Engineering Design Analysis (Physics of Failure)

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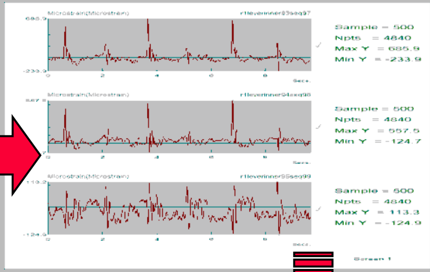
Why Physics of Failure?

- Army needs better approaches to identify potential reliability problems early so the appropriate actions can be taken
- Testers, Evaluators, Program Managers need the best tools to enable a T&E that gets the most out of every test
- Physics-of-Failure (PoF) M&S aids test evaluation by revealing the underlying physics that explain system performance – helps identify “root-causes” of test and field failures
- PoF in use by private sector –broader application of PoF can help achieve materiel reliability levels to those achieved by commercial sector

Mechanical PoF Overview

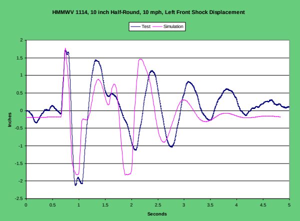
System-level Dynamics Model

Live Data from Instrumented Tests

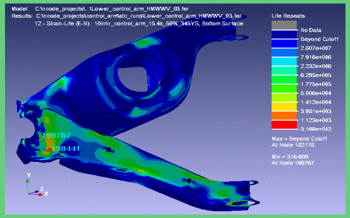


Strains, Accelerations, Displacements

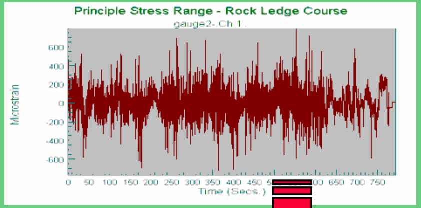
Loads, Accelerations



Finite Element Analysis (FEA)

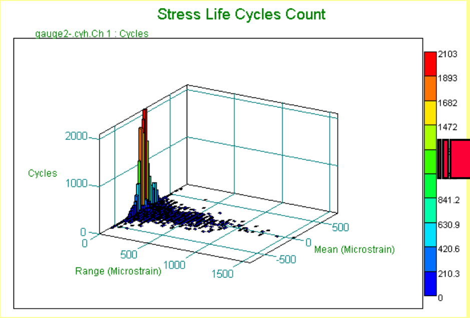


Strain Time History

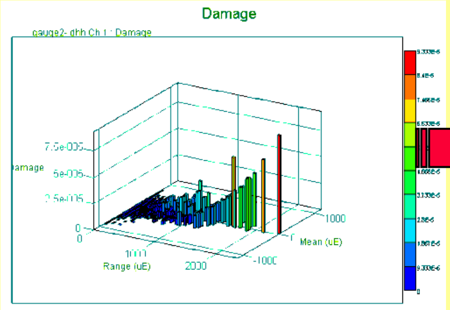


FEA tools, e.g. Abaqus, ANSYS, NASTRAN

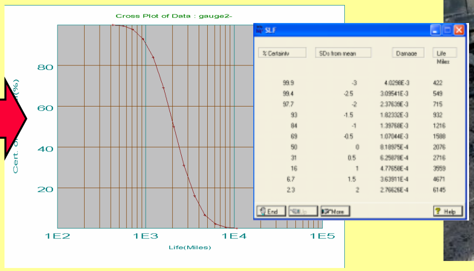
Rainflow Cycles Count



Damage Cycles Count



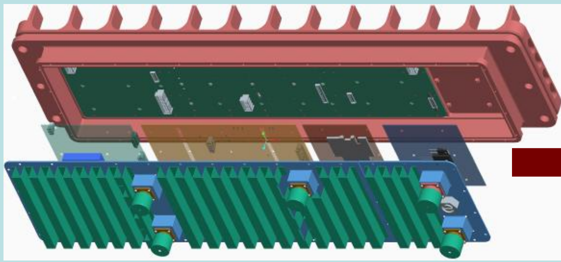
Component Life Prediction

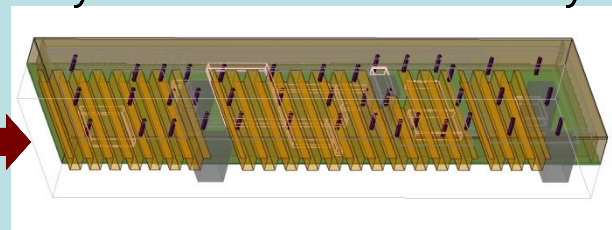


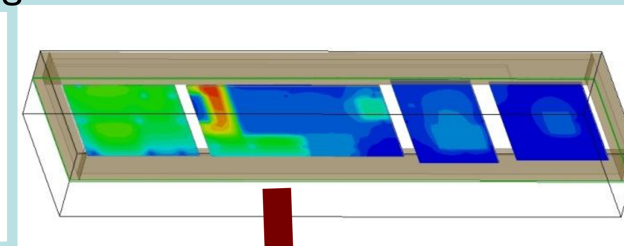
Computational fatigue analysis using nCode tools, BS7608, or similar standards

Electronics PoF Analysis Overview

System-Level Thermal Analysis

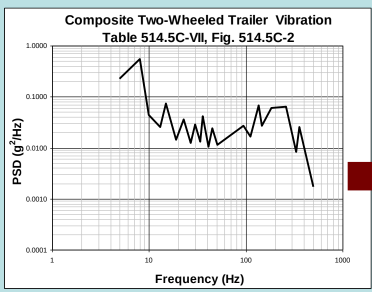


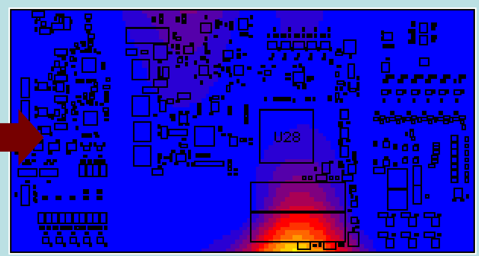




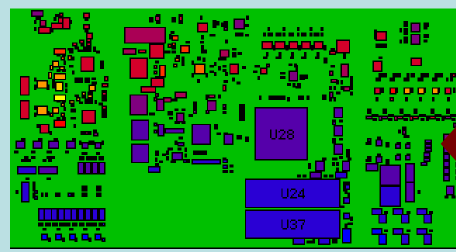
Board-Level Analysis

Mechanical Loads



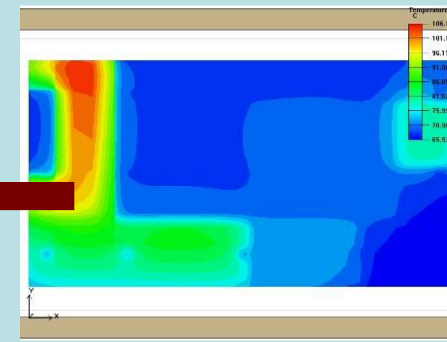


Board Displacement

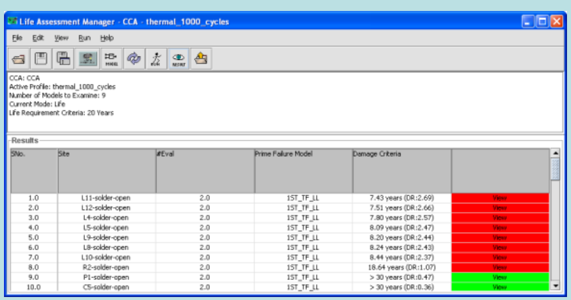


Thermal Overstress Analysis

Thermal Loads



Component Life Estimates



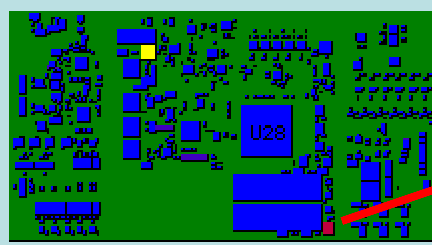
Life Assessment Manager - CCA - thermal_1000_cycles

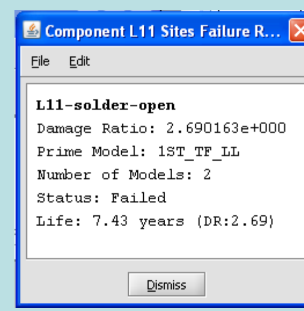
File Edit View Run Help

CCA: CCA
Active Profile: thermal_1000_cycles
Number of Models to Examine: 9
Current Mode: Life
Life Requirement Criteria: 20 Years

Results

SNo.	Site	#Eval	Prime Failure Model	Damage Criteria	
1.0	L11-solder-open	2.0	1ST_TF_LL	7.43 years (DR:2.69)	View
2.0	L12-solder-open	2.0	1ST_TF_LL	7.51 years (DR:2.66)	View
3.0	L4-solder-open	2.0	1ST_TF_LL	7.80 years (DR:2.57)	View
4.0	L5-solder-open	2.0	1ST_TF_LL	8.09 years (DR:2.47)	View
5.0	L9-solder-open	2.0	1ST_TF_LL	8.20 years (DR:2.44)	View
6.0	L8-solder-open	2.0	1ST_TF_LL	8.24 years (DR:2.43)	View
7.0	L10-solder-open	2.0	1ST_TF_LL	8.44 years (DR:2.37)	View
8.0	R2-solder-open	2.0	1ST_TF_LL	18.64 years (DR:1.07)	View
9.0	P1-solder-open	2.0	1ST_TF_LL	> 30 years (DR:0.47)	View
10.0	C5-solder-open	2.0	1ST_TF_LL	> 30 years (DR:0.36)	View





Electronics Physics of Failure

- **Physics of Failure (PoF) -** Is used to model dominant failure mechanism(s) and is aimed at eliminating failures through redesign

- **Benefits of Physics of Failure**
  - Determine if component will last in field
  - Find life limiting failures in fielded products
  - Determine root cause of failures
  - Improve design prior to testing
  - Analyze impact of design changes
  - Use models for prognostics
  - ***Identify simple inexpensive design changes***
  - ***Decrease O&S costs***

- **Physics of Failure lessons learned**
  - ***Apply early in the design process***
  - Can significantly reduce testing
  - Very high return on investment
  - Refine model as design changes

- **University of Maryland (UMD) CALCE Electronics Products Systems Center (EPSC) Tools**
  - ***CalcePWA***
  - CalceFAST
  - CalceEP

- **CirVibe**

- **Solder Reliability Solutions (SRS)**

- **Finite Element Analysis (FEA) Software**
  - ***Patran/Nastran***
  - ANSYS
  - Pro Mechanica

- **Computational Fluid Dynamics (CFD) Software**
  - ***ICEPAK***

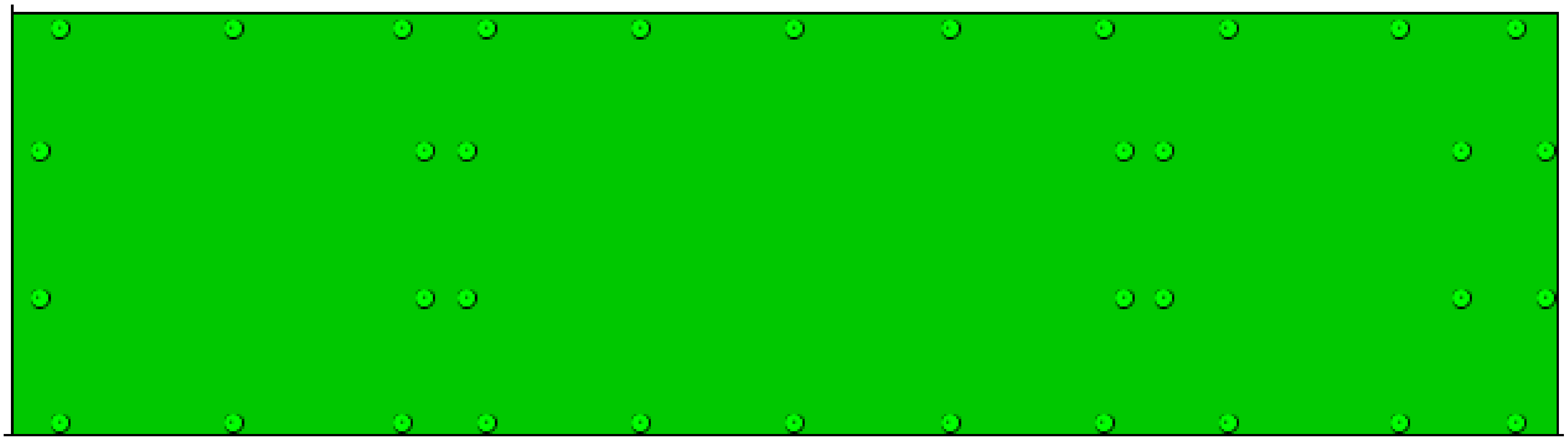
Analyses Performed

- **LRU Thermal Analysis**
  - Determines temperature profile within enclosure
- **CCA Thermal (Overstress) Analysis**
  - Determines temperatures of components & compares results to rated temperatures
- **CCA Modal Analysis**
  - Determines natural frequencies of circuit boards
- **CCA Random Vibration Response Analysis**
  - Determines displacement & curvatures of circuit boards based on random vibration input
- **CCA Shock Response Analysis**
  - Determines displacement, curvature and strain of circuit boards from specified shock pulse

Life Assessments Performed

- **CCA Shock Survivability Assessment**
  - Determines whether circuit board and components will survive given shock pulse
- **CCA Vibration Fatigue Life Assessment**
  - Estimates fatigue life of component solder-joints and leads based on input from vibration analysis
- **CCA Thermal Fatigue Life Assessment**
  - Estimates fatigue life of component solder-joints and leads based on thermal cycles (loading)
- **CCA Combined Fatigue Life Assessment**
- **CCA Thermal Plated-Through Hole Fatigue Life Assessment**
  - Estimates through hole & via plating fatigue life based on thermal cycles

Apply Early In The Design Process



CCA dimensions: 567 x 154 x 2.337 mm
Board thickness: 2.337 mm

Modeled PWB Layers: 6

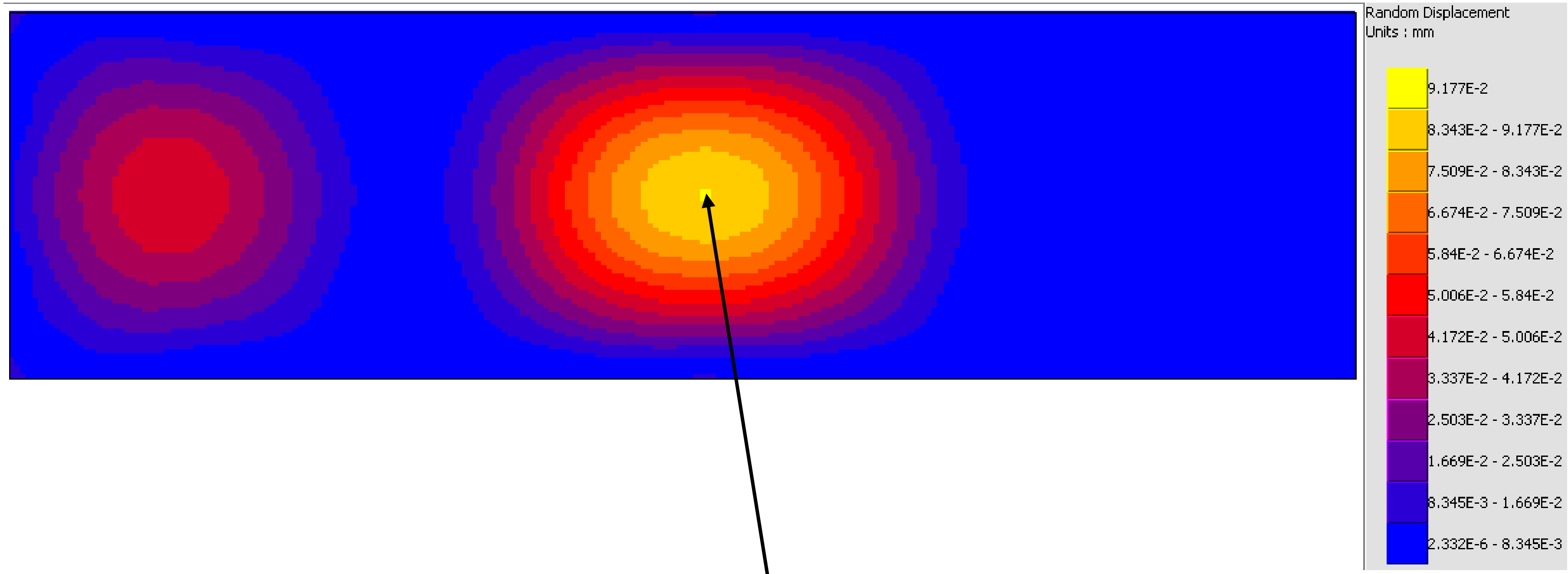
Board materials: Epoxy glass laminate (FR-4) with copper metallization

Boundary Conditions Legend:

s - Simple Support at single node, usually representing fastener (screw)

Damping factor: 0.05

Random Vibration Displacement Results

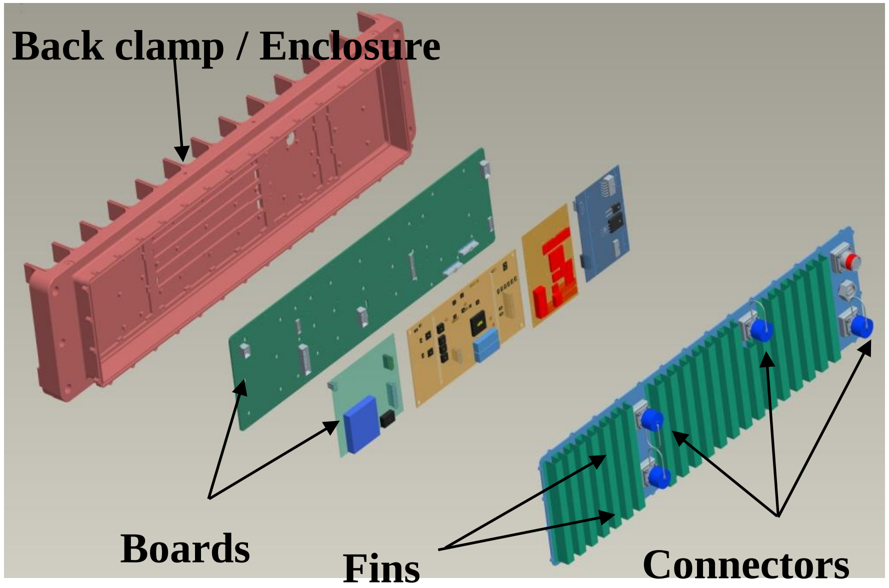


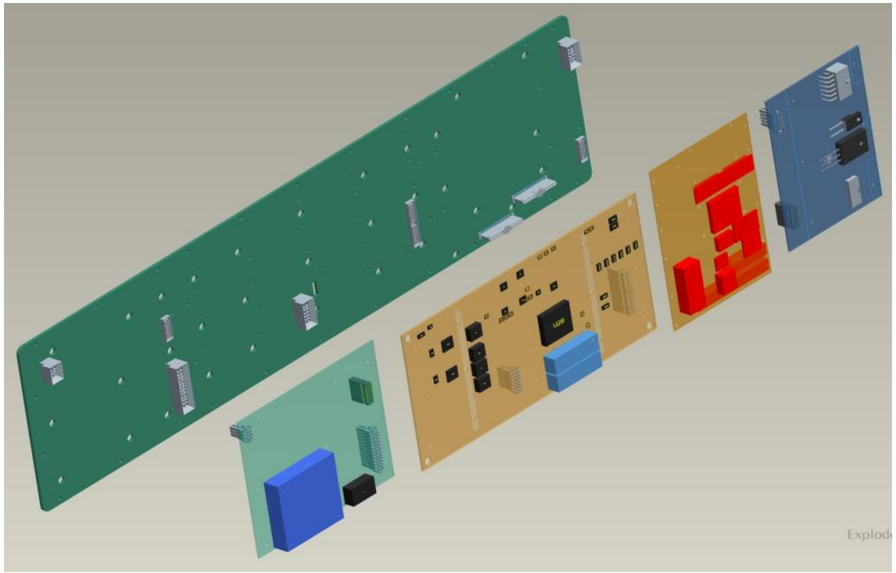
Max displacement:
0.09177 mm

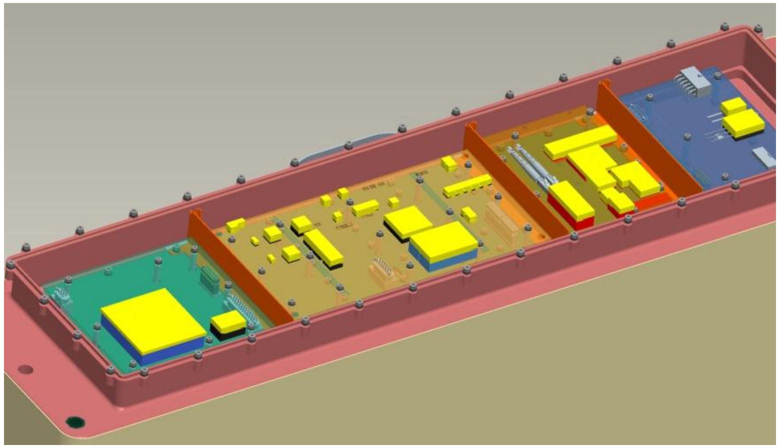
Avoid Large/Tall Leadless Components

EXAMPLE of Electronic Chassis Thermal Analysis and CCA PoF Analysis

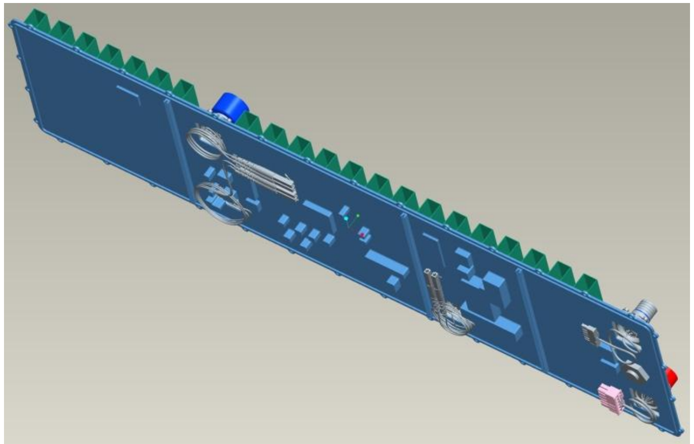
Electronic Chassis Thermal Analysis Pro-E model





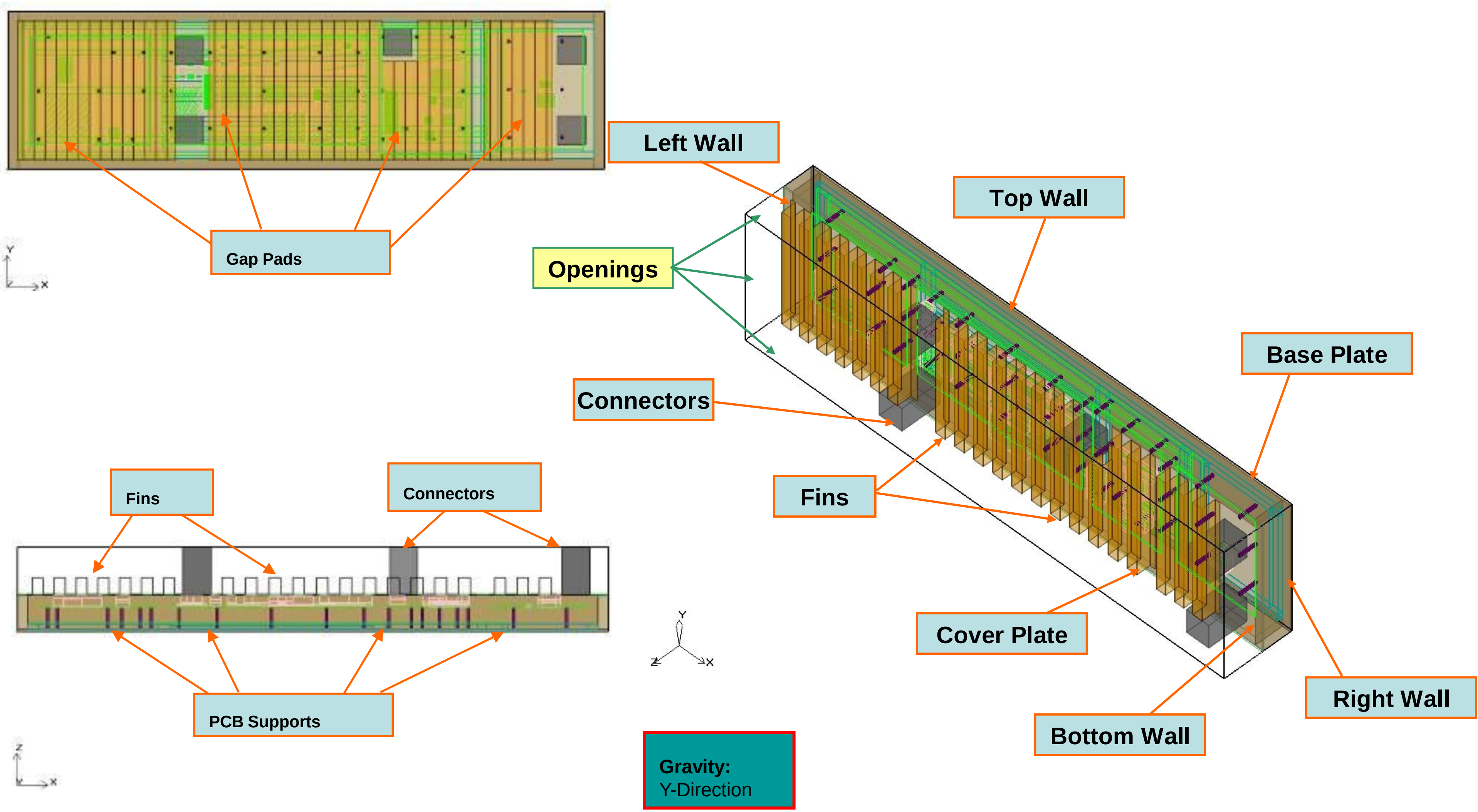


Thermal interface material / gap pad shown in yellow



Redesigned aluminum posts

Finished ICEPAK Model



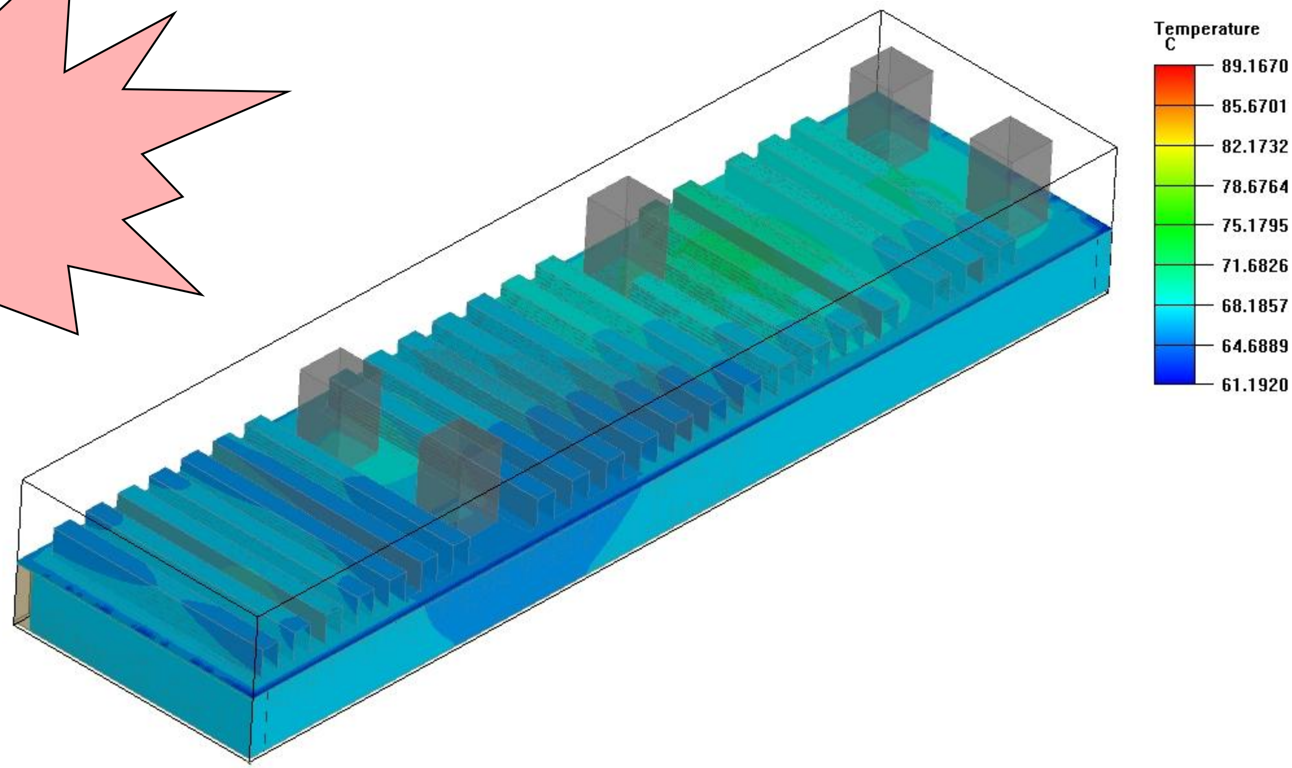
Results: Overall

Airflow through (and around) cover plate and fins calculated by ICEPAK

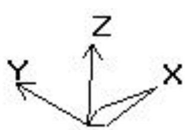
Natural Convection Cooling

Applied Heat Transfer Coefficient Values:

- Left Wall: 4.45 W/m^2-K
- Right Wall: 4.45 W/m^2-K
- Top Wall: 5.639 W/m^2-K
- Bottom Wall: 2.771 W/m^2-K



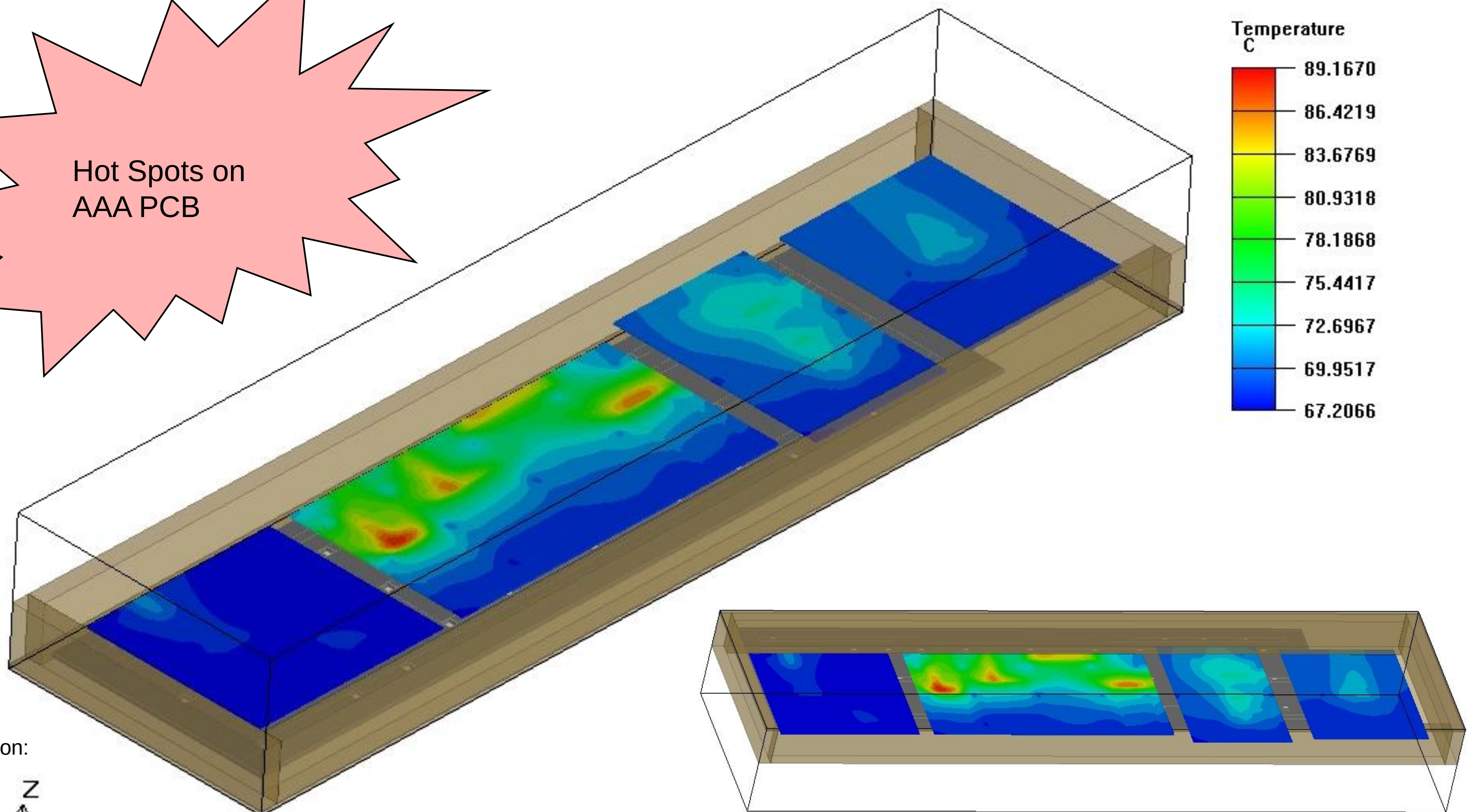
Orientation:



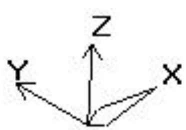
- Maximum temperature of 89.2^{o}C located within the enclosure on the AAA PCB

Results: PCB Temperatures

Hot Spots on AAA PCB

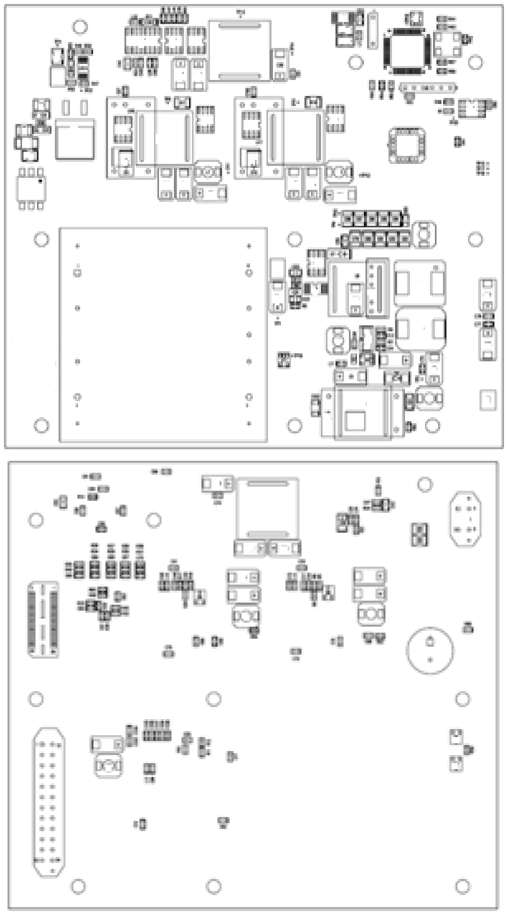


Orientation:

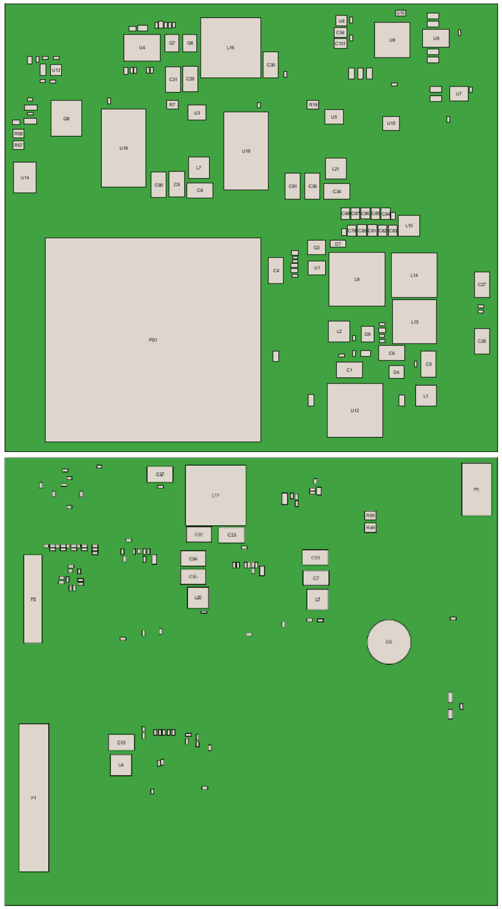


- Maximum temperature of 89.2ºC at all the PCB’s located on the AAA PCB

CCA Modeling



Component Placement Drawing



CalcePWA Model

CCA dimensions: 139.7mm x 127mm x 1.534mm

Modeled PWB Layers: 11 total
(6 signal/power/gnd)

Board materials: Epoxy-glass laminate (FR-4) with 50% copper metallization on each signal/power/ground layer

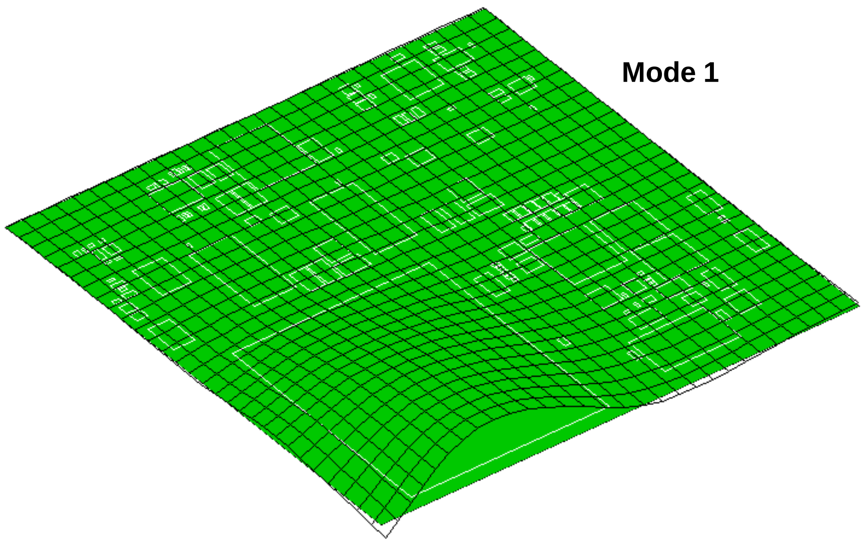
- Layers 1,3,5,7,9,11 - 1 oz Cu

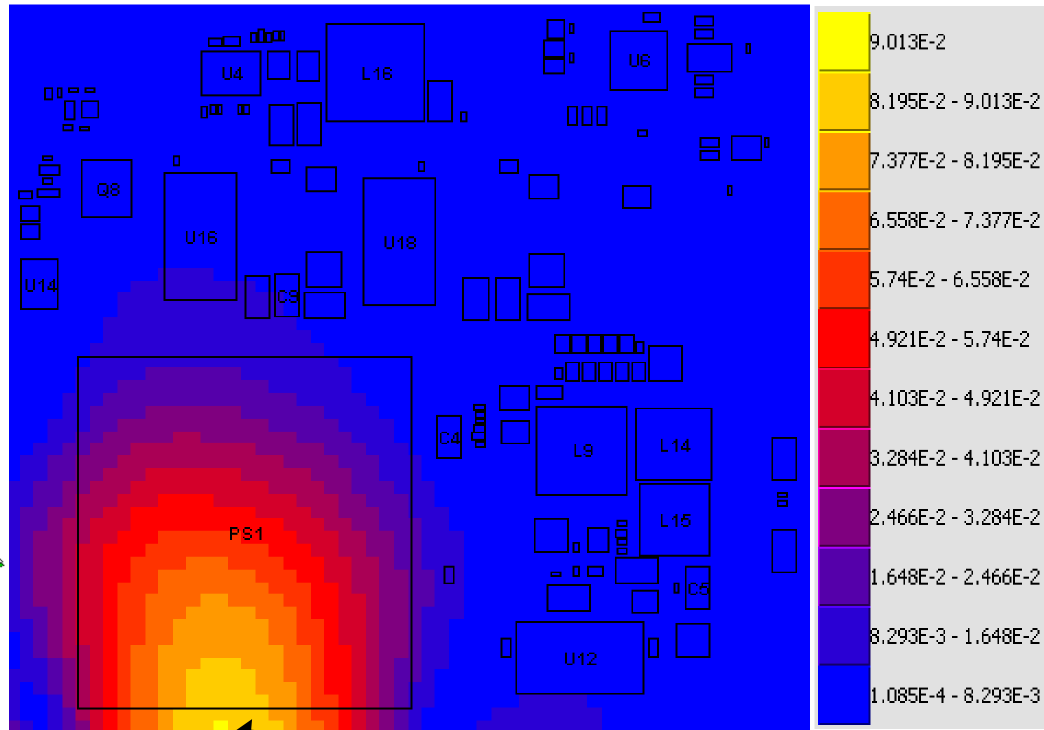
Components:

- Leadless ceramic capacitors
- Leadless ceramic resistors
- SMT Power Inductors
- SOPs, SOICs, SOTs, TQFP
- Axial-leaded diodes
- Radial-leaded inductors
- Tantalum capacitors
- Aluminum electrolytic capacitors
- Power Converter (DC/DC)
- Schottky Diodes

Modal / Random Vibration Response

Mode	1	2	3
Frequency (Hz)	272	517	581

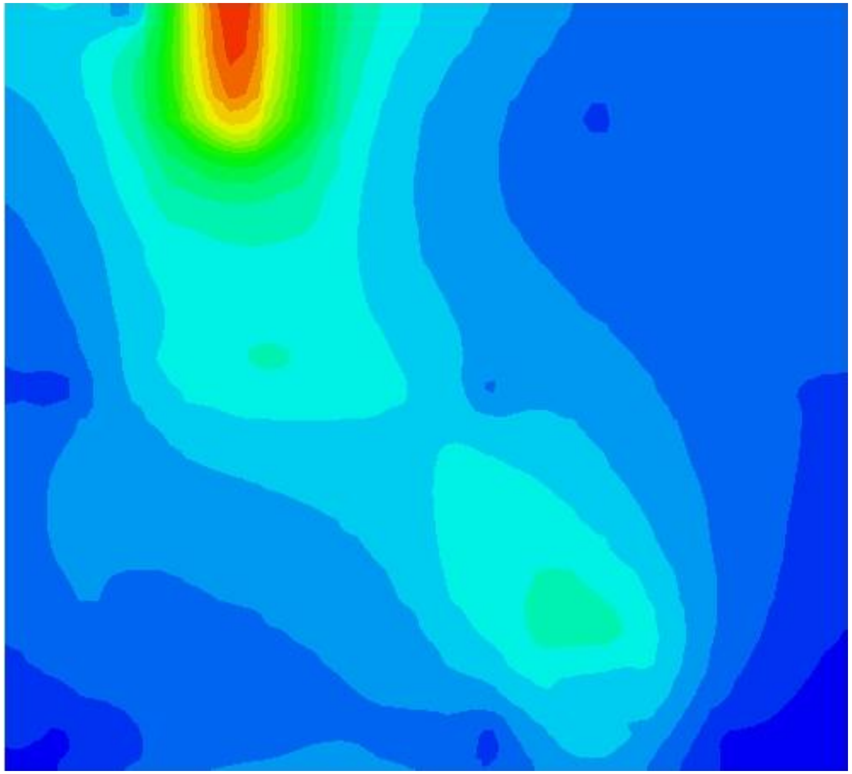


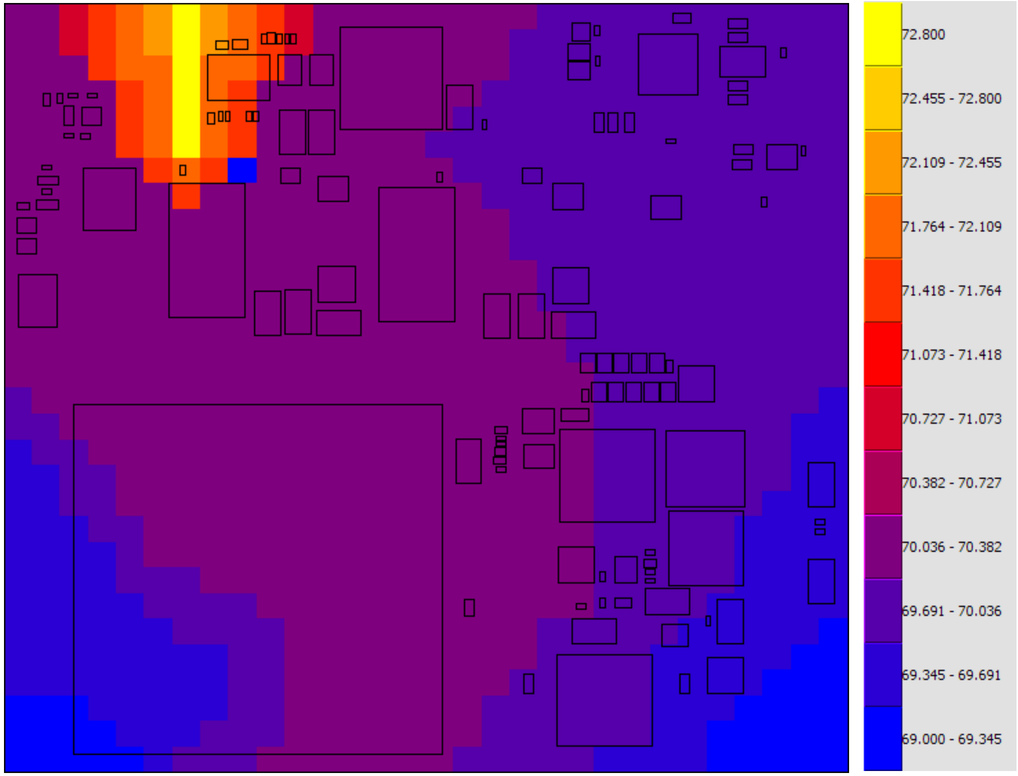


Two wheeled trailer
0.09013mm

Maximum displacement of 0.09013mm due to Composite Two-Wheeled Trailer vibration exposure

CalcePWA Thermal Fatigue Setup

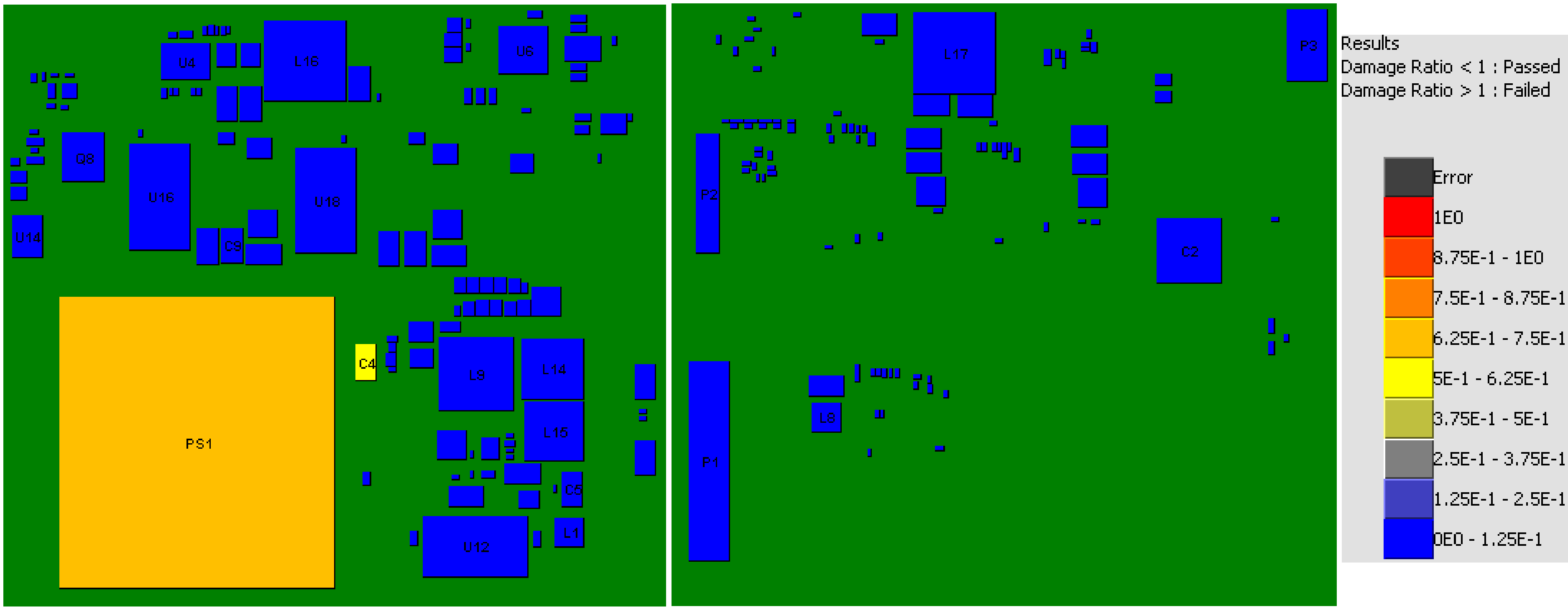




ICEPAK Thermal Analysis Results

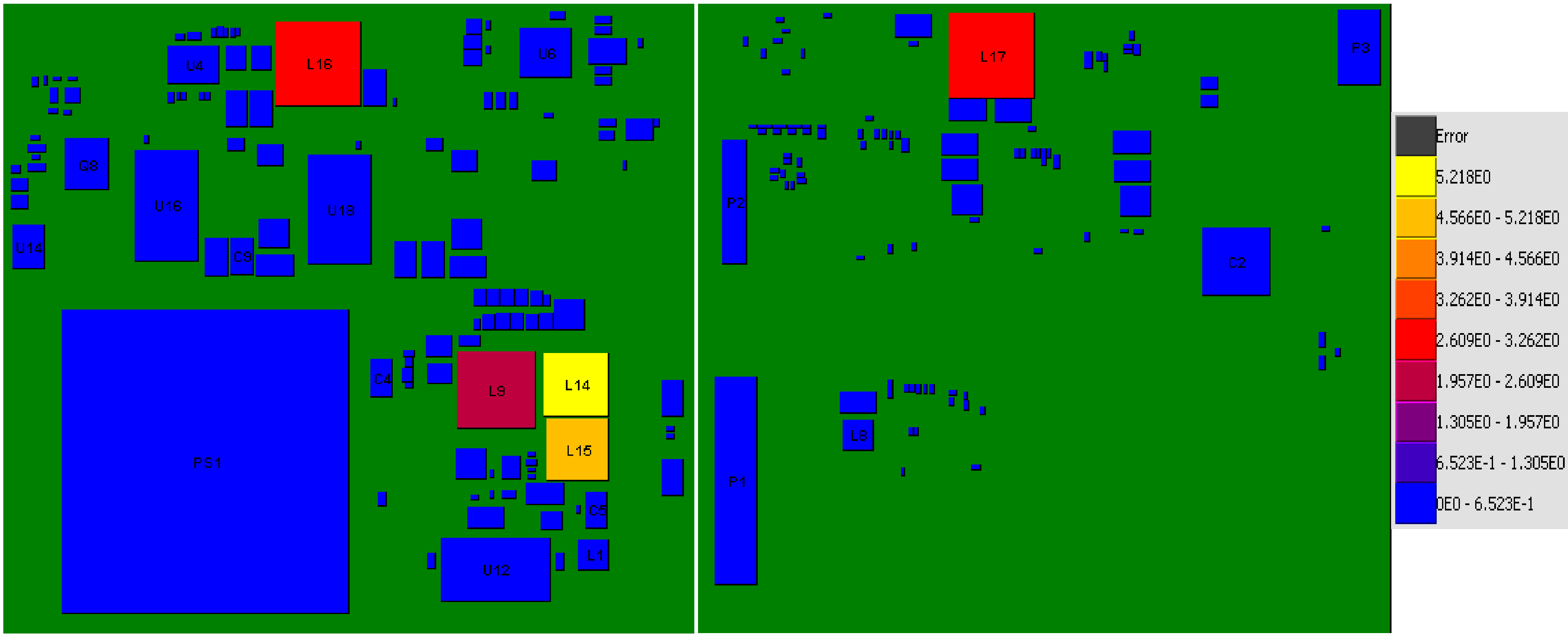
CalcePWA Substrate Temperature

Life Estimate due to Vibration Loading Only



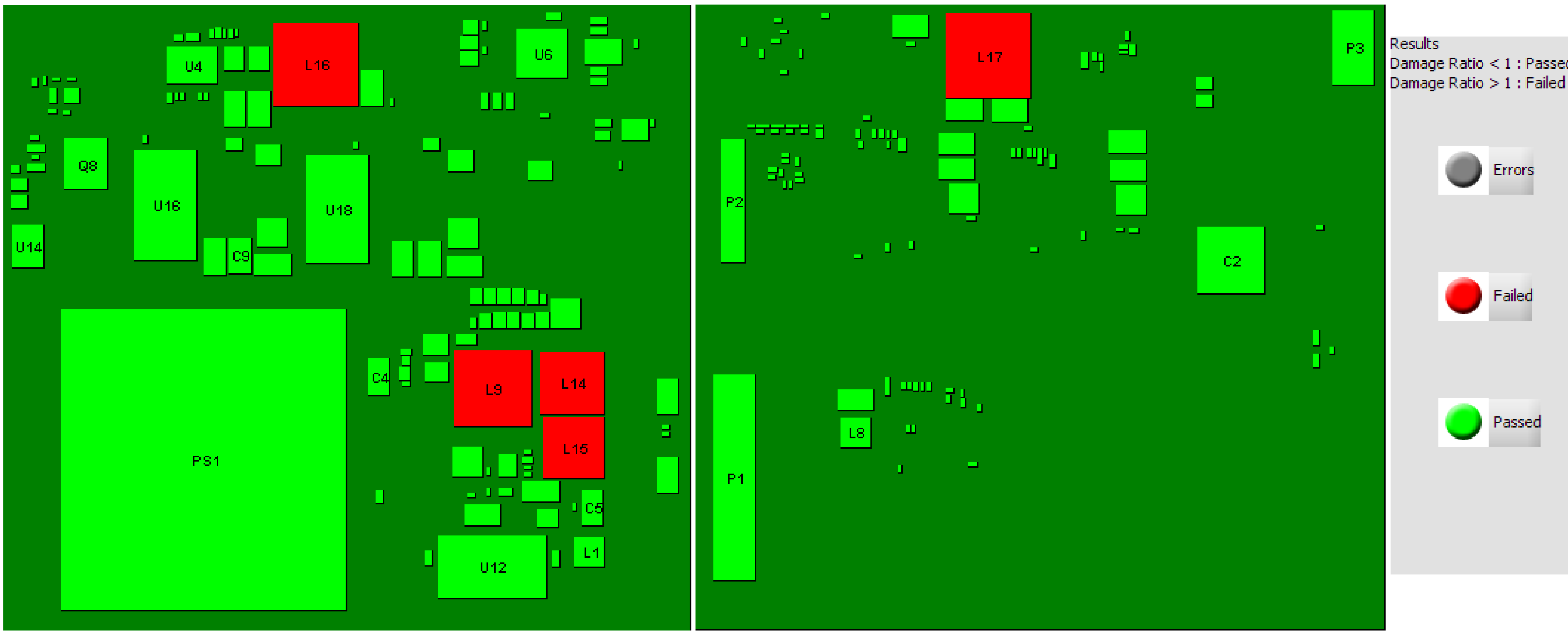
- **DC/DC Converter PS15 expected to accumulate the most damage over lifetime from vibration loading (DR = 0.64)**
- **Tantalum capacitor C45 expected to accumulate the second most damage over lifetime from vibration loading (DR = 0.55)**

Life Estimate due to Thermal Loading Only



- **Inductor L145 expected to accumulate the most damage over lifetime from 210 annual thermal cycles (DR = 5.22)**
- **Inductors L95, L155, L165, and L175 expected to receive significant damage over lifetime from 200 annual thermal cycles (DR>1)**

Life Estimate due to Combined Thermal & Vibration Loading



Components L95, L145, L155, L165, and L175 have life estimates of less than 20 years due to combined vibration loading and thermal cycling (50th Percentile)

Worst-Case Component Life Estimate Combined Loading

Temperature cycles on/off per year wartime	Components Name	Part	Damage Ratio	Thermal Fatigue life (Years)
200	L145	Inductor	3.54	5.66
	L155	Inductor	3.24	6.18
	L165	Inductor	2.21	9.05
	L175	Inductor	2.17	9.20
	L95	Inductor	1.56	12.78
200-500	L145	Inductor	7.42	2.69
	L155	Inductor	6.79	2.95
	L165	Inductor	4.63	4.32
	L175	Inductor	4.55	4.39
	L95	Inductor	3.26	6.13
	C45	Inductor	0.68	29.41
500-1000	L145	Inductor	12.81	1.56
	L155	Inductor	11.70	1.71
	L165	Inductor	7.93	2.52
	L175	Inductor	7.80	2.56
	L95	Inductor	5.55	3.60
	C45	Capacitor	0.76	26.31
	PS15	DC/DC Converter	0.64	>30
	L25	Inductor	0.60	>30

Life requirement Criteria : 20 Years

Reliability Improvement Suggestions

Board	Ref. Des.	Package Type	Failure Mechanism*	Possible Solution
A	L99999	SMT Power Inductor	TSJF	• Use equivalent through-hole versions of inductors L9, L14 - L17 with compliant spacer or kinked leads. Tie down body of component. • Select equivalent component with known CTE and re-run analysis. Make recommendation based on result.*** • Perform component testing to determine actual CTE. Re-run analysis. Make recommendation based on result.***
A	L145678	SMT Inductor	TSJF	Same as above.
A	L152345	SMT Inductor	TSJF	Same as above.
A	L161212 L171819	SMT Power Inductor	TSJF, SHCK	Same as above. • Perform component shock test using representative solder processes. ***
A	PS145	DC/DC Converter	TSJF**, SHCK	• Add PWB mounting screws in four corners of device. • Attach PS1 base to PWB with compliant cement (such as RTV).***
B	L2093	SMT Inductor	TSJF	Same as L9 Power Board.
B	P40167	Surface Mount High-Speed Header	TSJF	• Use equivalent through-hole version. • Perform component testing. Re-run analysis. Make recommendation based on result.***
C	L41,L51, L121, R21, C11111	SMD Components	VSJF	• Add support (standoff) to PWB at high deflection region. • Use equivalent through-hole version with looped (or kinked) lead. Tie down body of component.***
C	L200, L30	Through-Hole Chokes	TSJF**	• Add compliant spacer or kink leads. Tie down body of component.

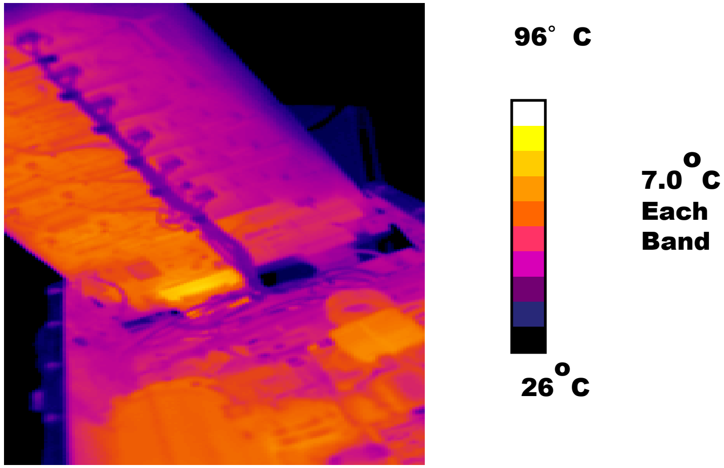
* - Failure mechanism: TSJF = Thermal Solder-Joint Fatigue, VSJF = Vibration Solder-Joint Fatigue, SHCK = Shock

** - Out-of-Plane Thermal Expansion ***- Alternative

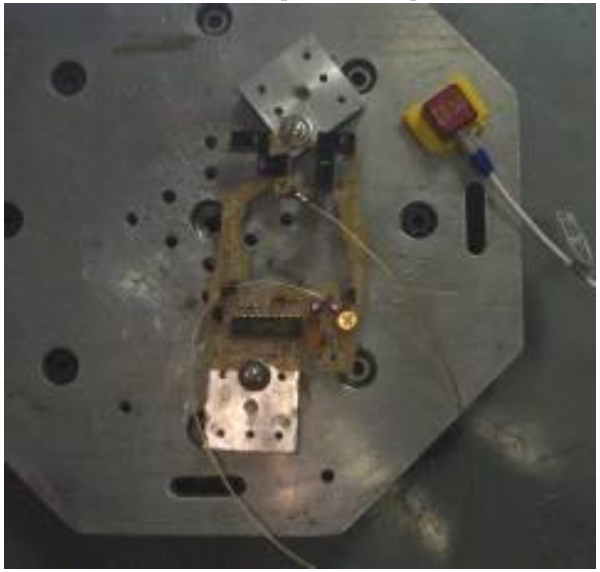
Survey Testing

- Used to refine/verify analysis predictions
- Used to determine interaction of multiple circuit card assemblies & chassis

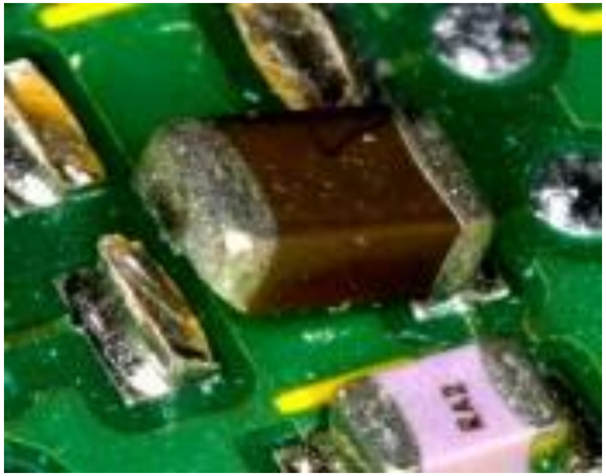
Thermal



Vibration (Modal)



Shock



Thermal/Modal Survey Testing

- Thermal analysis predicts component temperatures and identifies components to monitor
- Thermal test measures actual component temperature using thermocouples, thermal imaging, or both

- Modal / Random Vibration analyses predict card natural frequencies and identify locations of maximum deflection for accelerometer placement
- Modal test measures actual CCA & Chassis natural frequencies

Contact Information

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U.S. Army Materiel Systems Analysis Activity

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