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Ceramic Capacitor Failures and Lessons Learned

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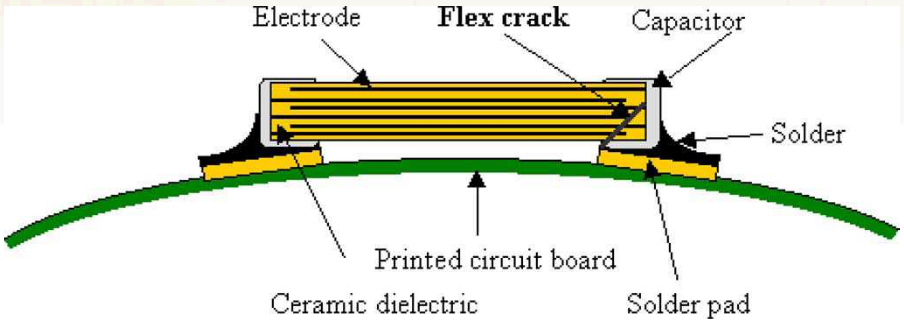
Sandia's Capacitor Experiences in FY10

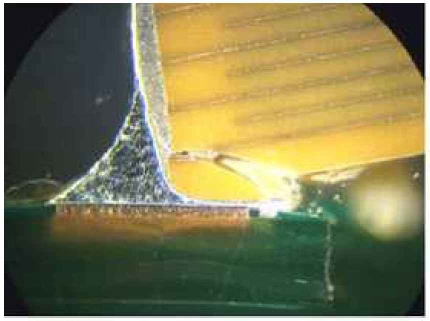
- Sandia had two projects in FY10 that involved damage to ceramic capacitors
  - One where a commonly-available ceramic capacitor was a dominant failure mode
  - One where we deliberately damaged ceramic capacitors in order to understand their electro-mechanical response

Background: Capacitor Mechanical Failure



M. Keimasi, et al., Flex Cracking of Mulilayer Ceramic Capacitors Assembled with Pb-Free and Tin-Lead Solders, IEEE Trans. Device and Materials Reliability, Vol. 8, No. 1, March 2008

Failure of ceramic capacitors due to PCB flexure is a common problem.



Example MLCC flex crack

http://www.johansondielectrics.com/technical-notes/general/capacitor-cracks-still-with-us-after-all-these-years.html

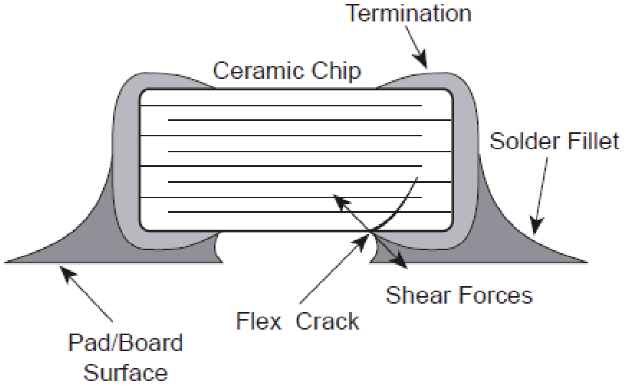
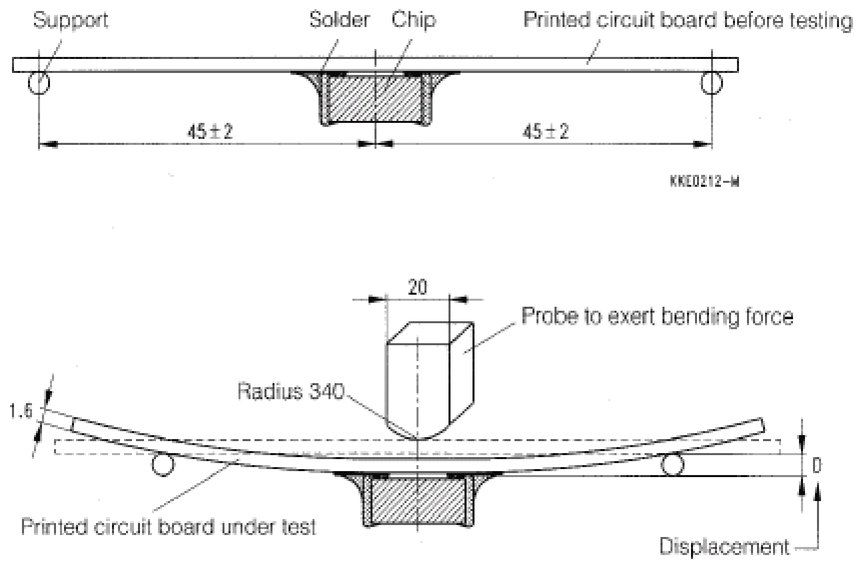


Diagram of an MLCC flex crack

Capacitance Monitoring While Flex Testing, J. Bergenthal and J. Prymak, Kemet F-2110, reprinted 8/98, http://www.kemet.com/kemet/web/homepage/kechome.nsf/file/f2110/$file/f2110.pdf

Bend Testing

Bend testing is a common way to evaluate the strength of the capacitors – because it causes failures.



AEC-Q200-REV C, *Stress Test Qualification for Passive Components*, Method 005, Passive Component Board Flex / Terminal Bond Strength Test

See also:

- *Bend Testing, Methods and International Specifications*, AN0002 – Bend Testing, Issue 3, Syfer Technology Limited
- L. Mercado, B. Phillips, et al., *Handheld Use Condition-Based Bend Test Development*, IEEE Trans. Advanced Packaging, Vol. 29, No. 2, May 2006

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3DDR: Small Ceramic Capacitor Failures

- **3DDR is an instrumentation data recorder**
- **Seven units were tested to failure in order to understand dominant failure modes**
  - **Root cause of failure was determined for all**
- **The failure mode for 4 out of the 7 was a small ceramic capacitor failure**

Unit	Cause of Failure
F1540	Capacitors C84/C85 (open)
F1541	Capacitor C91 (shorted)
090804	Connector failure (caused by test)
F1538	Unit failure (caused by test)
090805	Capacitor C91 (shorted)
090806	No failure (yet)
090807	Capacitor C91 (shorted)

Each 3DDR unit failed after a number of mechanical tests.

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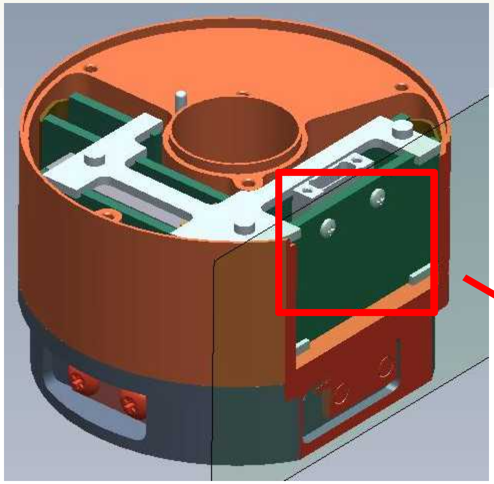
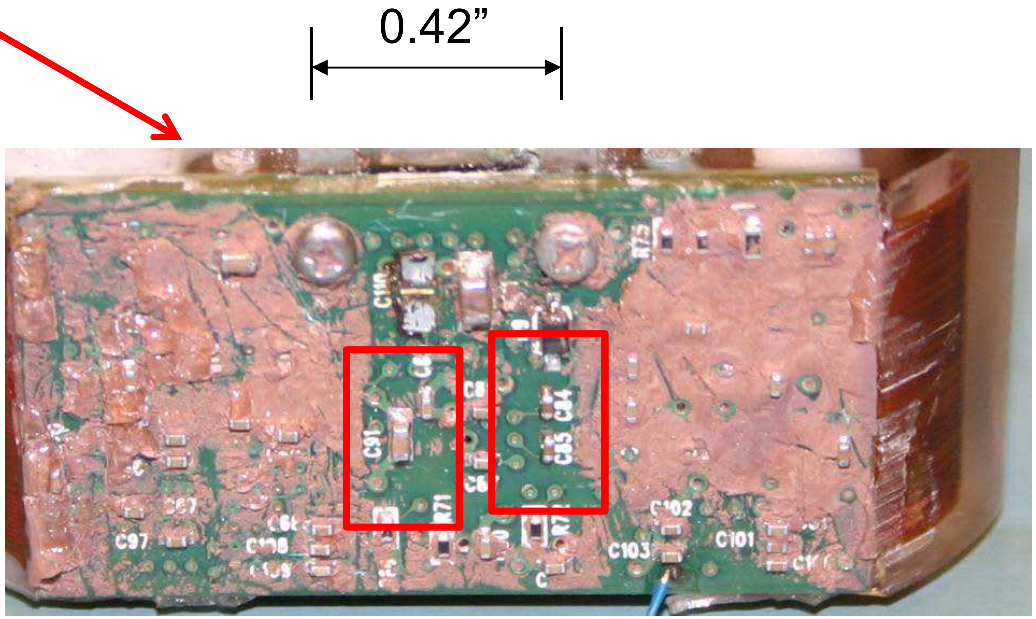
Locations of Failed Capacitors



The dominant failure mode was capacitor failure in a very specific region of the back side of one rigid section of PCB.

Capacitor C91 failed shorted 3 times while capacitors C84 (or C85) failed open once.



Locations of failed capacitors

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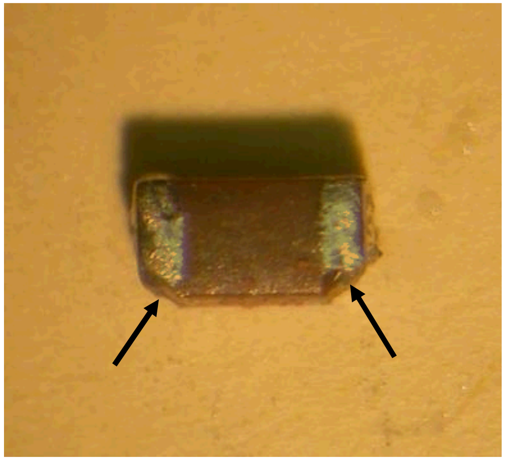
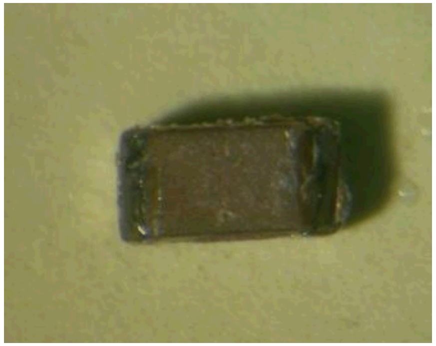
Example of Capacitor Failure

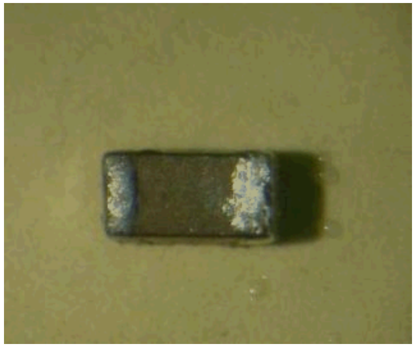
Damage to the capacitor is at the corners
where the capacitor is soldered to the PCB



Side View



Bottom View



Top View

The capacitor is a COTS, 0603-package, X7R dielectric component

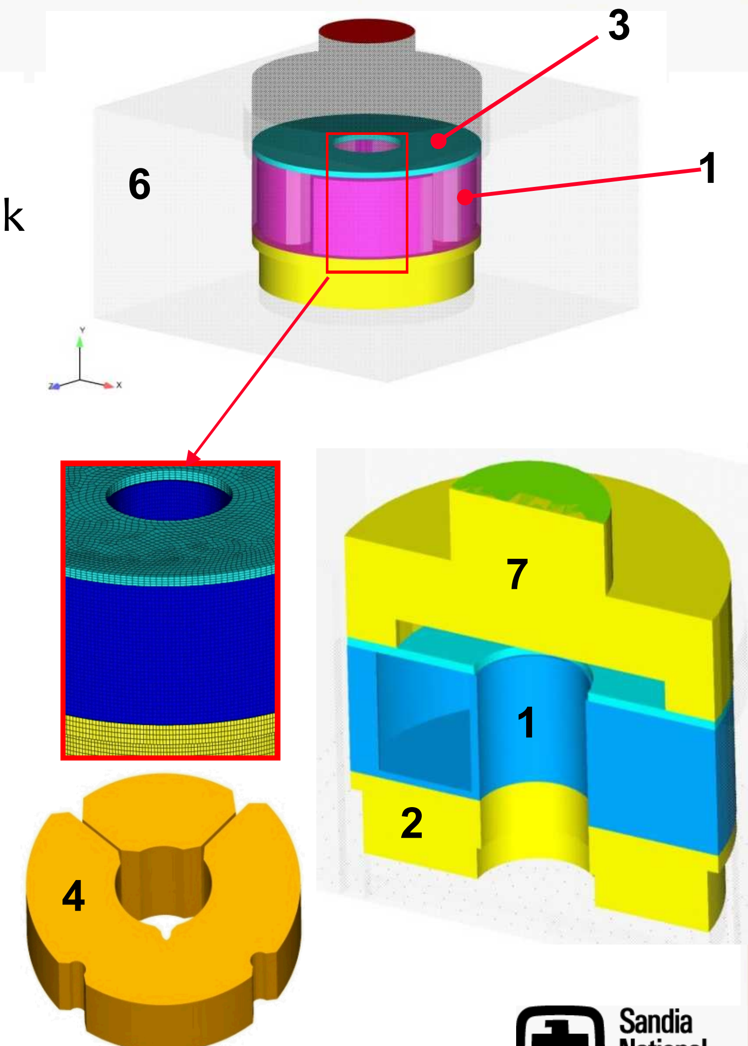
Simplified Finite Element Model

A finite element model was developed to test the hypothesis that PCB deformation was causing the capacitors to break.

A simplified model with no PCB was developed to look at stresses in the potting material

- Full 3D Hex Element model
- 7 Material Blocks
- Nodes = 480K
- Elements = 400K
- Element Length < 0.020-inch

Component	Block ID	Material Model
Upper Housing	1	4340 Steel Elastic-Plastic
Lower Housing	2	4340 Steel Elastic-Plastic
Housing Lid	3	4340 Steel Elastic-Plastic
Potting	4	Hysol Elastic (Ref. Adolph)
Battery Pack	5	Aluminum Elastic
Fixture	6	Aluminum Elastic
Pressure-Bar/Retaining ring	7	Aluminum Elastic



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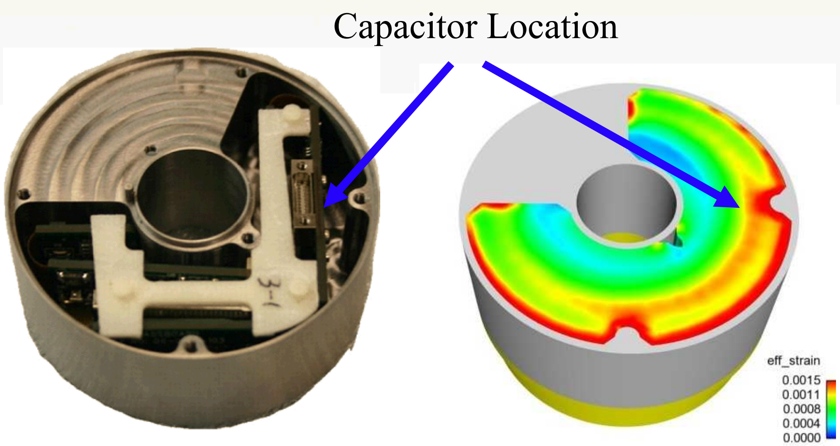
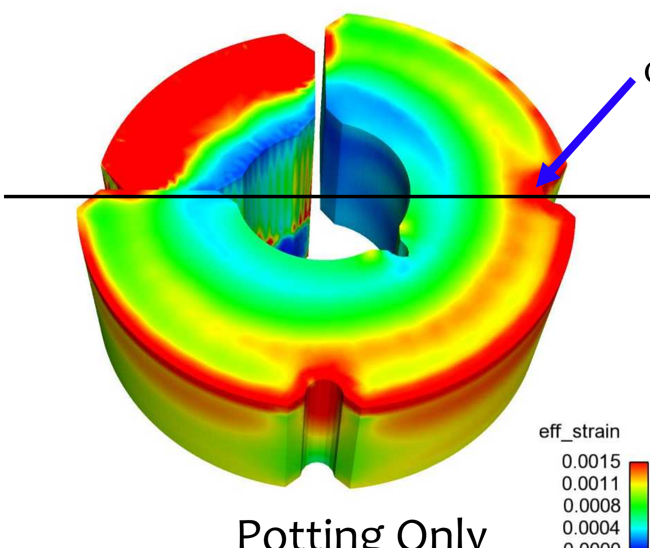
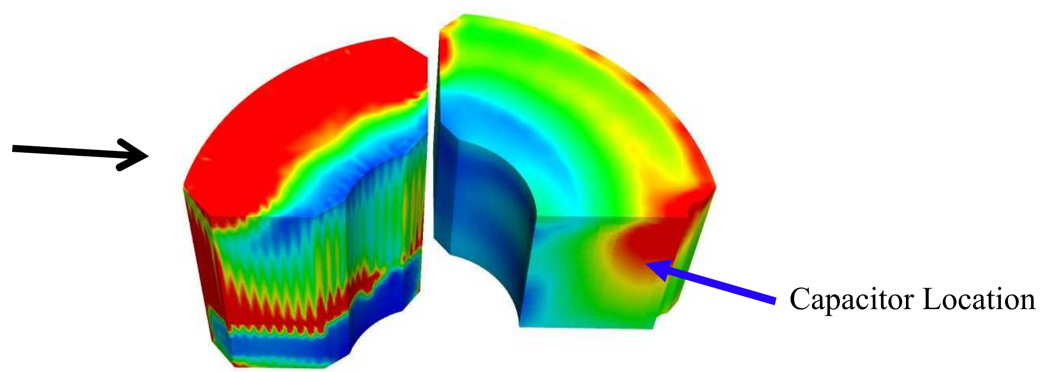
Static Loading Results



- No yielding in potted 3DDR housing
- High stress in potting near lid
- Main potting maximum effective strain = 1500με
- ***High strain at capacitor location***



Potting Only



Cross-section of potting

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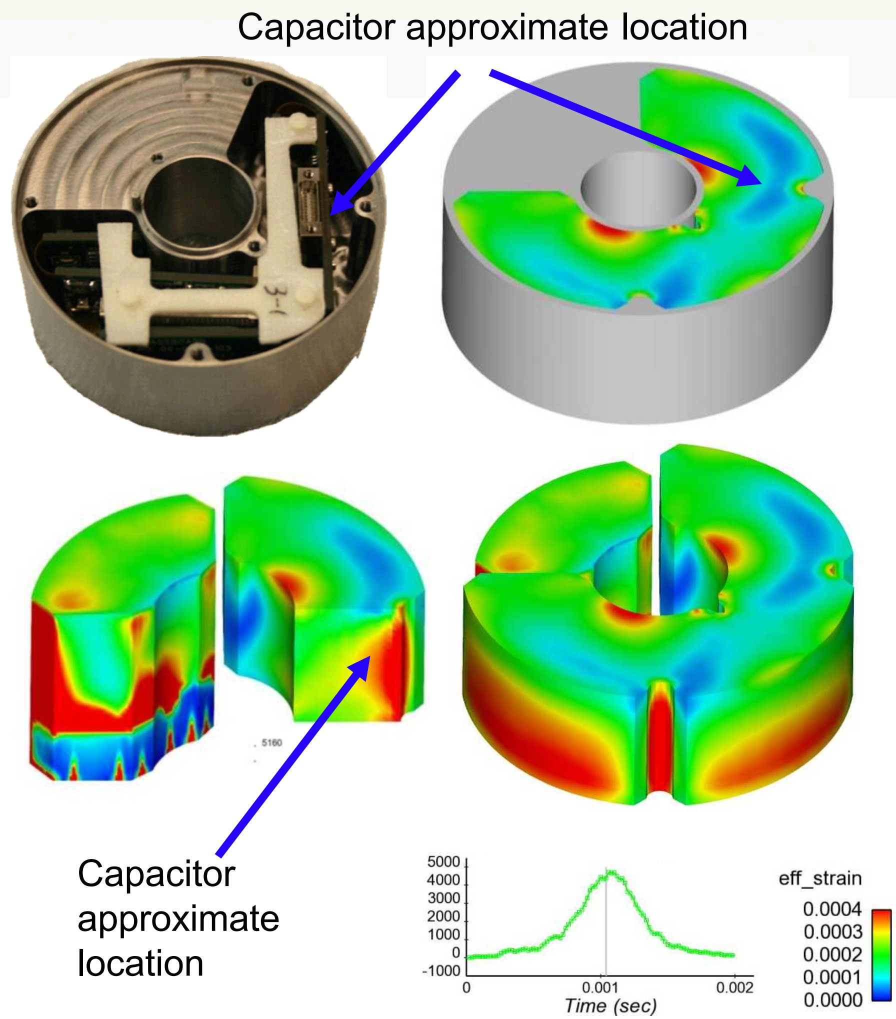
Dynamic Loading Results

- Acceleration loading applied at bottom of fixture
- No yielding in potted 3DDR housing
- High stress in potting propagate from bottom up
- Main Potting Maximum effective strain = 400με
- ***Noticeable strain at capacitor location***



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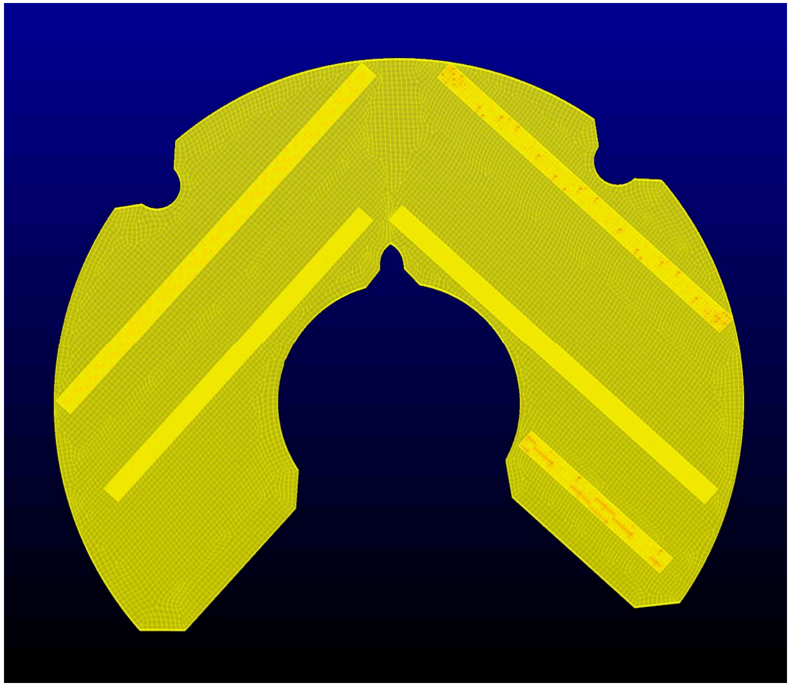
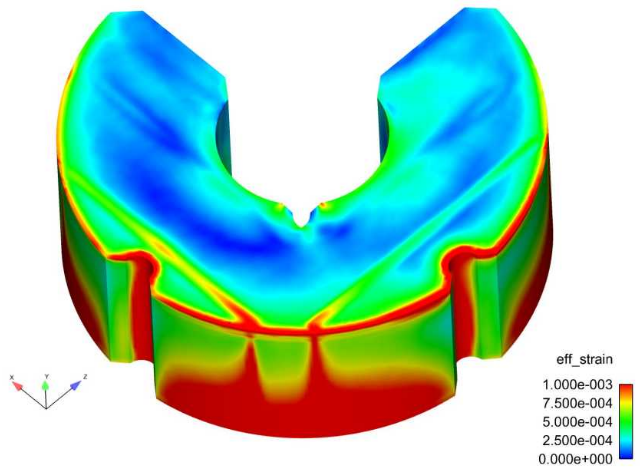
Higher Fidelity Model

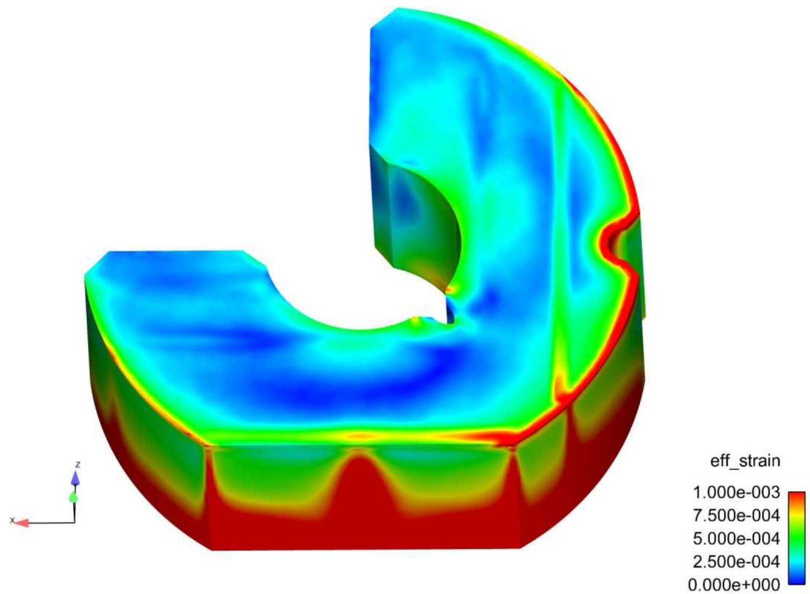
A higher fidelity model was developed that included the PCB in order to understand its strain.

- 1.3M elements, 1.4M nodes
- Approximately 750K elements for the potting material
- Linear elastic PCB material model



High Fidelity Model Results



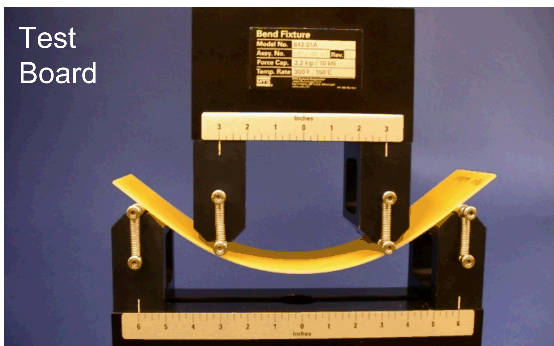


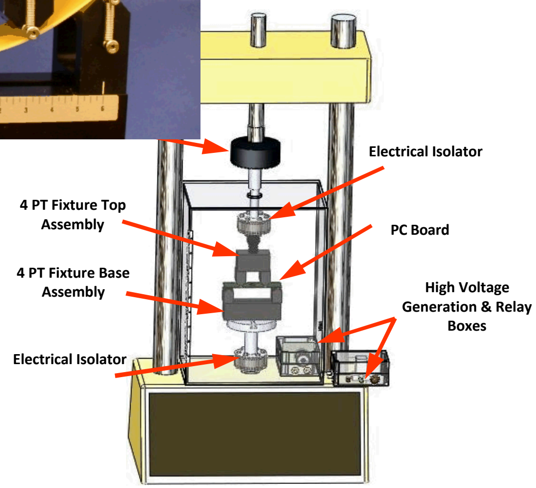
- Results based on a measured acceleration input
- Model results show that there is a strain of approximately 500με at the surface of the PCB near where the capacitors failed
- Strain is not enough* to break the capacitor off the PCB in one test – modeling matches experiment

* - Using Keimasi (2008) as the reference for necessary strain to induce flex cracking in small ceramic capacitors

Breaking Capacitors – On Purpose

- We took ceramic capacitors with three dielectrics and subjected them to mechanical, electrical and combined tests





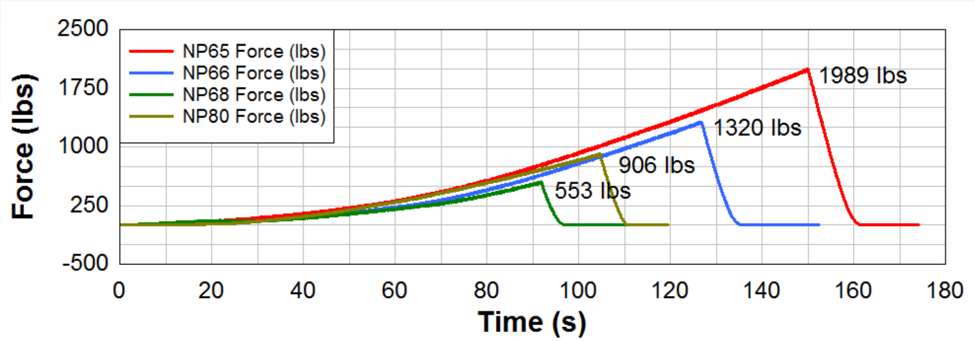
Electrical Tests

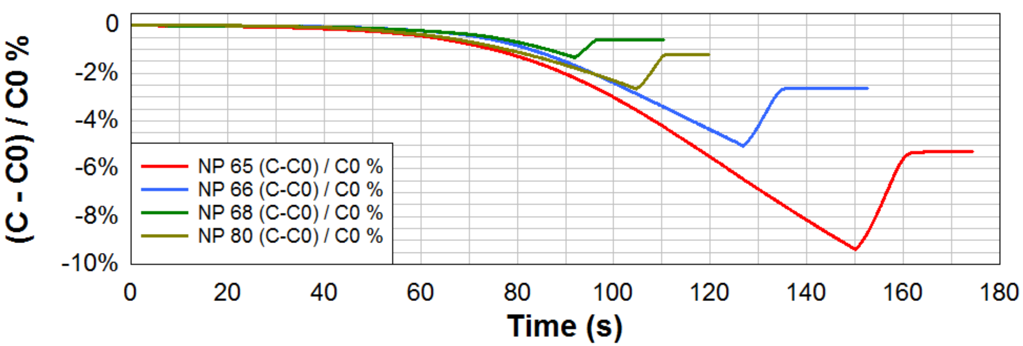
	Nominal	Breakdown Voltage	Pulse Discharge
Nominal		Benchtop Breakdown Voltage Characterization	Benchtop Pulse Discharge Characterization
Static Compression	Isolated Mechanical Compression	Breakdown Voltage under Compression	Pulse Discharge under Compression
Static Bending	Isolated Mechanical Bending	Breakdown Voltage under Bending	Pulse Discharge under Bending

Three Results

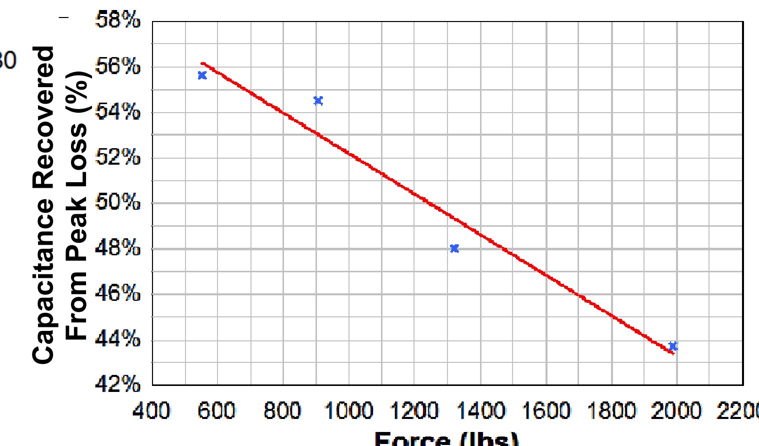
1. Capacitance recovery after mechanical compression
2. Effect of reflow soldering on mechanical failure
3. Capacitance change caused by mechanical compression

Capacitance Recovery





One dielectric showed reduced capacitance after mechanical compression



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Effect of Reflow Soldering on Mechanical Strength

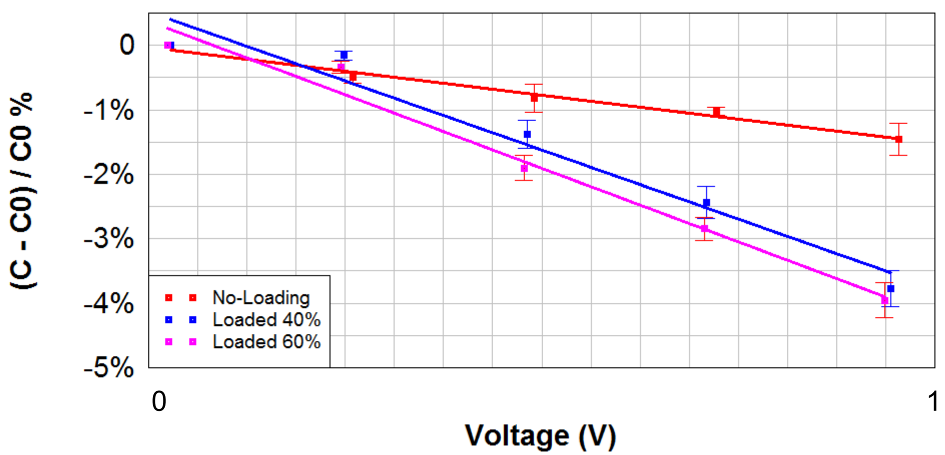
- We found that reflow soldering these capacitors causes them to fail at lower mechanical stresses than using a non-solder attachment technique
- Manufacturer soldering guidelines were followed

Average compressive displacement at failure (mils)

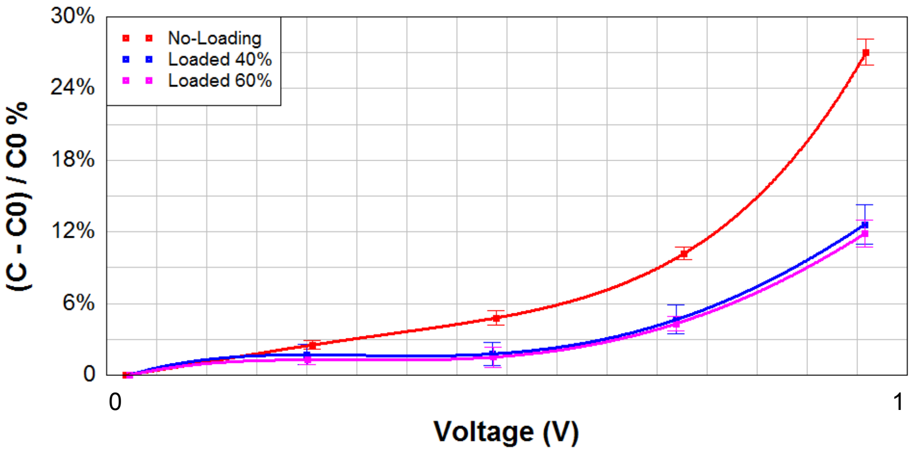
Type	Solder	Conductive Epoxy
A	5.60	8.77
B	6.71	16.0
C	9.65	18.5

Capacitance Change During Mechanical Compression

Dielectric B



Dielectric C



- Dielectric B showed a diminished capacitance when compressed
- Dielectric C showed a diminished increase in capacitance when compressed

Summary

- PCB flexure is one sure way to damage even tiny capacitors
  - But modeling and simulation, combined with existing experimental data, can help predict this
  - Even relatively low fidelity modeling can help qualitatively
- Ceramic capacitors can change characteristics during and after mechanical stresses

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Acknowledgements

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