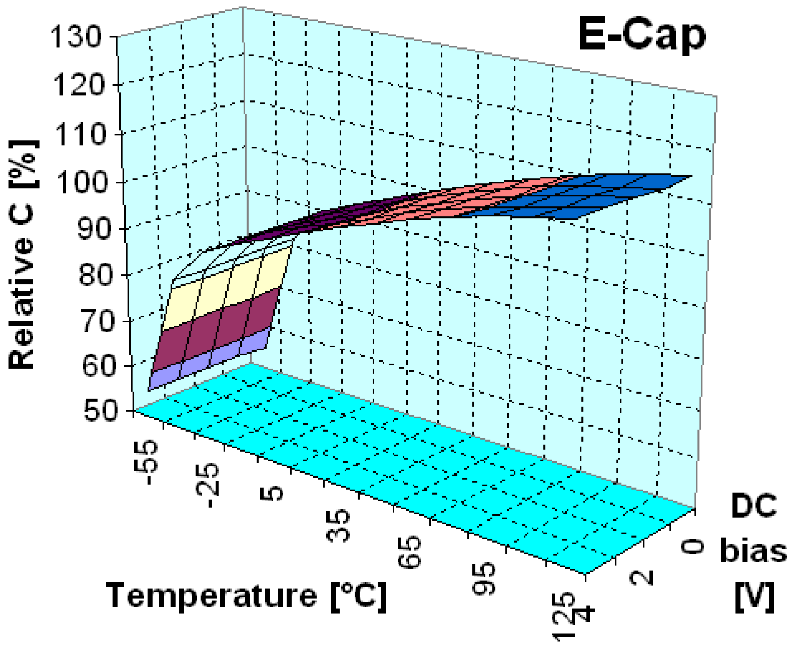
PARAMETER	STACKED CERAMIC	RADIAL ELECTROLYTIC
Weight - grams	4.6	11.5
Volume - cubic mm	1463	7600
Board Area (X-Y) – square mm	217	211
Height - mm	6.75	36
Weight/uf - grams/uf	0.098	0.0035
Volume/uf - cubic mm/uf	31.13	2.30

ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Electrical:

- Capacitance vs. Temperature vs. Bias

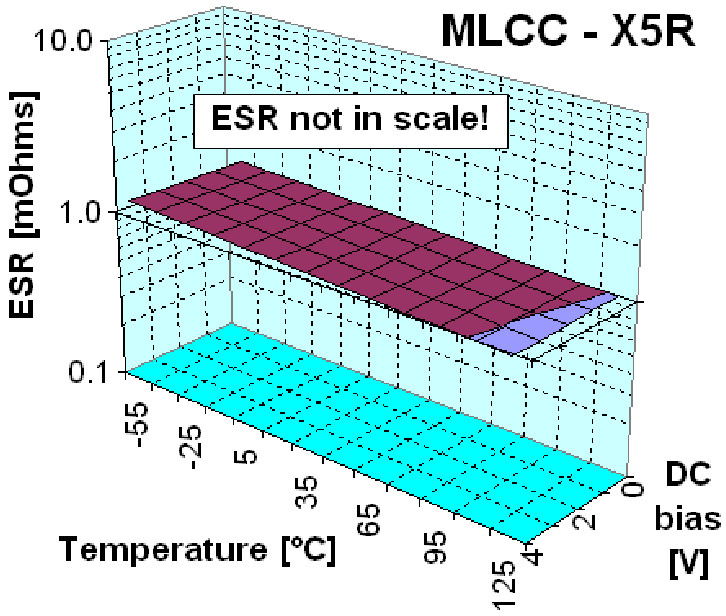


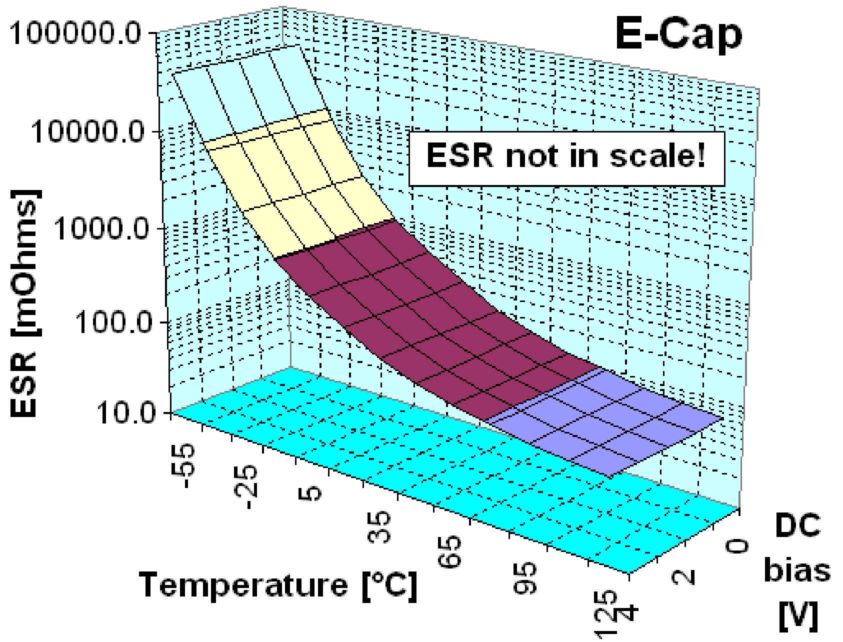


ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Electrical:

- ESR vs. Temperature

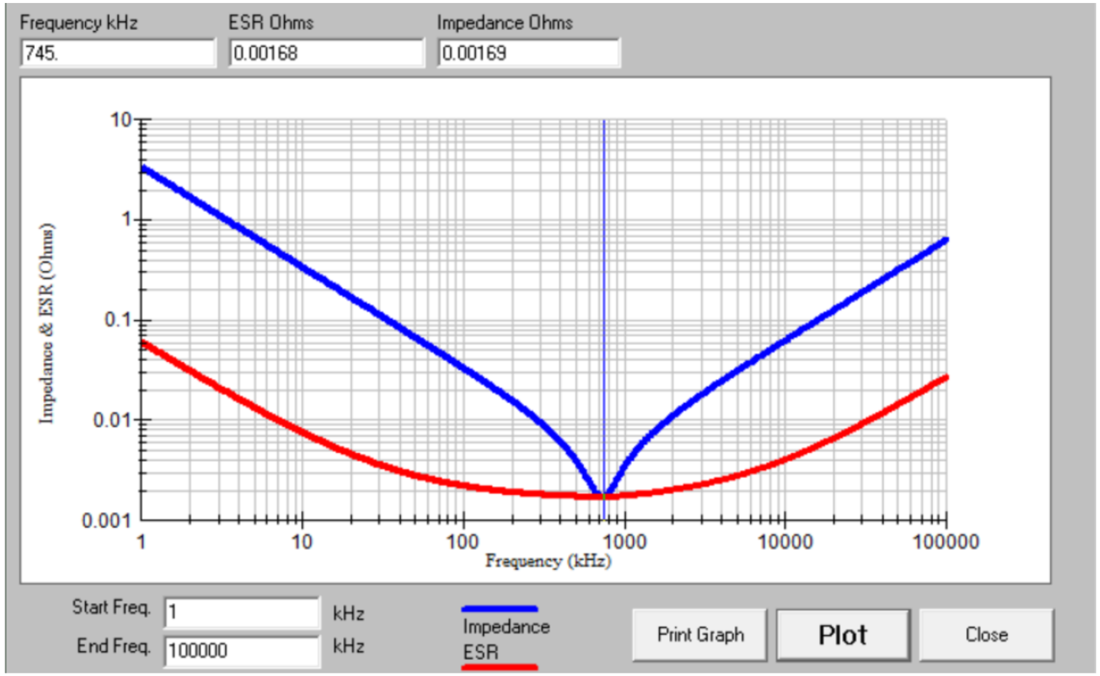




ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Electrical:

- Stacked MLCC Frequency response



ALUMINUM ELECTROLYTIC VS. STACKED CERAMICS

Electrical:

- Stacked MLCC Frequency response

Reliability:

- MIL PRF 49470/1
- MIL PRF 49470/2
- DSCC 87106
- DSCC 88011

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

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.

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

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

Product Type	Lots Tested	Max. Rated V &T (100% rated voltage, 125ºC) Equivalent Device Hrs.	Max. Rated V &T (100% rated voltage, 125ºC) Failure Rate 1/	Non-Standard Conditions (50% rated voltage, 50ºC) Equivalent Device Hrs.	Non-Standard Conditions (50% rated voltage, 50ºC) 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

NOTES:

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

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

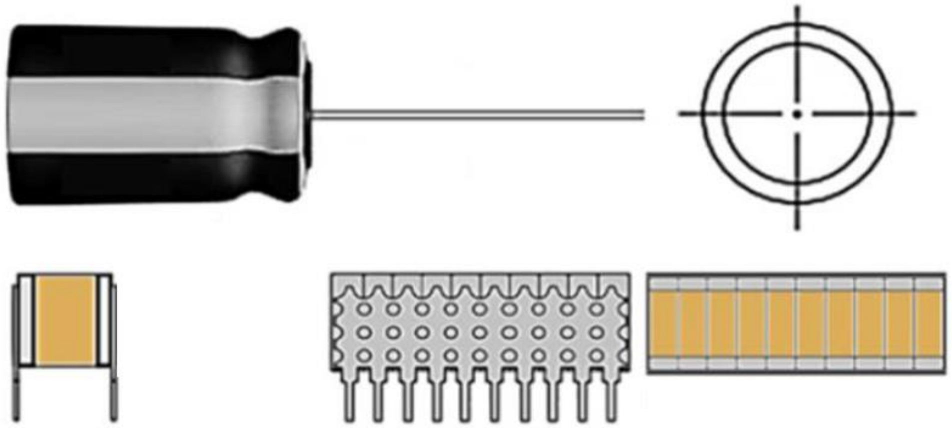
Results:

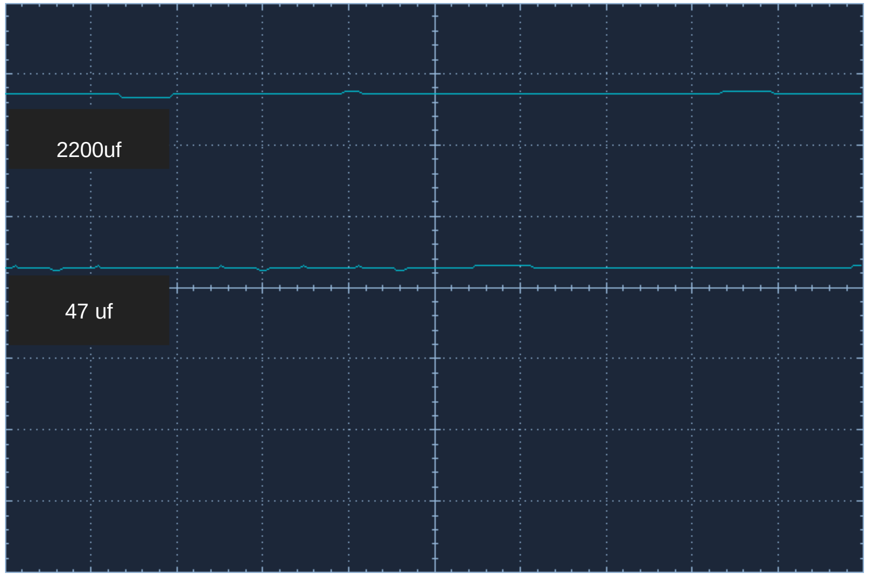
ORIGINAL VS. MODIFIED DESIGN	TEST CASE 1: OPEN FRAME SWITCHER	TEST CASE 2: CLOSED FRAME MINIATURE SWITCHER
Original radial electrolytic value	2200	3000
Stacked MLCC value	200	47
Supply load (ohms)	3.3	5

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

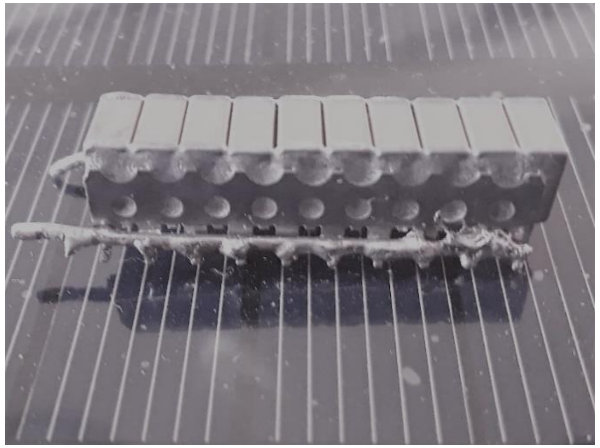


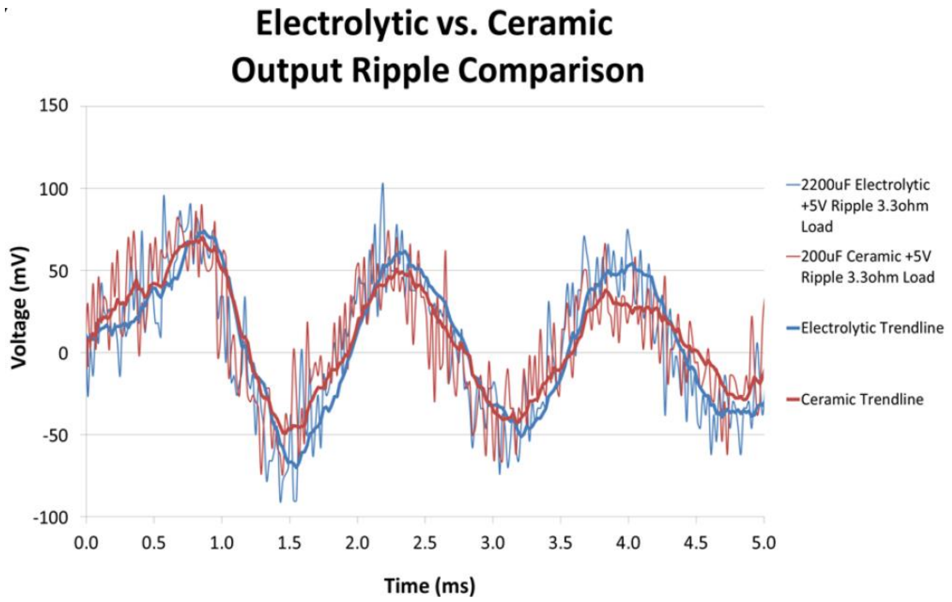


TEST DESCRIPTION & RESULTS

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

Results: commercial grade open frame switcher





GENERAL CAPACITOR SELECTION RULES

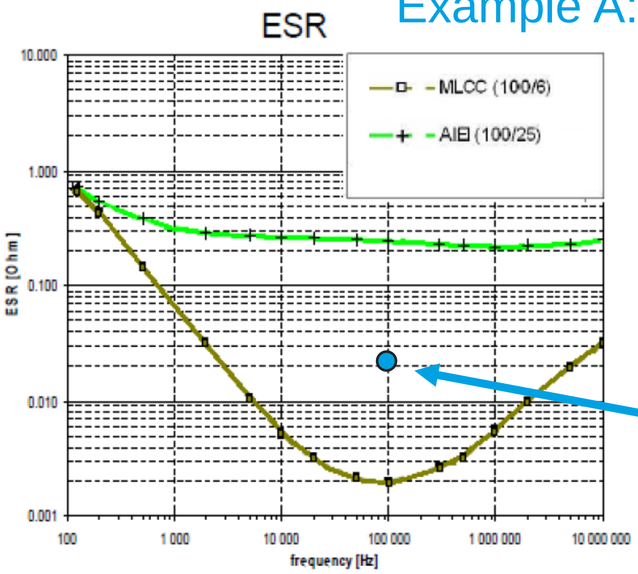
- Aluminum Electrolytic work as evidenced by commercially available switchers
- When smaller sized solutions are needed consider low inductance stacked MLCCs
- Two options are available within Stacked MLCCs – horizontal & vertical sacked parts:
  - Horizontal have larger cap value & voltages
  - Vertical 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 C: 3300uf

Example B: 24uf

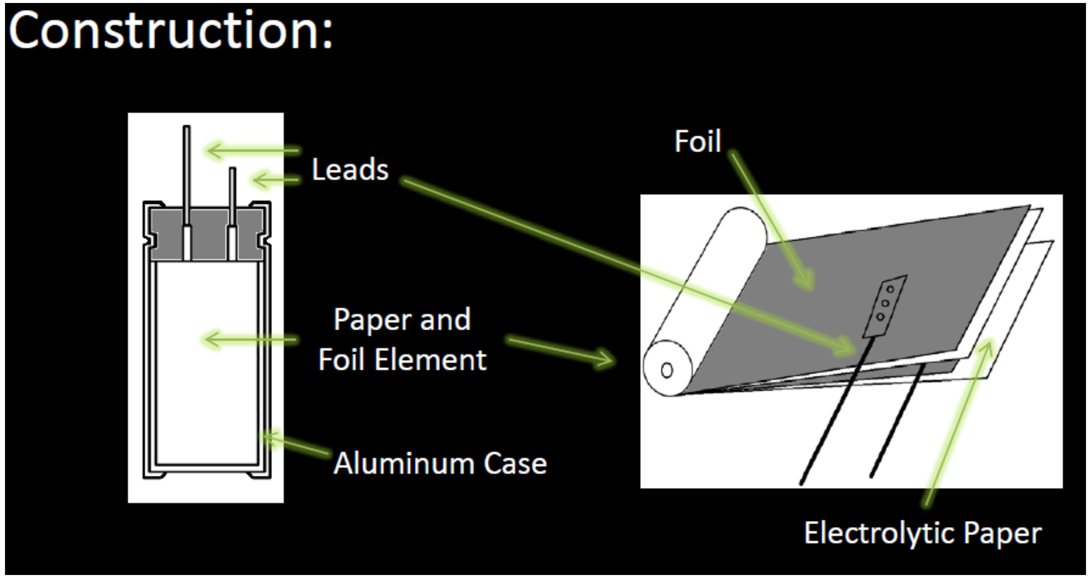
Typical ESR (mΩ)

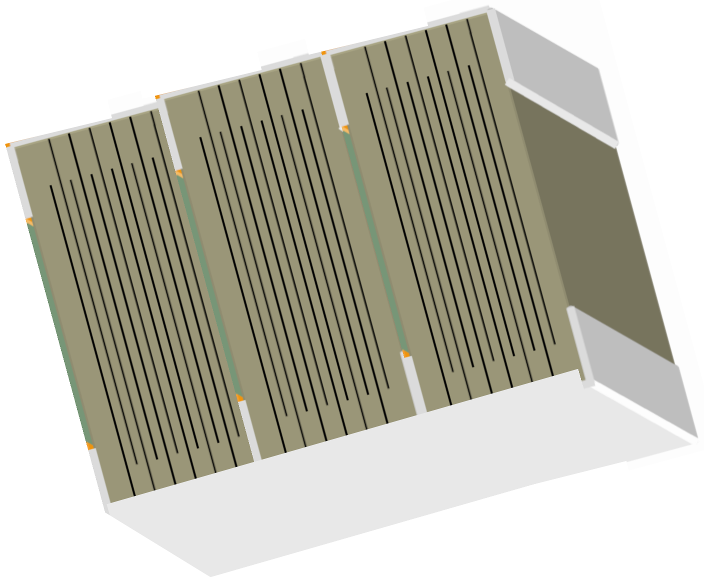
24 µF Performance

	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:

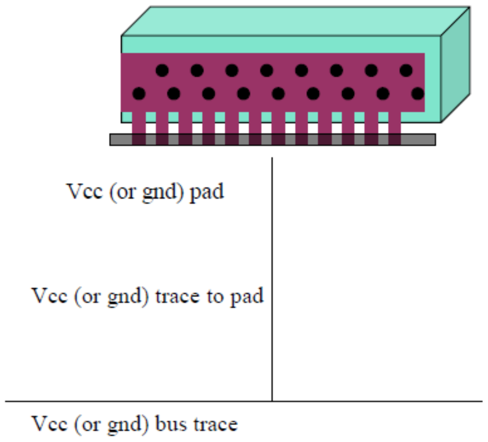




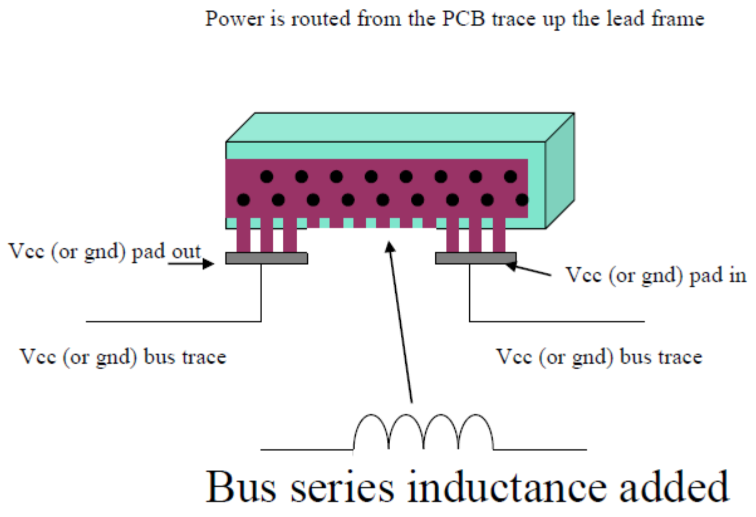
ALTERNATE BOARD IMPLEMENTATION:

Reduce Stacked cap parallel inductance and maximize series inductance:

STANDARD CONFIGURATION



LOW INDUCTANCE CONFIGURATION



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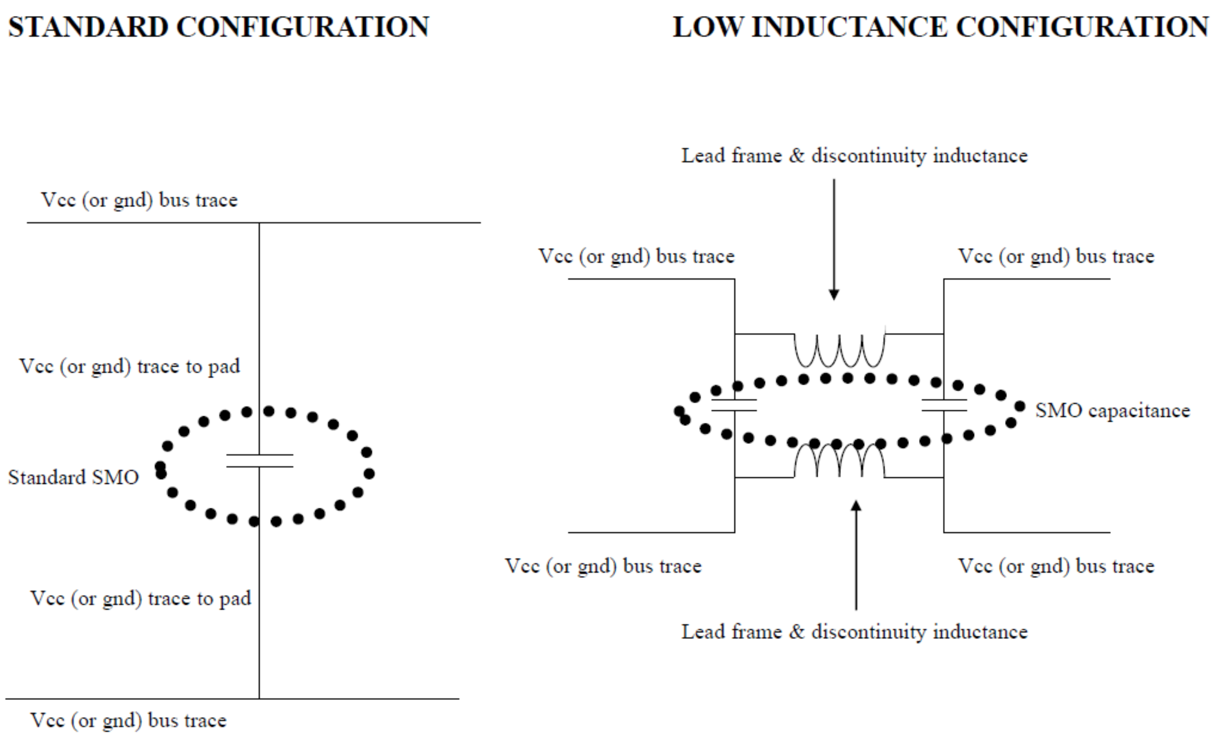
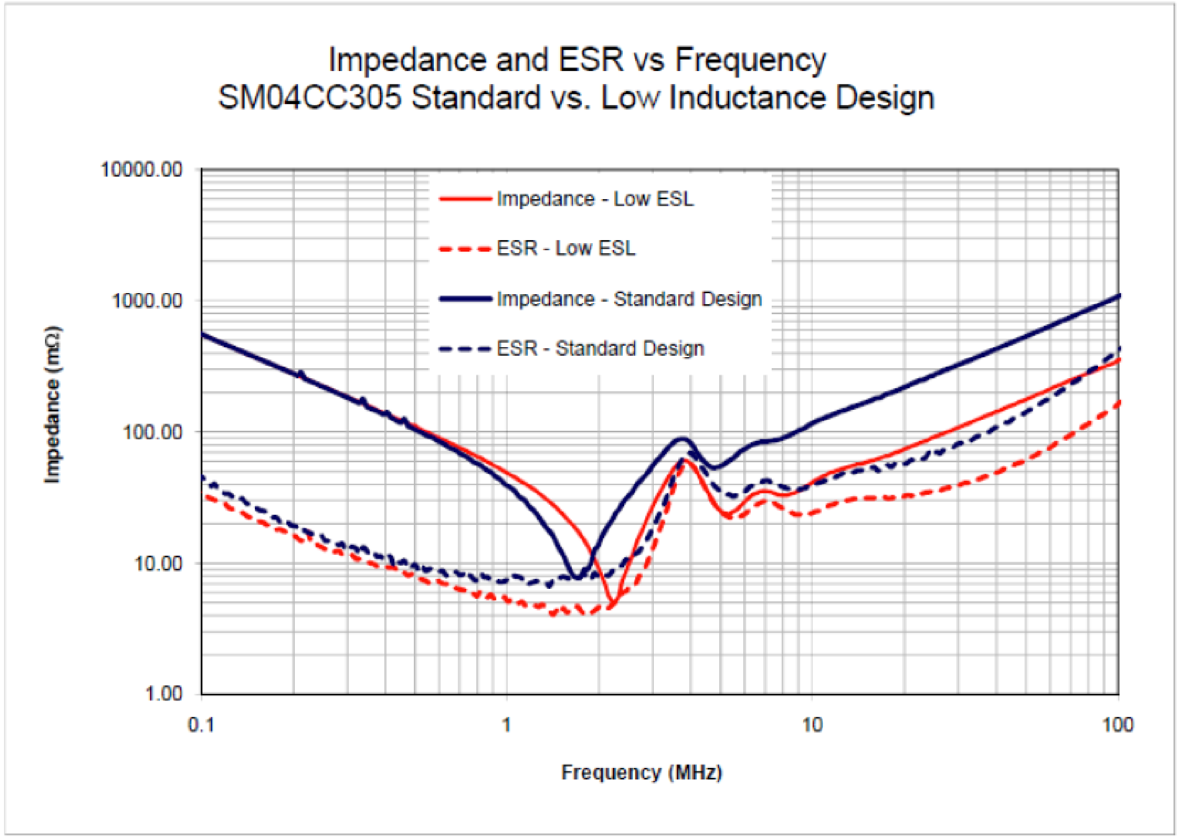
Reduce Stacked cap parallel inductance and maximize series inductance:



ALTERNATE BOARD IMPLEMENTATION:



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:
  - AlEl 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 & 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