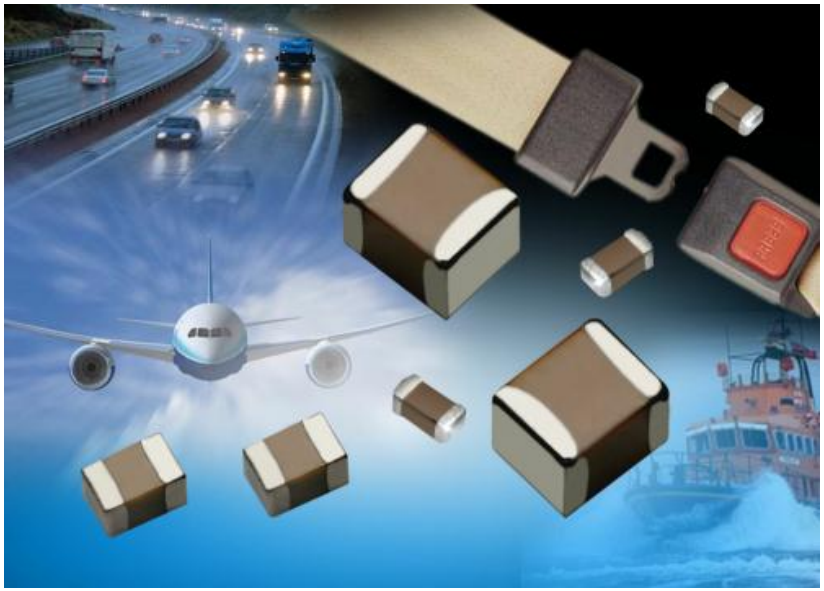
FlexiSafe MLCC Termination Device Performance



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BT52 2DA

AVX
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Raleigh, N.C. 27064

The MLCC advantages in Automotive Applications

Benefits include:

- Higher operating temperatures than competing technology
- Higher ripple current capability
- Small and light
- Cost competitive
- No end of life failure mechanism
- High reliability

The MLCC and Automotive customers

Potential problems:

Thermal stress

- Thermal stress damage from soldering
- Severe thermal gradient or soldering iron contact

Mechanical damage

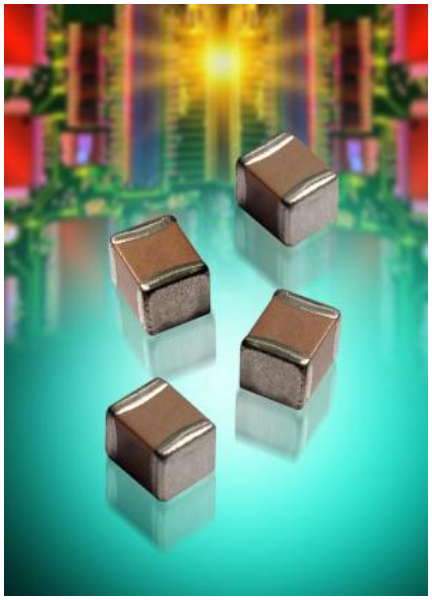
- Experience shows >95% of the components returned for analysis

Electrical damage

- Electrical damage from irregular circuit occurrence
- Electrical damage from customer MM or CDM ESD strike

A KYOCERA GROUP COMPANY

Sources of Mechanical Damage

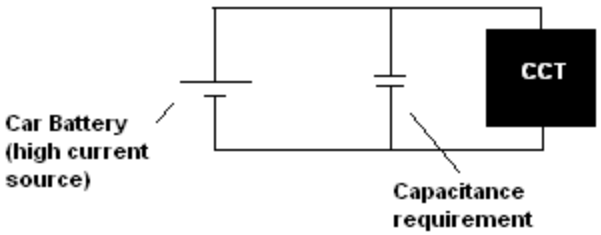


- MLCCs located close to the edge of PCBs
- ICT pin induced board flexure
- Board flexure during PCB assembly into fixtures / cases etc.
- Insertion / removal of PCBs from connectors etc.
- PCB thermal expansion / contraction causing mechanical damage to the MLCC.

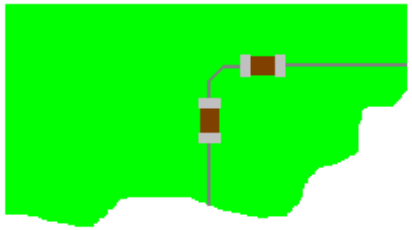
The Automotive end customer solution

In circuits where the capacitor is situated across the terminals of the battery, 2 capacitors in series orientated at 90° is typically recommended by the automotive customers.

For this…..



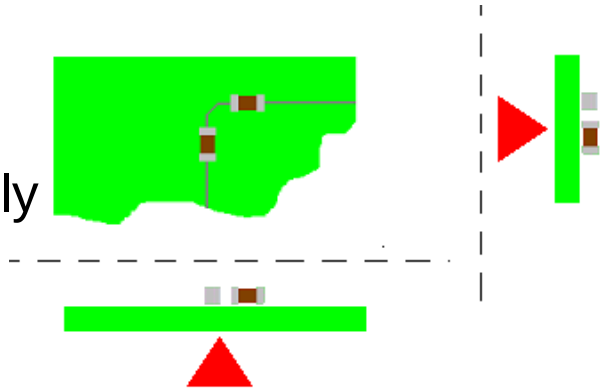
Use this…..



To try to prevent this!

The Automotive end customer solution

The problem is that with this solution it is assumed that board flex always effects only 1 of the 2 components.



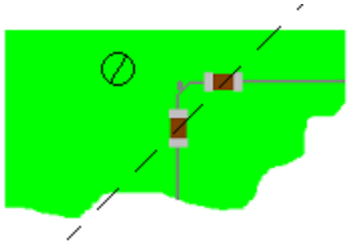
What happens if the board flex is coming from any other known cause?

- ICT pin induced board flexure
- Board flexure occurring during PCB assembly into fixtures / cases etc.
- Insertion / removal of PCBs from connectors etc.
- PCB thermal expansion / contraction causing mechanical damage to the MLCC.

The Automotive end customer solution

The Process

- To test the “2 Capacitor in Series” solution against other causes of board flexure, we performed bend testing at 45° to each capacitor.

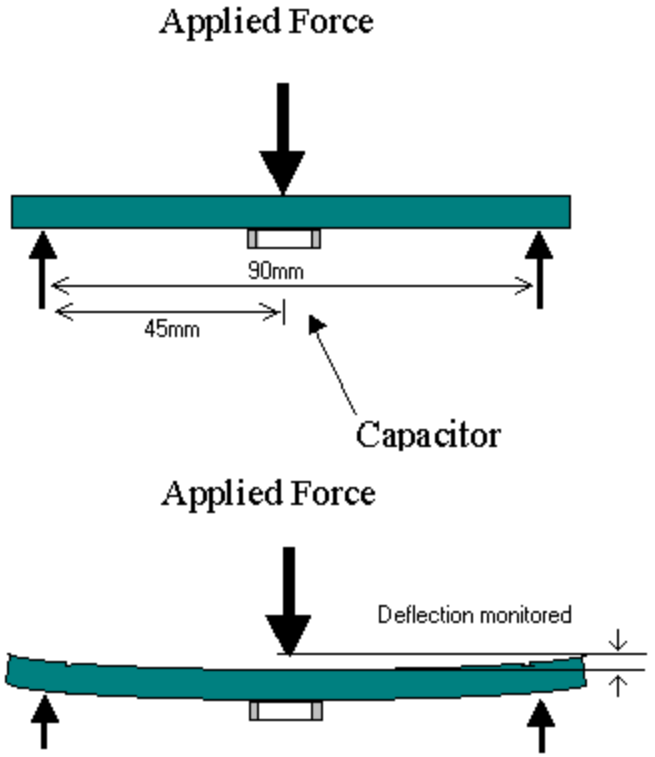


- The testing was also performed with a test of a single standard MLCC, a single FLEXITERM® MLCC and a single FLEXISAFE™ MLCC for comparison.

The Automotive end customer solution

The Process

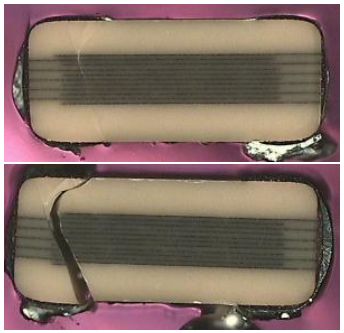
- Each board was bent to 3mm (2600um/m strain) across a 90mm span.
- Each unit was then measured for low insulation resistance, and sectioned to review internal structure.

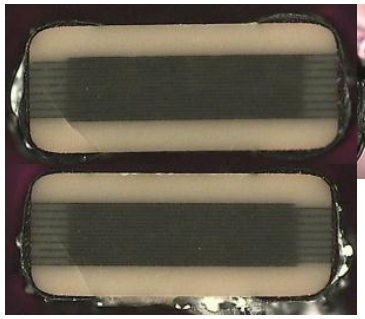


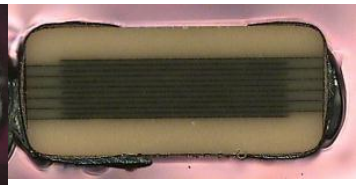
The Automotive end customer solution

The results

	Standard 1 chip 08051C103M4T	**2 in series** 2x 08055C223M4T	**Single FLEXITERM®** 08051C103M4Z	**Single FLEXISAFE™** FS055C103M4Z
Low insulation resistance	**FAIL** 8/10 pieces	**Fail** 19/20 pieces, 9 / 10 short Circuits	Pass 0/10 pieces	Pass 0/10 pieces
No of cracked chips	**FAIL** 8/10 pieces	**Fail** 19/20 pieces	Pass 0/10 pieces	Pass 0/10 pieces







The Automotive end customer solution

The Test Conclusion

- A single FLEXITERM® or FLEXISAFE™ component gives much greater protection against all forms of flexure damage.
- A single FLEXITERM® or FLEXISAFE™ component also gives additional protection against temperature cycle induced damage.
- “2 Capacitors in Series” only protects against 1 specific type of board flexure damage.

The Automotive end customer solution

How about the ESD Performance?

The Process

- To test the “2 Capacitors in Series” solution against other causes of board flexure, testing performed ESD testing as per AEC-Q200 procedure.
- 25 piece samples were used for the single units, 50 pieces with 2 capacitors in series were used for the “2 capacitor in series” solution.

The Automotive end customer solution

The Process

- Each component was mounted on a PCB and ESD tested, one (1) with a positive polarity and one (1) with a negative polarity (as per AEC requirements).
- 2 Voltages were used, 8kV direct contact and 15kV air discharge.

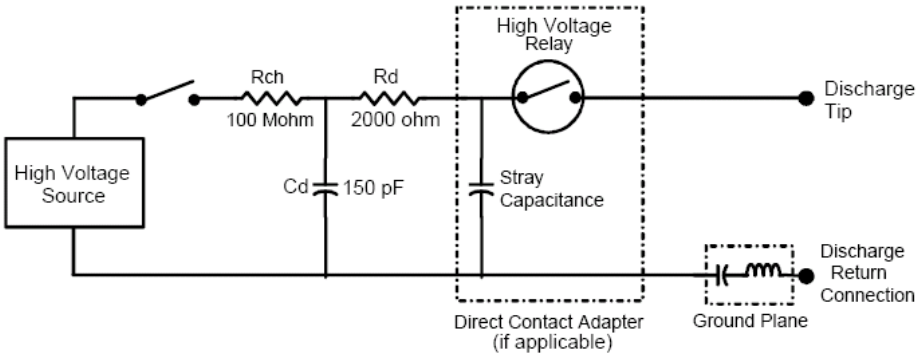


Figure 1: Equivalent Passive Component HBM ESD simulator circuit

The Automotive end customer solution

The results

ESD progressive testing	**Standard 1 chip** 08051C103M4T	**2 in series** 2x 08055C223M4T	**Single FLEXITERM®** 08051C103M4Z	**Single FLEXISAFE™** FS055C103M4Z
25kV (air)	N/A	N/A	N/A	N/A
15kV (air)	**Fail** 25/25 low IR	**Fail** 24/25 low IR On complete circuit	Pass	Pass
8kV (direct)	Pass	Pass	Pass	Pass
4kV (direct)	N/A	N/A	N/A	N/A

The Automotive end customer solution

The Test Conclusion

- “2 Capacitors in Series” provides no additional protection against ESD strike over a single standard, FLEXITERM® or FLEXISAFE™ component.

- FlexiTerm & FlexiSafe have acceptable ESD response

Weighted comparison

In order to better understand the overall performance of the various safety solutions, a weighted table was adopted which will allow the performance to be assessed against most common causes of short circuit.

This weighted table has been designed along similar lines to FMEA type comparison.

Weighted comparison

Single chip vs 2 in series

How does the 2 capacitor in series solution perform against common causes of failure?

- In order to assess the relative merits of the short circuit protection methods we would like to use a weighted comparison.

Potential cause of low IR and estimate of level of occurrence **Effectiveness of Solution**

Single chip Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution	Effectiveness	Risk rating
		9 = most severe		9 = most common		9 = Least effective	
Soldering	low insulation resistance	9	High delta T	1	single chip	9	81
	low insulation resistance	9	Soldering iron strike	2	single chip	9	162
Mechanical damage	low insulation resistance	9	Board break out	9	single chip	9	729
	low insulation resistance	9	ICT damage,assembly and other	5	single chip	9	405
	low insulation resistance	9	Thermal expansion of the PCB	5	single chip	9	405
ESD damage	low insulation resistance	9	ESD damage	2	single chip	9	162

Single chip Solution Risk rating = 1944

2 Capacitors in Series Solution

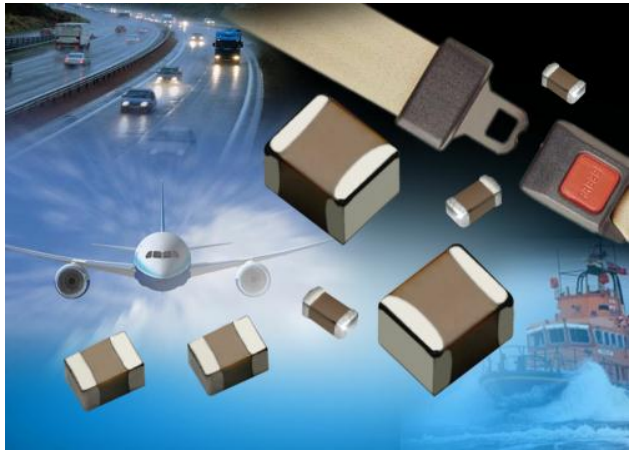
Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	2 chip in series	6	54
	low insulation resistance	9	Soldering iron strike	2	2 chip in series	6	108
Mechanical damage	low insulation resistance	9	Board break out	9	2 chip in series	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	2 chip in series	7	315
	low insulation resistance	9	Thermal expansion of the PCB	5	2 chip in series	7	315
ESD damage	low insulation resistance	9	ESD damage	2	2 chip in series	8	144

2 Capacitors in Series Solution Risk rating = 1098

Solution options

FLEXITERM® and FLEXISAFE™ are products that work by preventing the failure from occurring

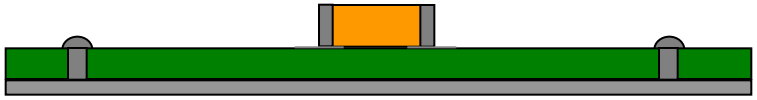
Other industry design modifications like the open failure mode and MLSC Capacitors accept that cracking occurs but try to limit the potential damage

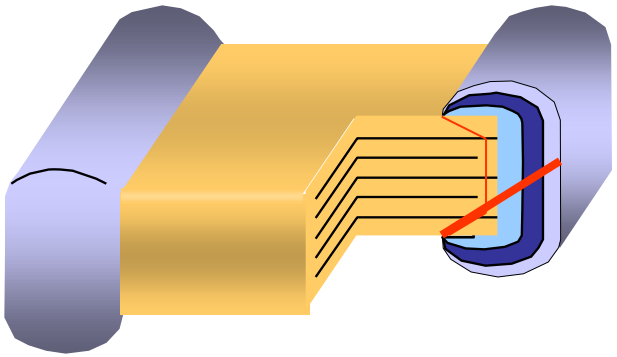


FLEXITERM®

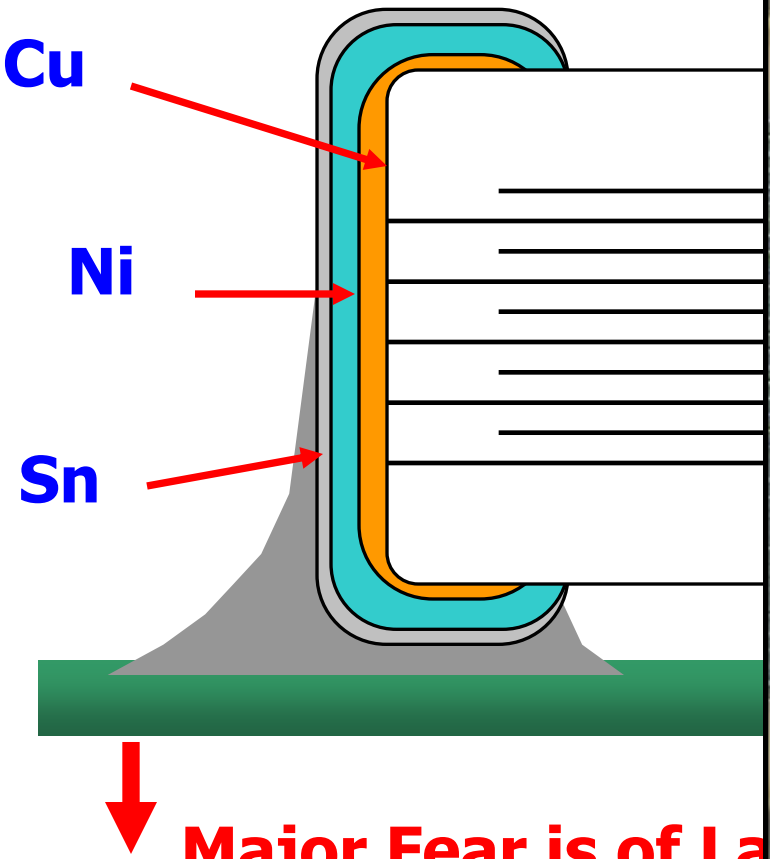
A Solution to Thermal & Mechanical Board Flex

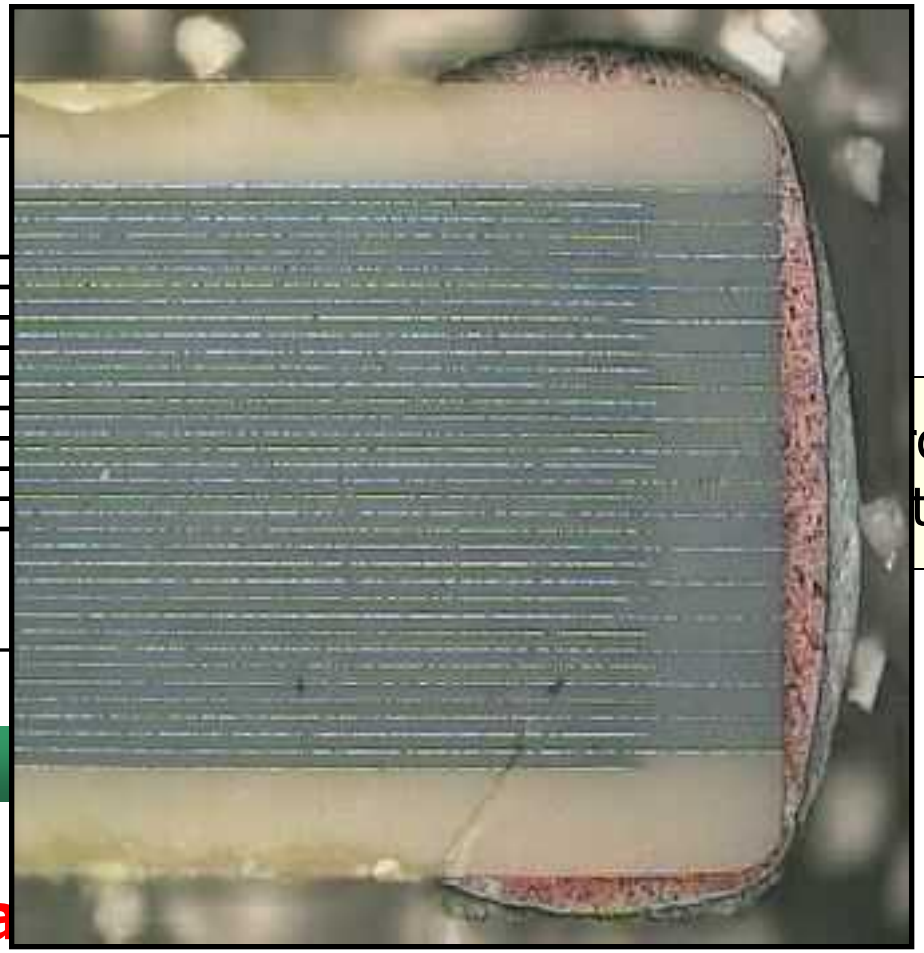
- High Flexure Stress Circuit Boards
  - e.g. Depanelisation: components near edges of board
  - Board Flexure during manufacture
  - Insertion of PCB in assembly
- Variable Temperature Applications





Cu Termination - Mechanical Performance





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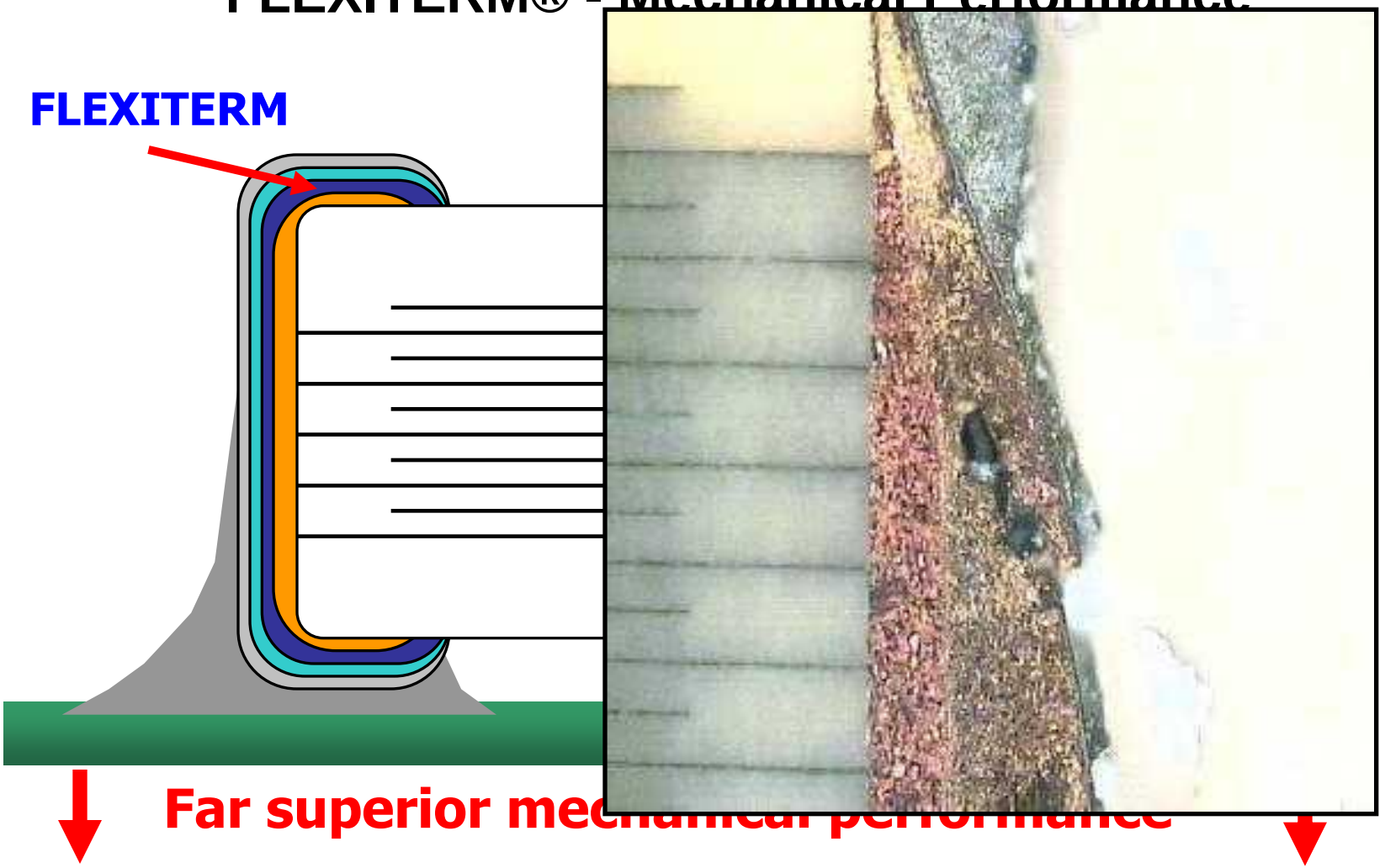
FLEXITERM® - Mechanical Performance



Performance Testing to Automotive Spec.

AEC-Q200 Qualification:

- Created by the Automotive Electronics Council
- Specification defining stress test qualification for passive components

Testing:

Key tests used to compare FLEXITERM to Cu termination as per AEC-Q200:

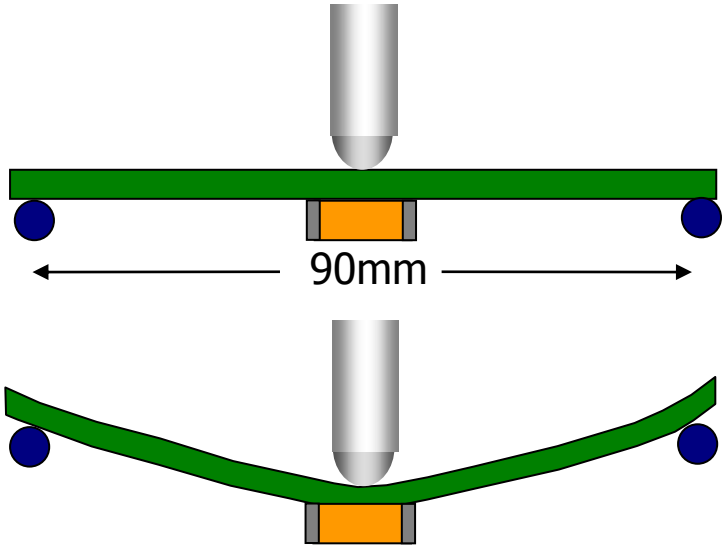
- Board Bend Flex Test - 20 samples
- Temperature Cycle Test – 77 samples

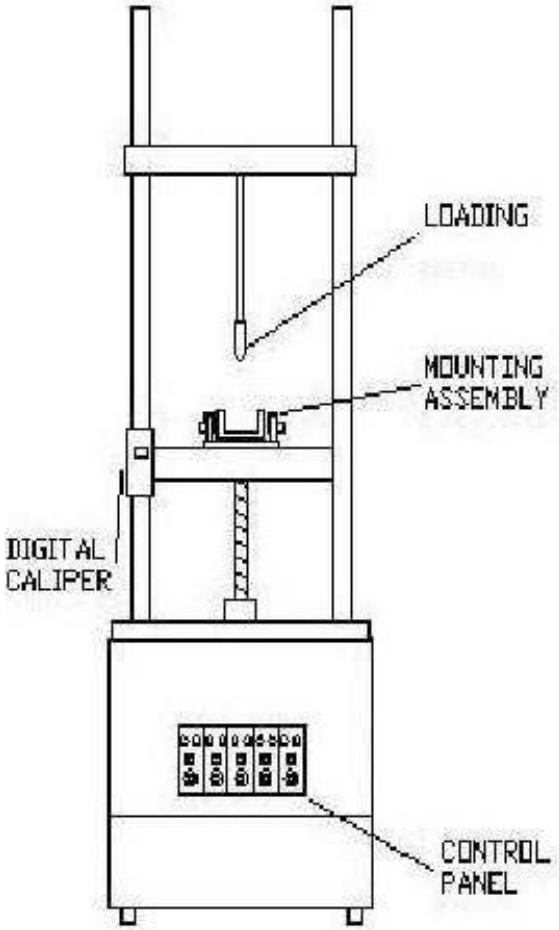
Board Bend Flex Test Procedure

Test Procedure as per AEC-Q200:

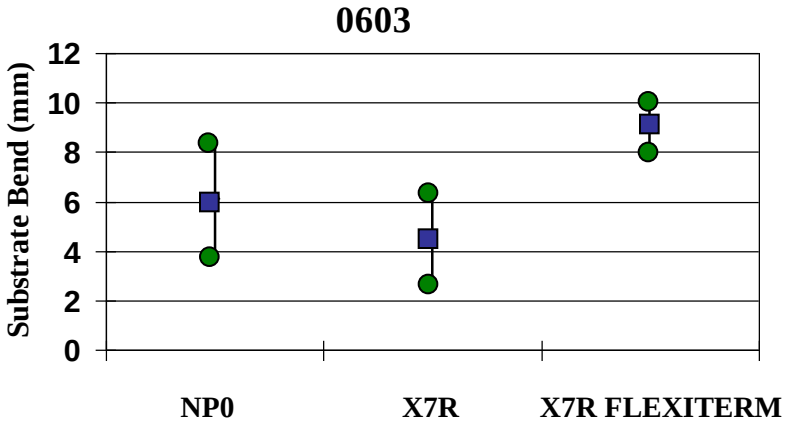
Minimum deflection spec: 2 mm (Class 2)

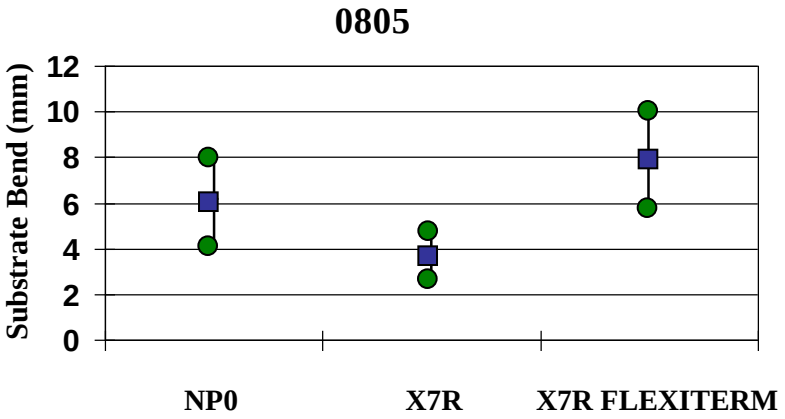
- Components soldered to FR4 PCB
- Board connected to the test equipment
- Motorized Moving Ram

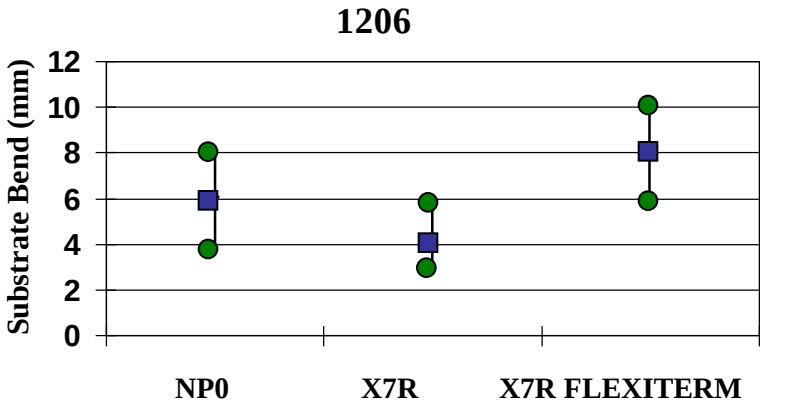


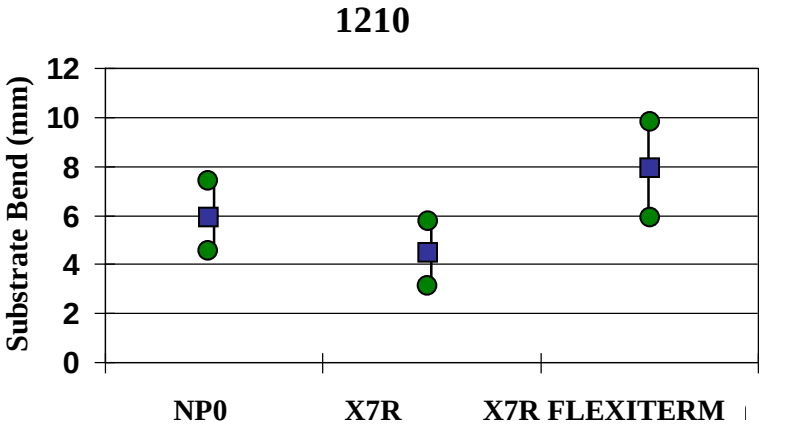


Board Bend Flex Test Results









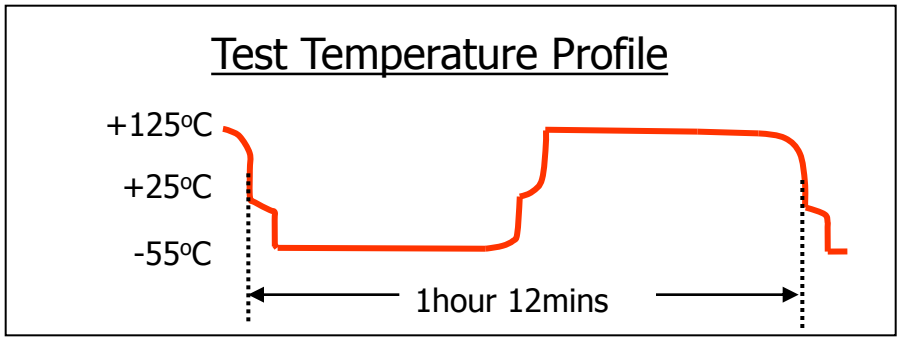
Board flex test is directly proportional to strain measurements on PCB

Temperature Cycle Test Procedure

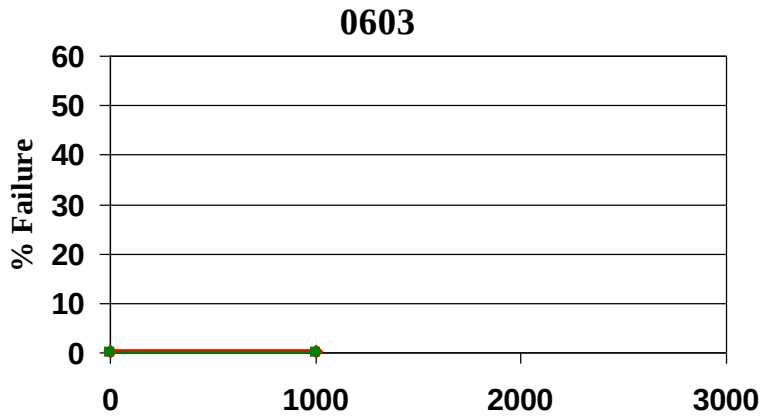
Test Procedure as per AEC-Q200:

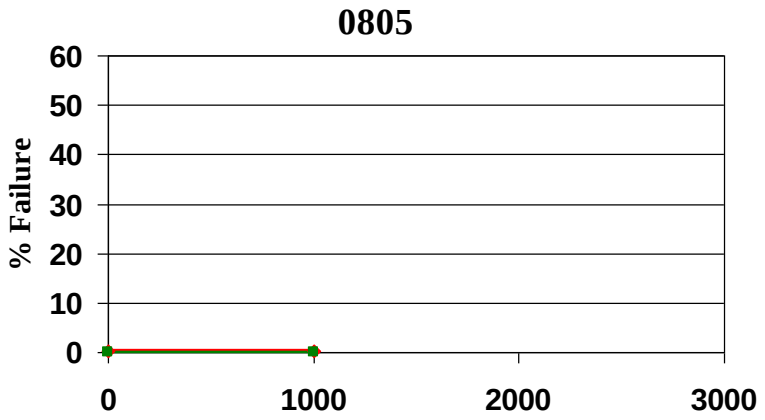
The test is conducted to determine the resistance of a part to extremes of high and low temperatures by alternative exposure to those extremes.

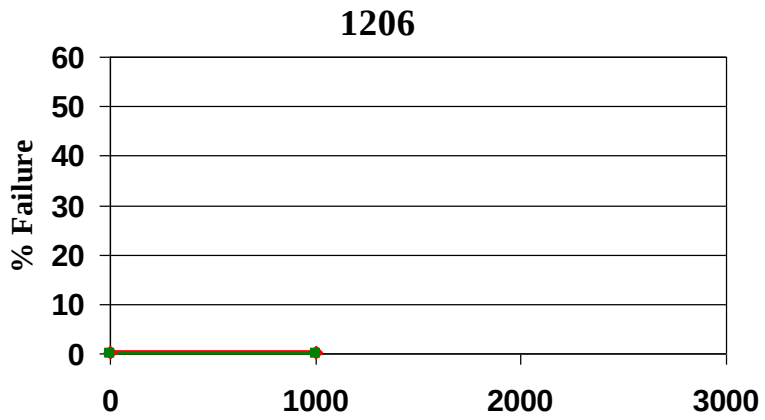
- sample size 77 – Soldered to PCB
- TC chamber cycle from –55^{0}C to +125^{0}C for 1000 cycles
- Interim electrical measurements at 250, 500, 1000 cycles
- Measure Parameters- Capacitance, Dissipation factor, Insulation resistance

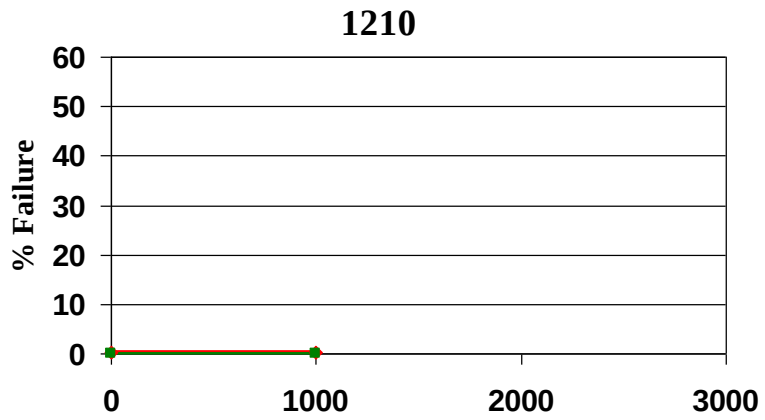


Temperature Cycle Test Results





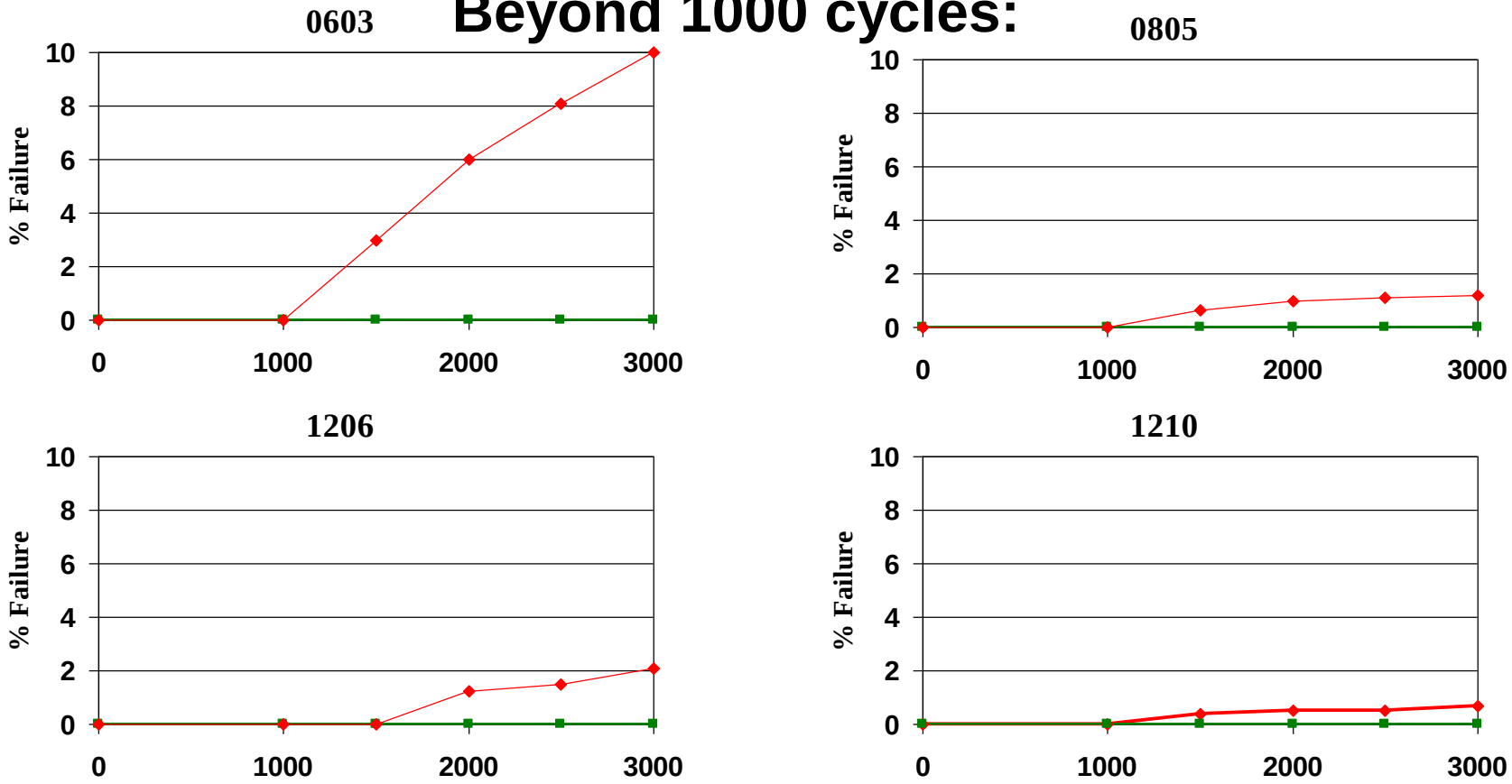




The Test was progressed beyond the AEC-Q200 requirements

Temperature Cycle Test Results

Beyond 1000 cycles:



FLEXITERM® Test Summary

- Performance measured using ‘Automotive Electronic Council’ specified tests; e.g. Temperature Cycle & Board Bend Test
- FLEXITERM® provides improved performance compared to copper termination > 2x Improved resistance to board flex
  - Board Bend Flex Test improvement by a factor of 2 to 4 times
  - Temperature Cycling
    - 0% Failure up to 3000 cycles
    - No ESR change up to 3000 cycles

Weighted comparison

FLEXITERM ® vs Single chip vs 2 in series

Single chip Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution	Effectiveness	Risk rating
		9 = most severe		9 = most common		9 = Least effective	
Soldering	low insulation resistance	9	High delta T	1	single chip	9	81
	low insulation resistance	9	Soldering iron strike	2	single chip	9	162
Mechanical damage	low insulation resistance	9	Board break out	9	single chip	9	729
	low insulation resistance	9	ICT damage,assembly and other	5	single chip	9	405
	low insulation resistance	9	Thermal expansion of the PCB	5	single chip	9	405
ESD damage	low insulation resistance	9	ESD damage	2	single chip	9	162

Single chip Solution Risk rating = 1944

2 Capacitors in Series Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	2 chip in series	6	54
	low insulation resistance	9	Soldering iron strike	2	2 chip in series	6	108
Mechanical damage	low insulation resistance	9	Board break out	9	2 chip in series	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	2 chip in series	7	315
	low insulation resistance	9	Thermal expansion of the PCB	5	2 chip in series	7	315
ESD damage	low insulation resistance	9	ESD damage	2	2 chip in series	8	144

2 Capacitors in Series Solution Risk rating = 1098

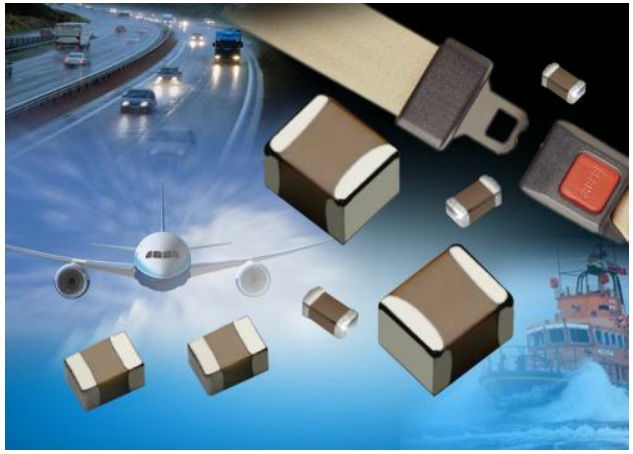
Single chip FLEXITERM® Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	FLEXITERM®	9	81
	low insulation resistance	9	Soldering iron strike	2	FLEXITERM®	9	162
Mechanical damage	low insulation resistance	9	Board break out	9	FLEXITERM®	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	FLEXITERM®	2	90
	low insulation resistance	9	Thermal expansion of the PCB	5	FLEXITERM®	2	90
ESD damage	low insulation resistance	9	ESD damage	2	FLEXITERM®	9	162

Single chip FLEXITERM® Solution Risk rating = 747

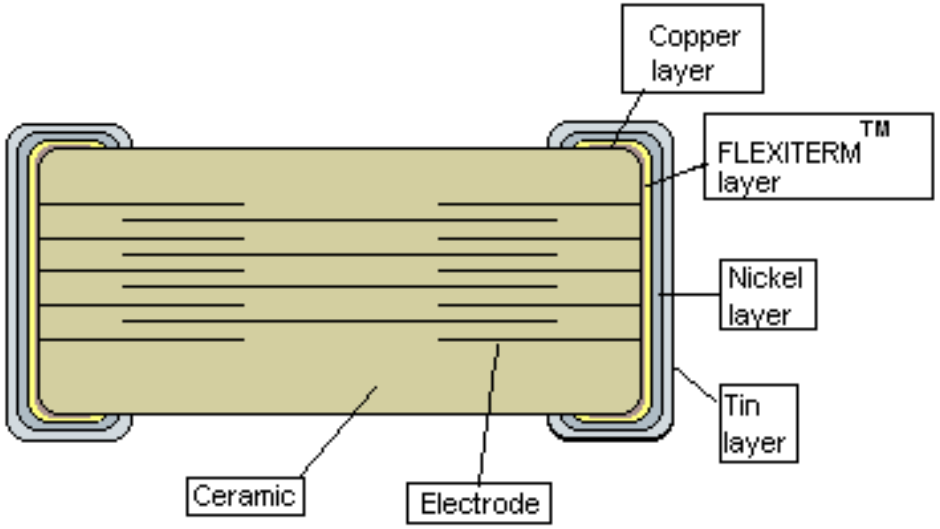
FLEXISAFE™

FLEXISAFE™ is a Capacitor specifically designed to virtually eliminate the risk of short circuit failure.



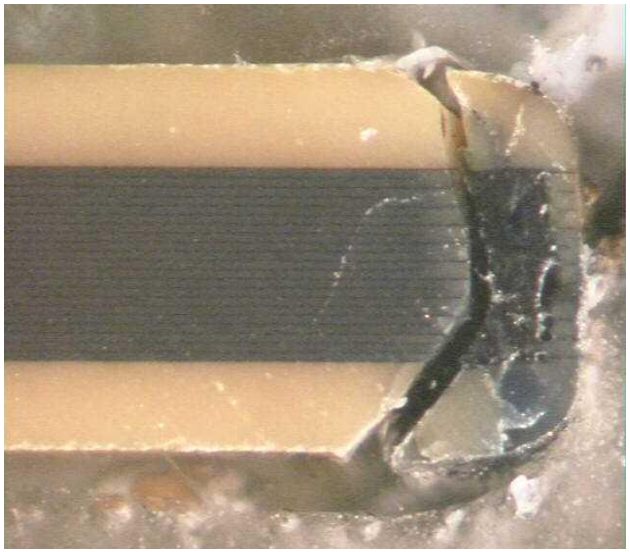
FLEXISAFE™

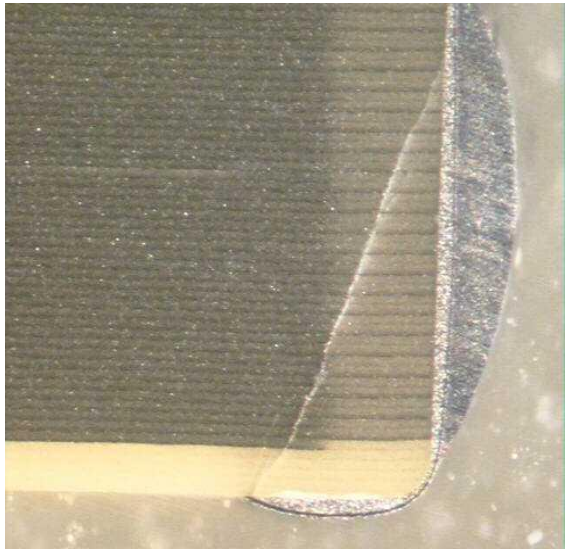
The FLEXISAFE™ components are terminated with the award winning FLEXITERM® layer.



FLEXISAFE™

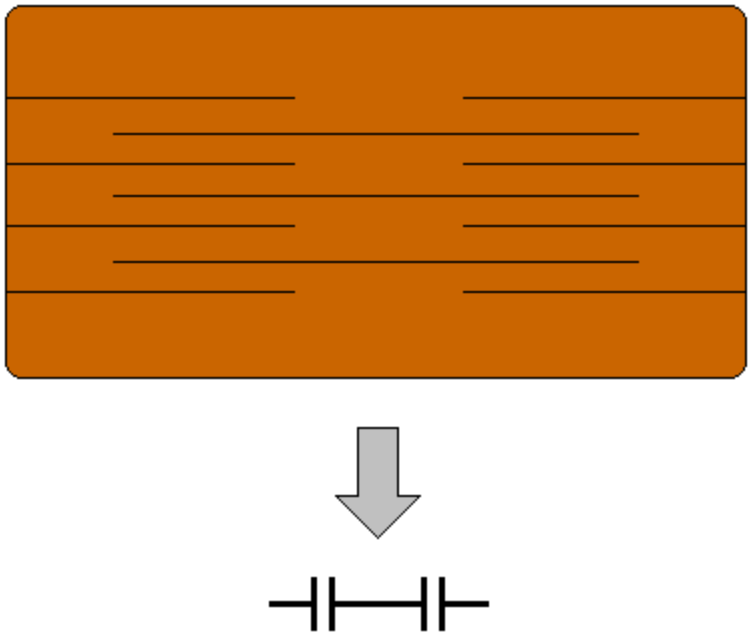
The FLEXITERM® layer works as a “Shock absorber”, preventing internal cracking resulting from board flexure / temperature cycling damage:-





FLEXISAFE™

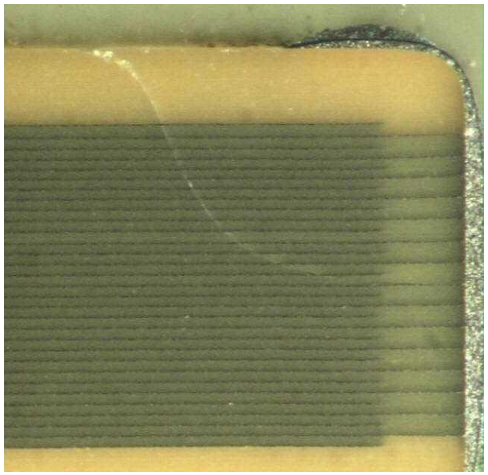
The FLEXISAFE™ components are manufactured with “Cascade electrode design” internal structure.

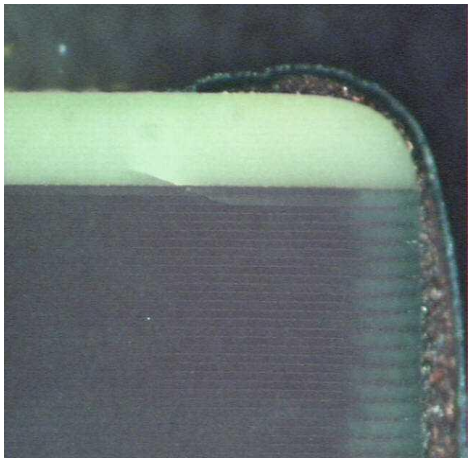


FLEXISAFE™

The cascade structure protects the ceramic capacitor from low insulation resistance failure resulting from the following issues:

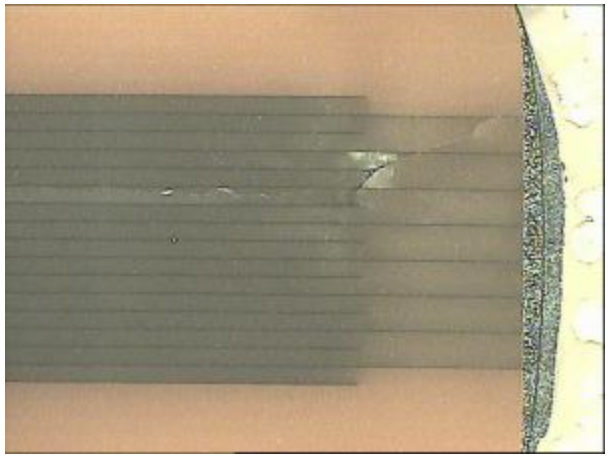
- **Thermal stress damage (typically from soldering / reworking)**

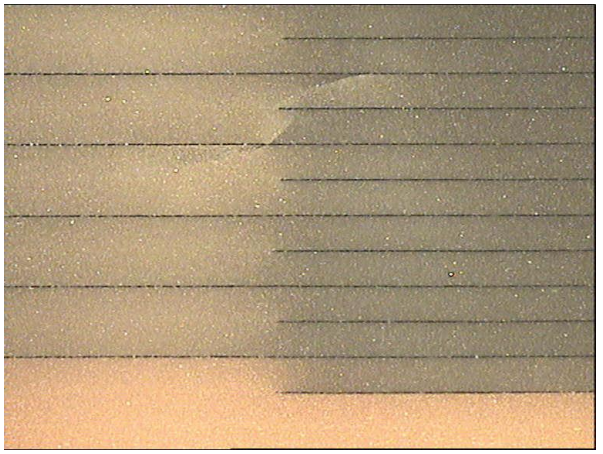




FLEXISAFE™

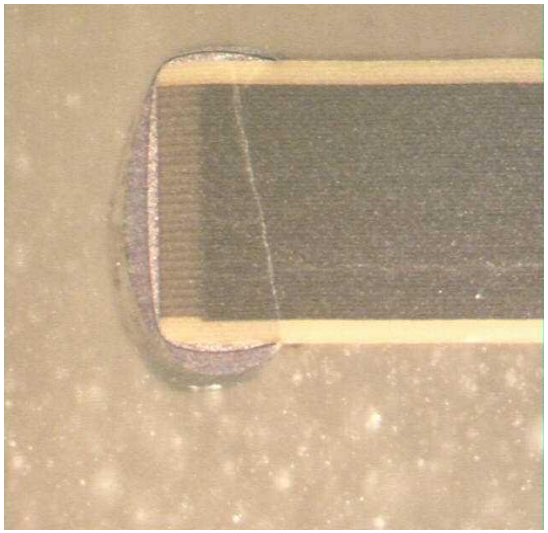
- **ESD damage**





FLEXISAFE™

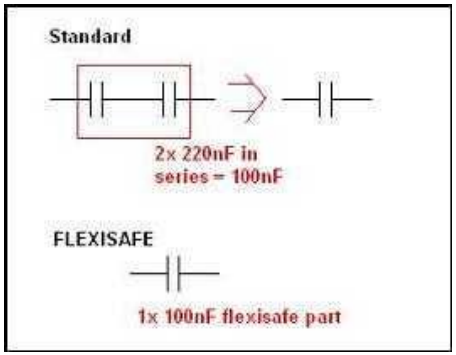
- **Placement damage**



FLEXISAFE™

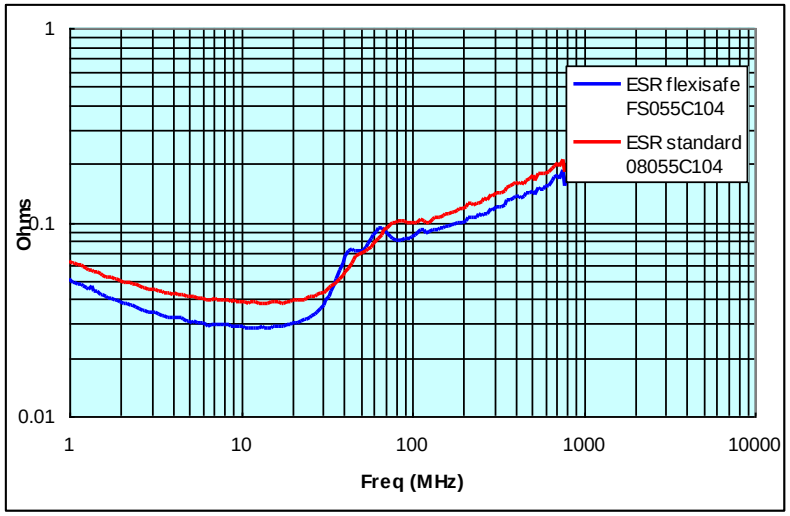
Additional benefits.

- Lower inductance than 2 capacitors in series.



2x 220nF in series		Flexisafe 100nF
ESL		ESL
1.579nH		0.855nH
1.450nH		0.783nH
1.405nH		0.764nH
1.408nH		0.858nH

- Lower ESR than 1 standard component.



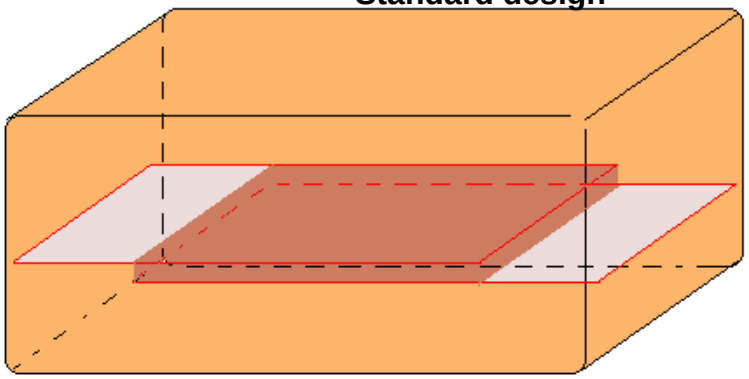
FLEXISAFE™

The Technology.

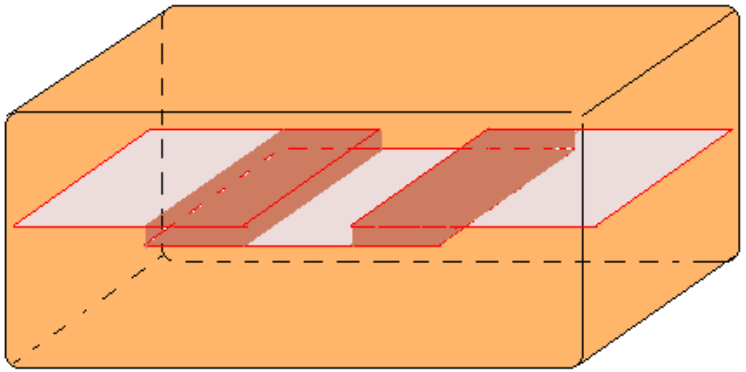
• The cascade design for the FLEXISAFE range of components results in an approximate reduction of the capacitance capability of the MLCC of a factor of 4.

• Half of the capacitance is lost because the electrode plate area is reduced.

Standard design



Cascade design



• Because 2 capacitors are now in series, there is also a resultant further reduction in the capacitance by a factor of 2.

Weighted comparison

Single chip Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution	Effectiveness	Risk rating
		9 = most severe		9 = most common		9 = Least effective	
Soldering	low insulation resistance	9	High delta T	1	single chip	9	81
	low insulation resistance	9	Soldering iron strike	2	single chip	9	162
Mechanical damage	low insulation resistance	9	Board break out	9	single chip	9	729
	low insulation resistance	9	ICT damage,assembly and other	5	single chip	9	405
	low insulation resistance	9	Thermal expansion of the PCB	5	single chip	9	405
ESD damage	low insulation resistance	9	ESD damage	2	single chip	9	162

Single chip Solution **Risk rating =** **1944**

2 Capacitors in Series Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	2 chip in series	6	54
	low insulation resistance	9	Soldering iron strike	2	2 chip in series	6	108
Mechanical damage	low insulation resistance	9	Board break out	9	2 chip in series	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	2 chip in series	7	315
	low insulation resistance	9	Thermal expansion of the PCB	5	2 chip in series	7	315
ESD damage	low insulation resistance	9	ESD damage	2	2 chip in series	8	144

2 Capacitors in Series Solution **Risk rating =** **1098**

Single chip FLEXITERM® Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	FLEXITERM®	9	81
	low insulation resistance	9	Soldering iron strike	2	FLEXITERM®	9	162
Mechanical damage	low insulation resistance	9	Board break out	9	FLEXITERM®	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	FLEXITERM®	2	90
	low insulation resistance	9	Thermal expansion of the PCB	5	FLEXITERM®	2	90
ESD damage	low insulation resistance	9	ESD damage	2	FLEXITERM®	9	162

Single chip FLEXITERM® Solution **Risk rating =** **747**

Single chip FLEXISAFE™ Solution

Process	Potential failure effect	Severity	Potential Causes	Occurrence	Design solution		Risk rating
Soldering	low insulation resistance	9	High delta T	1	FLEXISAFE™	7	63
	low insulation resistance	9	Soldering iron strike	2	FLEXISAFE™	7	126
Mechanical damage	low insulation resistance	9	Board break out	9	FLEXISAFE™	2	162
	low insulation resistance	9	ICT damage,assembly and other	5	FLEXISAFE™	1	45
	low insulation resistance	9	Thermal expansion of the PCB	5	FLEXISAFE™	1	45
ESD damage	low insulation resistance	9	ESD damage	2	FLEXISAFE™	8	144

Single chip FLEXISAFE™ Solution **Risk rating =** **585**

Summary

- Suppliers must consider that there is no 100% guaranteed safe solution for components in direct battery applications.

- However, with the development of FLEXITERM® and FLEXISAFE™ technologies, a supplier would be able to provide the customer with an improvement in safety over the accepted “2 capacitor in series” solution.

- FLEXI technology has already proven to provide excellent protection against flexure and thermally induced mechanical damage.

- A single FLEXITERM® or FLEXISAFE™ capacitor reduces the amount of board space required, and reduces placement costs.