Electronic Components

KEMET

CHARGED.®

Capacitors in Switching Power Conversion

Wilmer Companioni
Technical Marketing Manager

Who Am I:

Recovering Engineer

Old picture, back when I was young and pretty.

BSEE: University of Florida

- 10+ years electronics design experience
  - Motorola
  - Blackberry
  - Freelance/Consulting
- 5+ years in sales/marketing
  - Manufacturer sales rep
  - KEMET last 4 years.

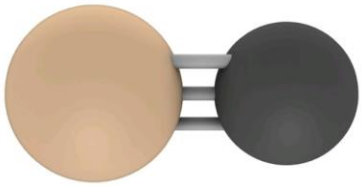
Power Conversion Industry Trends:

Let's Make Things Harder

Characteristic	Trend
Size	↓
Power	↑
Energy Density	↑
Frequency	↑
Temperature	↑
Voltage	↑
Cost	↓

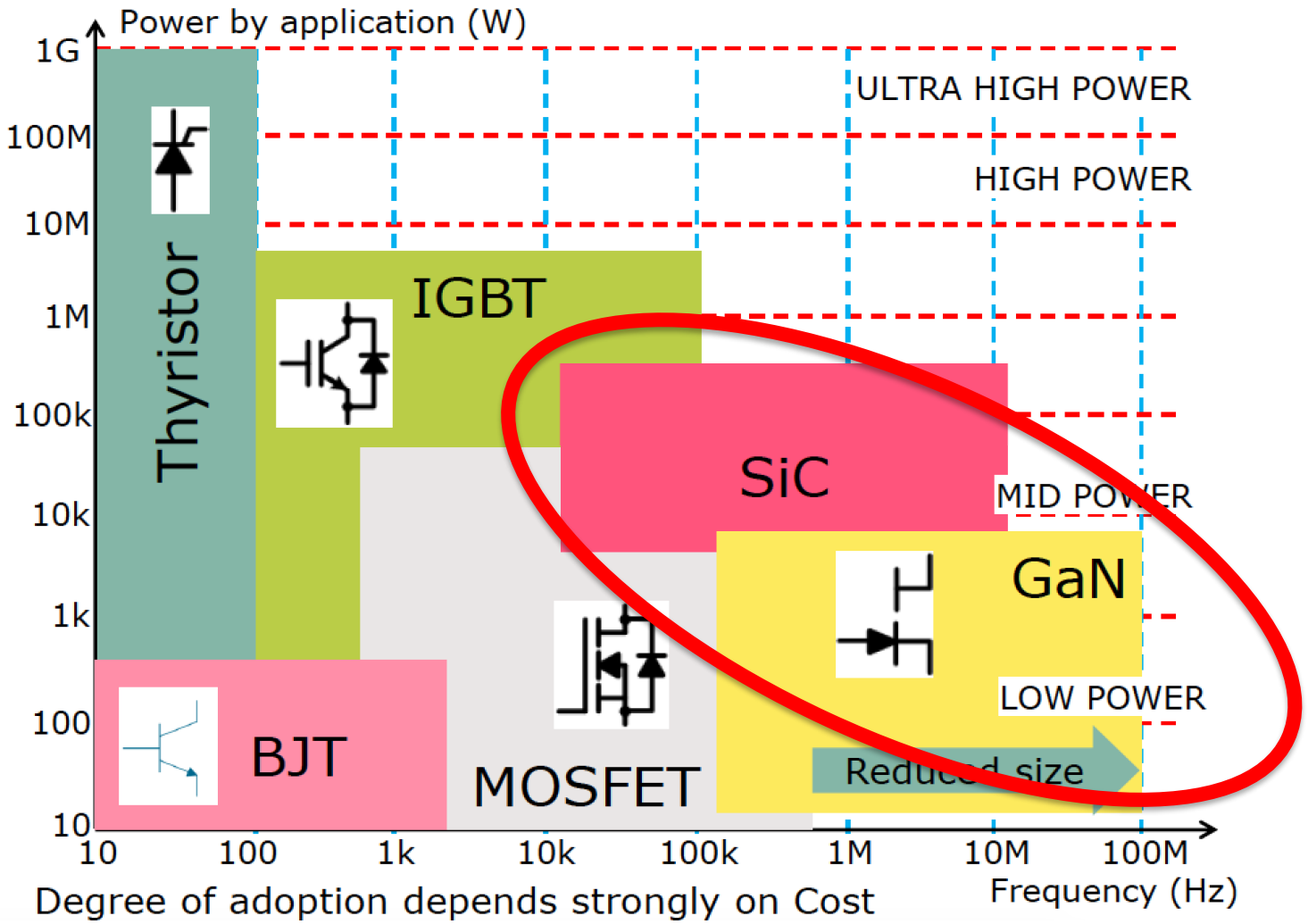
Silicon Industry Response:

Wide Band Gap Semiconductors



Especially attractive at 1.2+ kV

Cree SiC MOSFET
Six-Pack Power Module



Source: P. Friedrichs & M. Buschkuhle, Infineon AG, Energetica India, May/June 2016

Battle of the Materials:

SiC/GaN vs. Si

- Compared to Si, Wide Band Gap (WBG) IGBT and Power Modules:
  - Are smaller
  - Require less cooling
  - Are more energy efficient

Conversion Efficiency	Si Based	WBG Based GaN or SiC
DC to DC	85%	95%
AC to DC	85%	90%
DC to AC	96%	99%

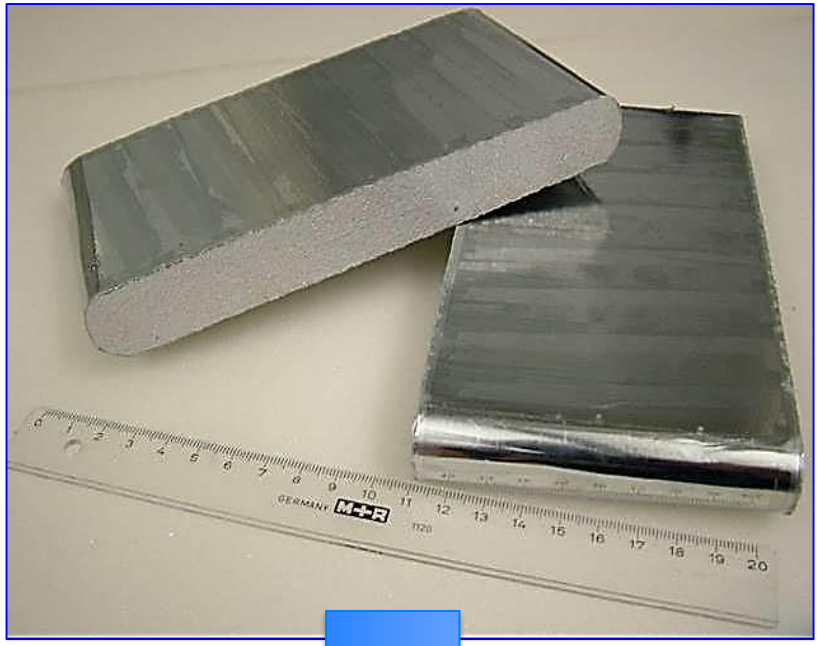
Source: Mouser Electronics, L. Culberson, 2016

- Snubber and DC Link capacitors requirements for AC/DC conversions in high power inverters and converters will be reviewed

Battle of the Materials:

PP Film vs. MLCC

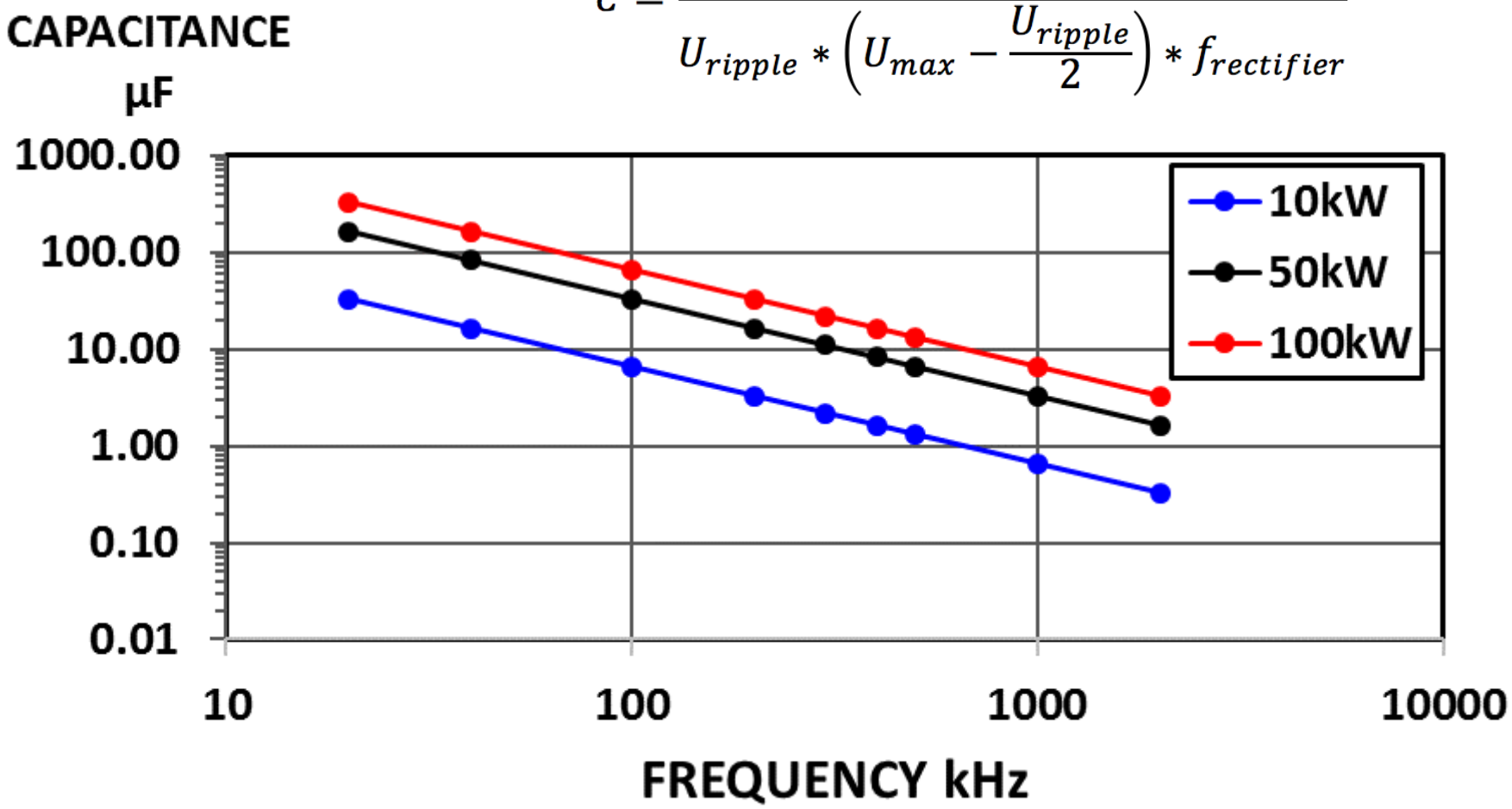
- For DC-Link Capacitors:
  - Lower capacitance required promotes miniaturization due to:
    - Increasing switching frequency
    - Higher voltages
- Lower capacitance is within the range of MLCC.
  - But these need must be:
    - Extremely reliable
    - Over-temperature capable
    - Over-voltage capable
    - High current capable
    - Mechanically robust
- ***PRO-TIP:*** MLCC for effective switching noise suppression when placed close to WBG where cooling is limited.



WBG Revolution:

Effects on The Capacitor

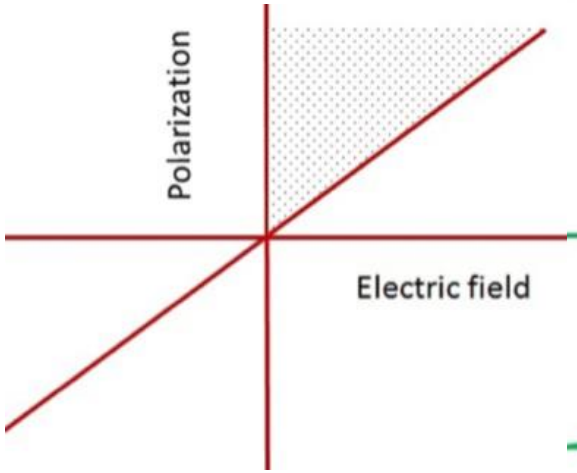
$$C = \frac{P_{load}}{U_{ripple} * \left(U_{max} - \frac{U_{ripple}}{2}\right) * f_{rectifier}} \quad *$$

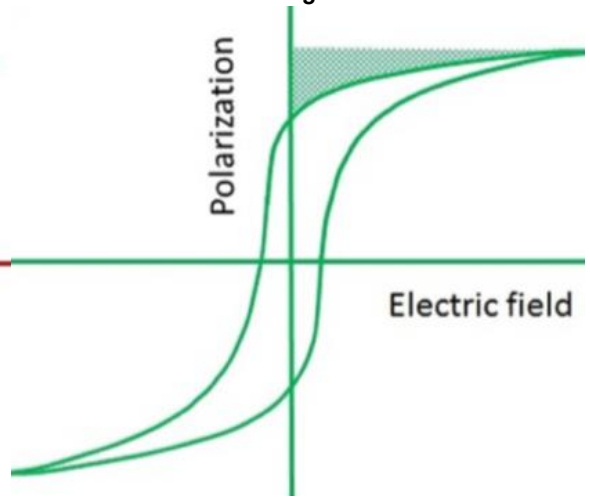


Ceramic Capacitors Choices:

Pairing with WBG Semi

	Paraelectric	Ferroelectric
EIA Types	*Class I*	*Class II*
Dielectric	*C0G, C0H, U2J*	*X7R, X5R*
	$CaZrO_3$	*$BaTiO_3$*





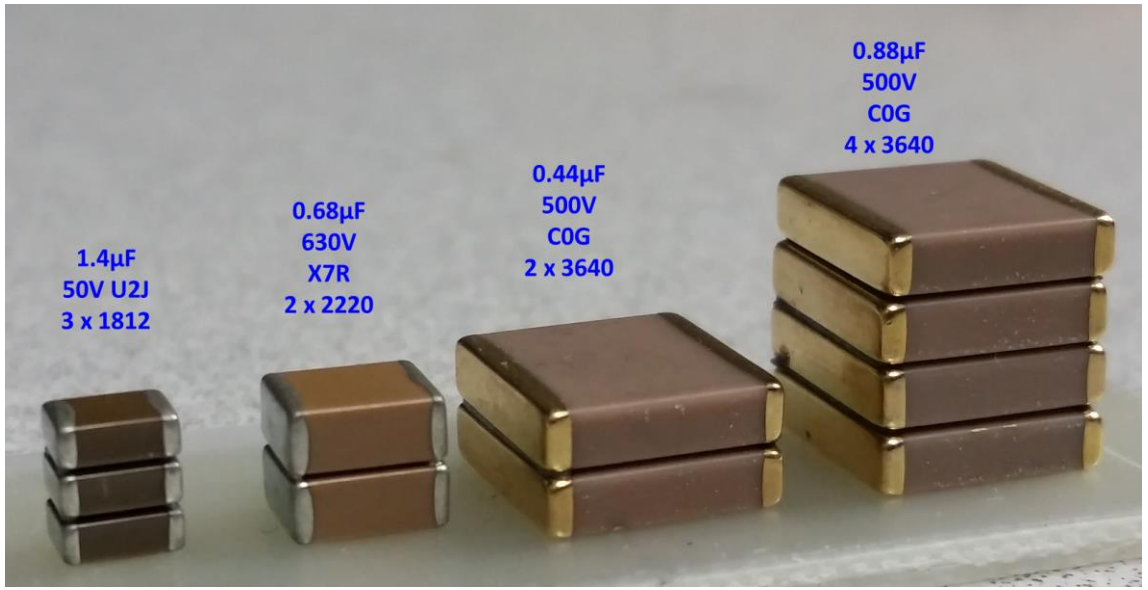
MLCC Attributes	Target	Paraelectric $CaZrO_3$	Ferroelectric $BaTiO_3$
Energy Storage	High	High	Low
Dielectric Constant K	High	Low	High
Current Handling	High	High	Low
Mechanical Robustness	High	High	Medium
Piezo (Electrostriction)	Low	Low	High
Voltage Stability	High	High	Low
Temperature Stability	High	High	Medium

Film caps are great for DC but their temp limitation makes it a difficult choice for WBG

Leadless Stacks

Packaged MLCC for Higher Capacitance Density

- Meet the need for increased capacitance in a given circuit board space in power applications.
- MLCC terminations are bonded together using Transient Liquid Phase Sintering.
- The Leadless Stacks are surface mounted on a circuit board using the same assembly processes as an MLCC.



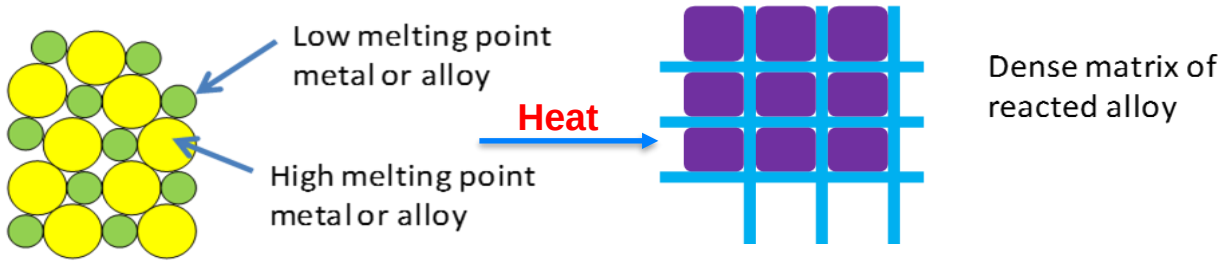
US Patents 8,902,565 B2 & 9,472,342 B2

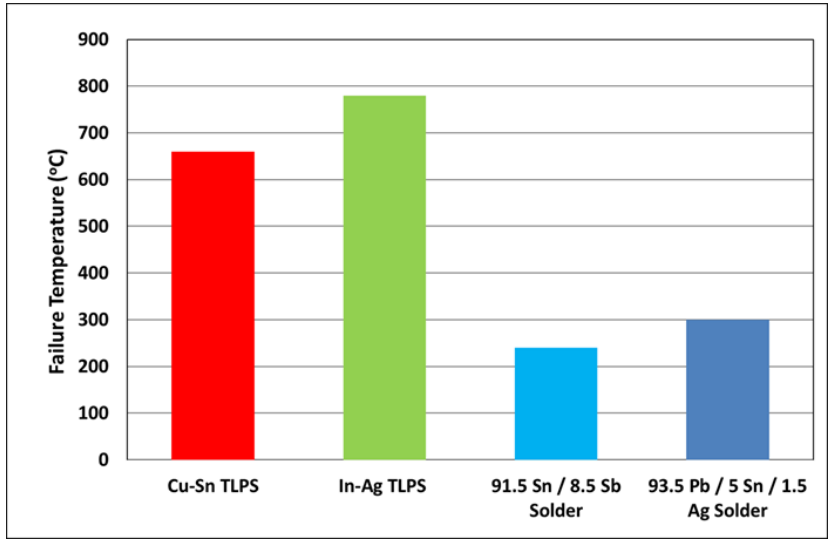
Transient Liquid Phase Sintering (TLPS)

Basic Technology

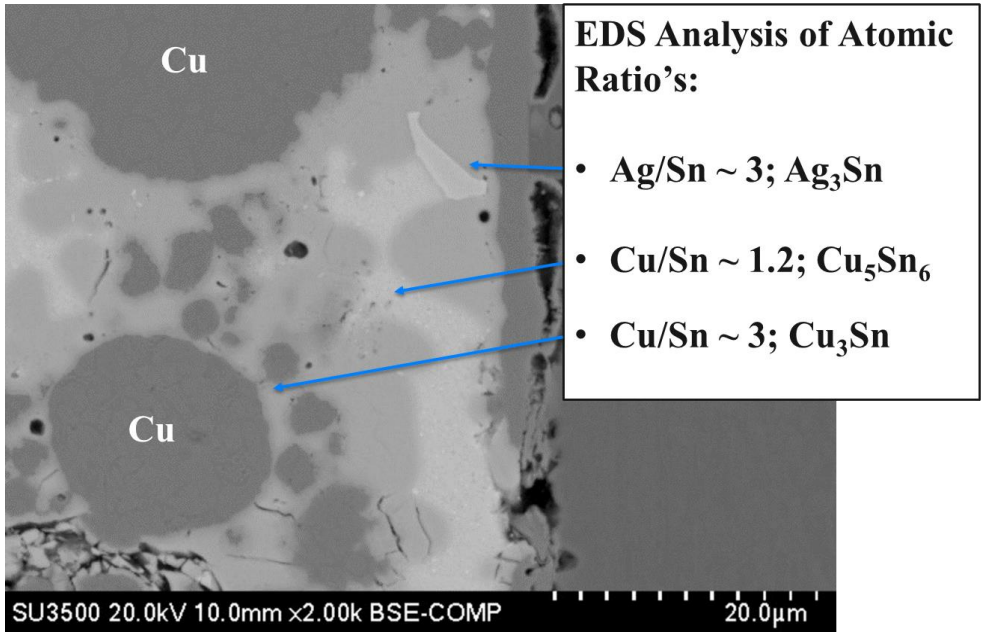
What is TLPS?

- Low temperature reaction of low melting point metal or alloy with a high melting point metal or alloy to form a reacted metal matrix or alloy.
- Forms a metallurgical bond between 2 surfaces .
- Has high failure temperatures.





CuSn TLPS

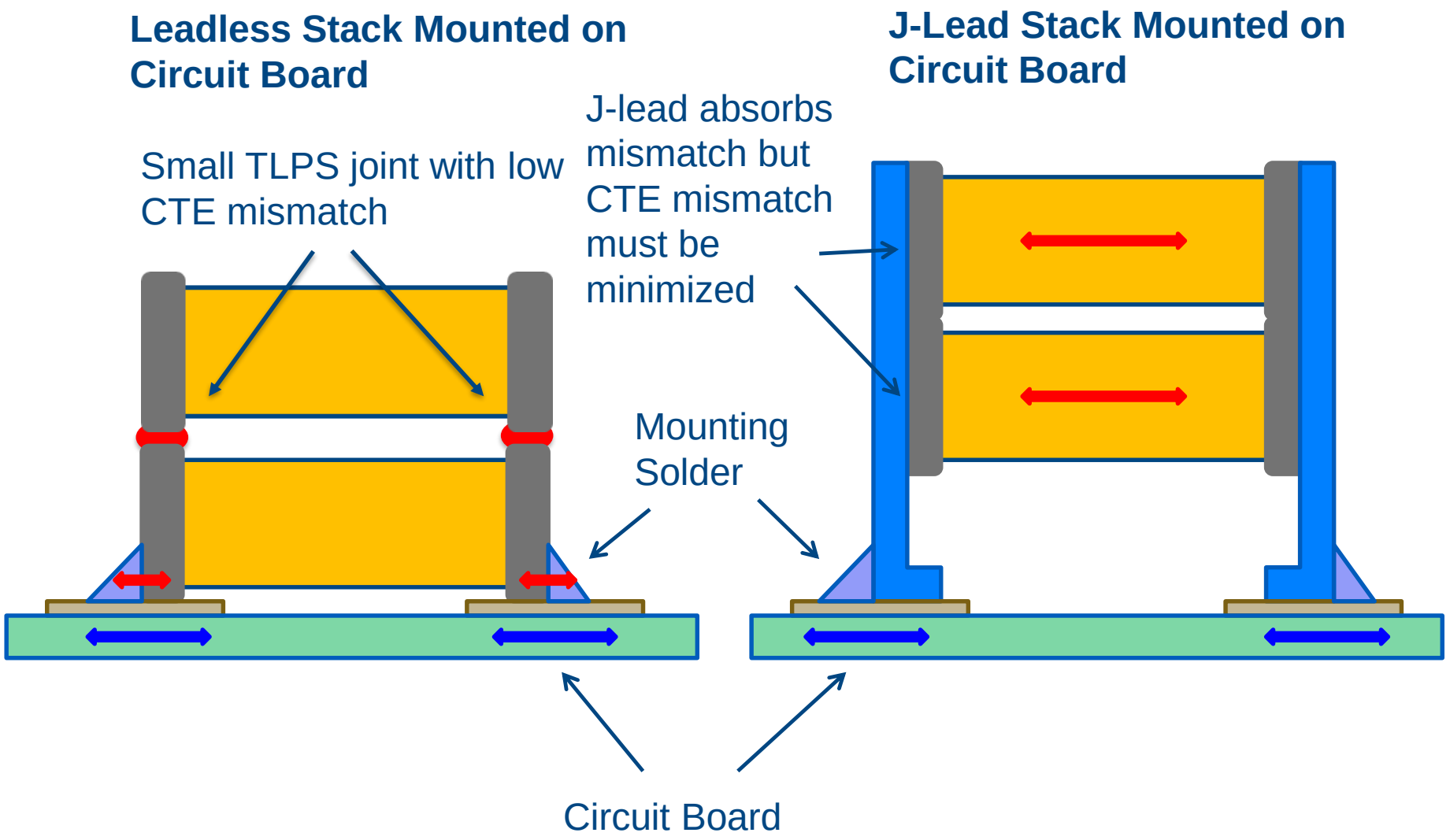


EDS Analysis of Atomic Ratio's:

- Ag/Sn ~ 3; Ag_3Sn
- Cu/Sn ~ 1.2; Cu_5Sn_6
- Cu/Sn ~ 3; Cu_3Sn

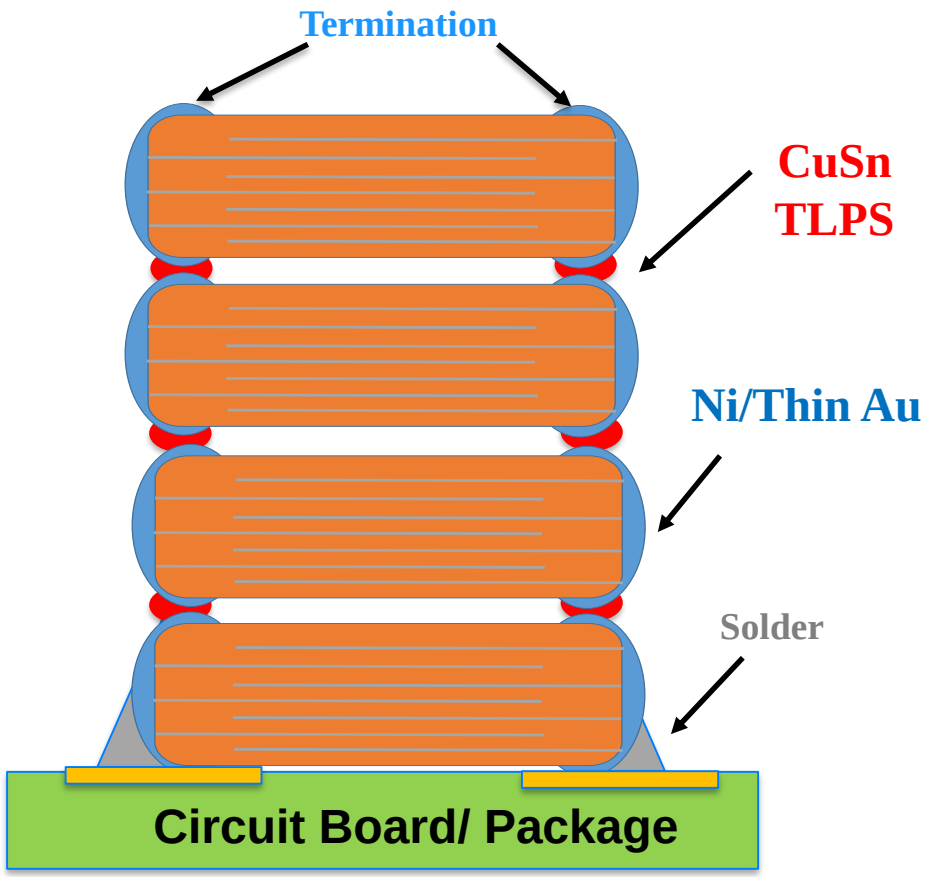
CTE Mismatch Comparison

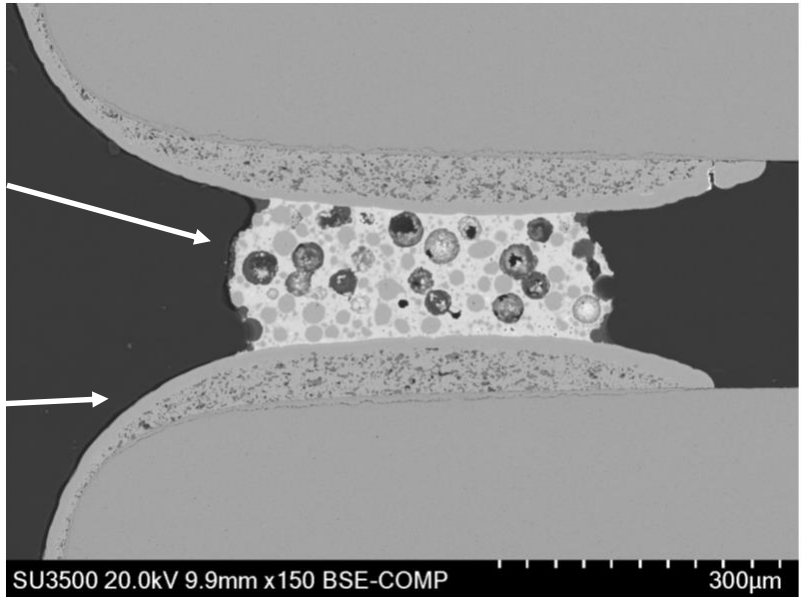
Leadless Stacks vs. Leaded MLCC

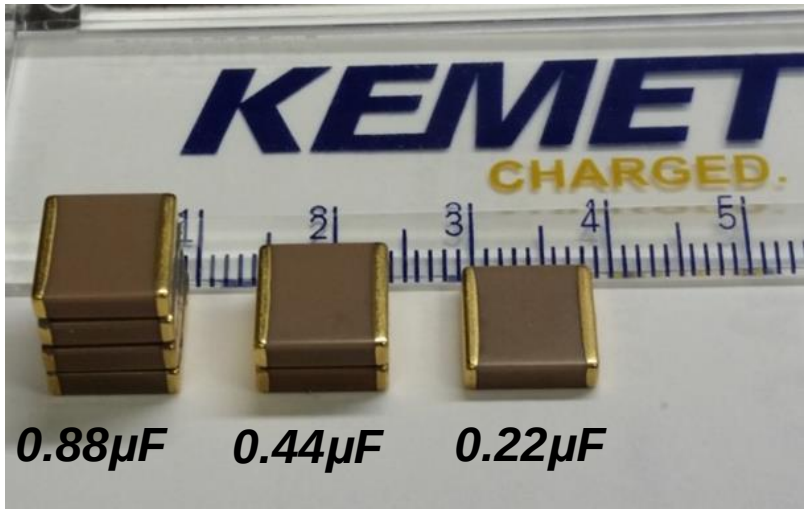


Leadless Stacks 3640 0.22µF 500V MLCC

Form Factors & Materials





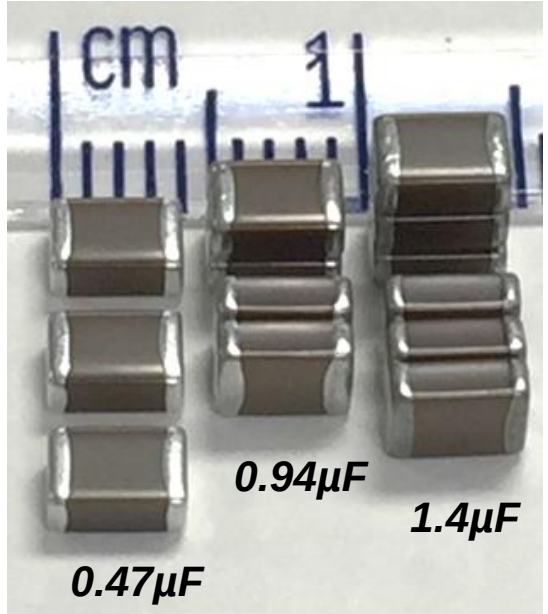


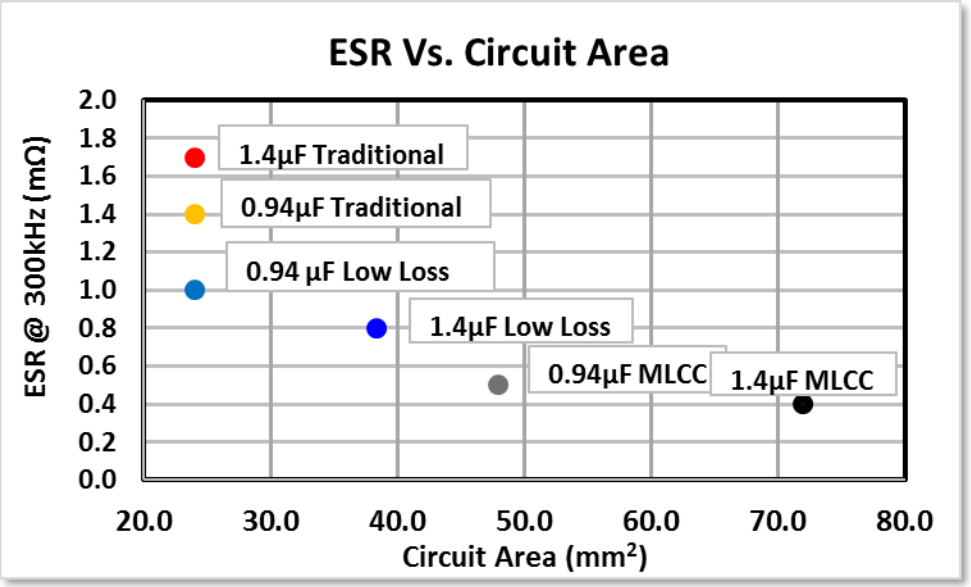
U2J MLCC for 48V Power Applications

Leadless Stacks of 1812, 0.47µF, 50V

Minimize Power Dissipation at 300kHz:

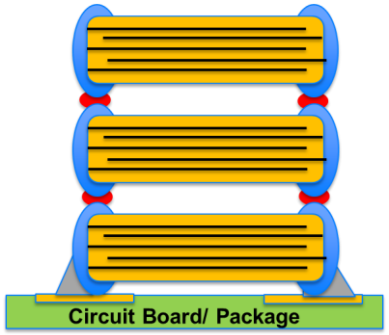
- Low ESR (P = I^2R)
- Smaller Circuit Area than MLCC



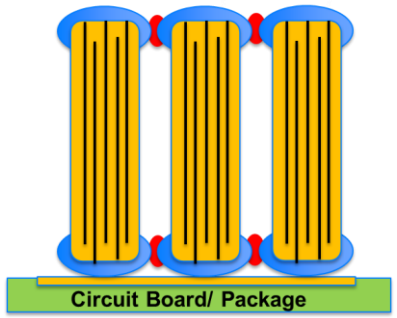


No circuit ESR for MLCC Data

Traditional



Low Power Loss



Low Power Loss Orientation combines low ESR with a smaller circuit area

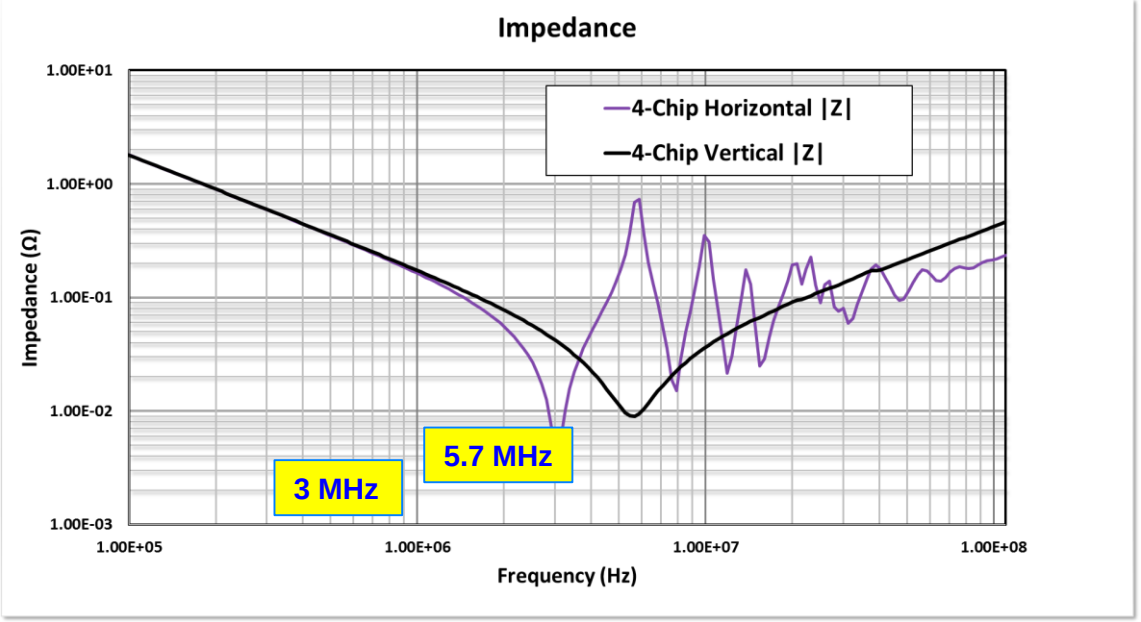
Leadless Stacks of 4 X 3640 0.22µF 500V

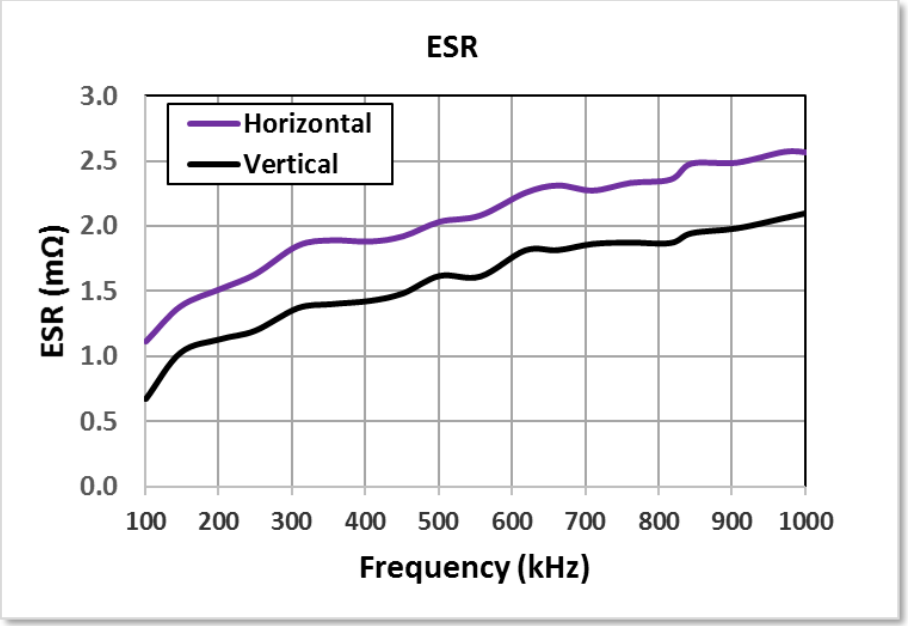
Stack Orientation; Horizontal vs. Vertical

Horizontal **Vertical**

2.9 nH

0.9 nH





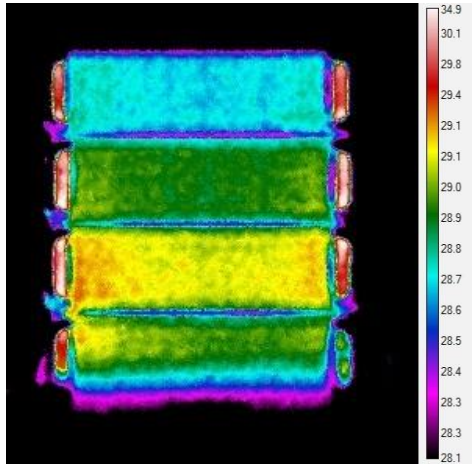
Vertical Orientation has:

- Lower ESL
- Higher SRF
- Lower ESR

Leadless Packages of 4 X 3640 0.22µF 500V

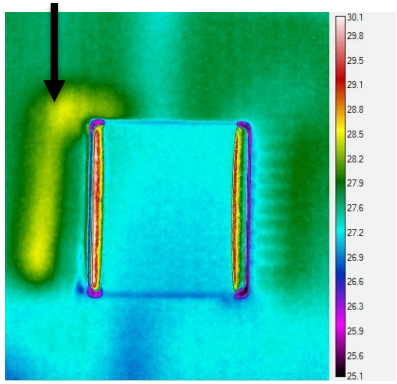
Ripple Current Heating; Horizontal vs. Vertical

Horizontal

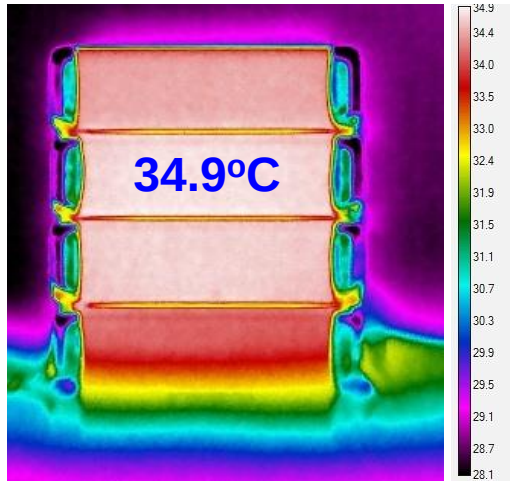


Side View

Heat dissipation into Cu board.



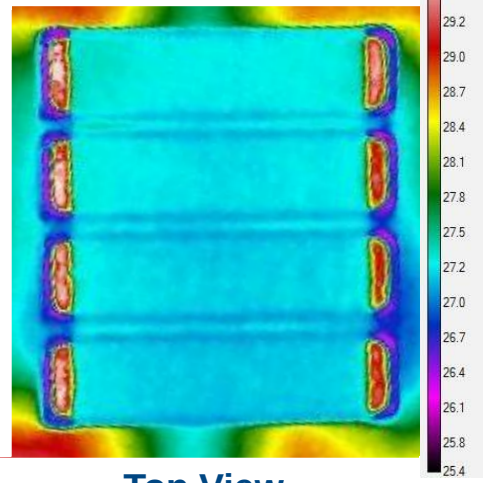
Top View



12A$_{RMS}$ @ 140kHz WARMING UP

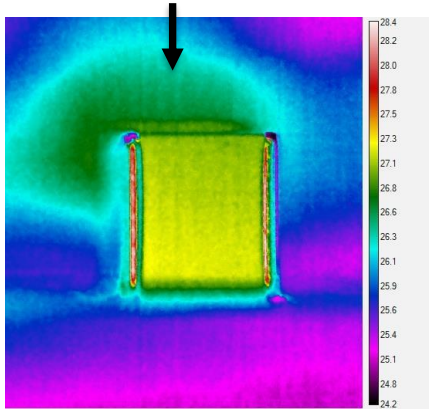
STEADY STATE

Vertical

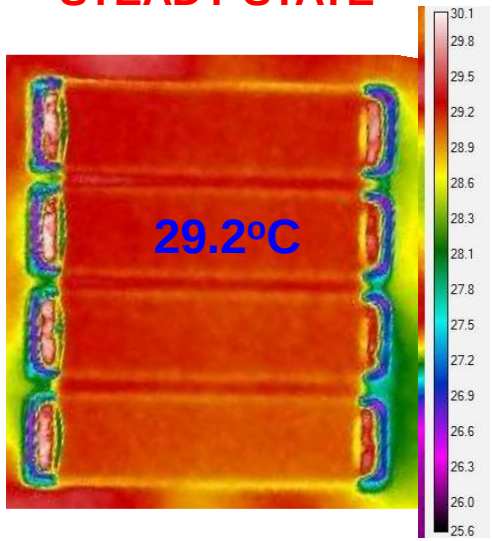


Top View

Heat dissipation in Air above.



Side View

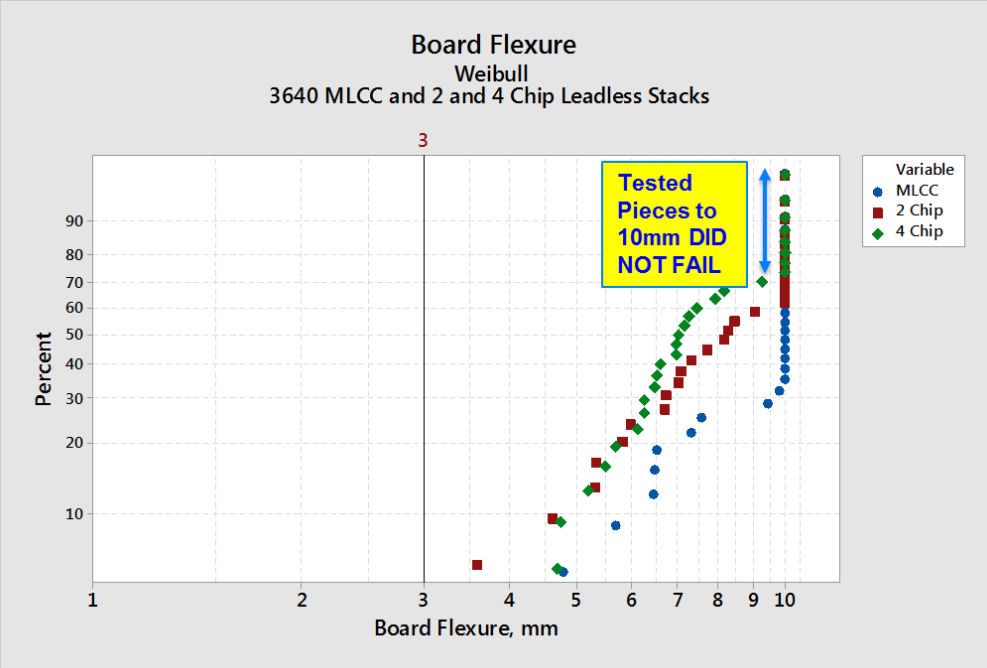


Vertical Orientation:

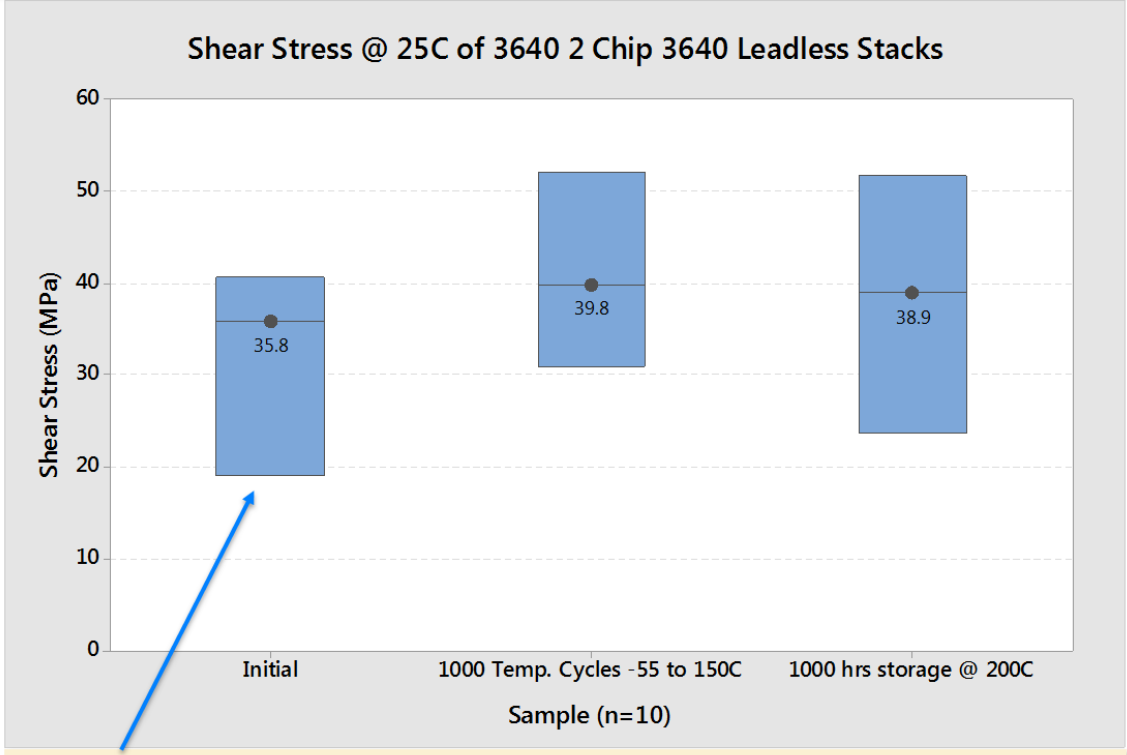
- More even heating
- Lower Temp. @ Steady State ≈ - 5ºC

Leadless Stacks of 3640 0.22µF 500V MLCC

Surface Mounted Performance



- Board Flexure is > 3mm similar to MLCC
- No Failures 0/50 through 1000 cycles -55 to +150°C



19.1MPa failure at 27.9kg > 15 x the 1.8kg minimum AEC Q200