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Mechanical Reliability of Electronics

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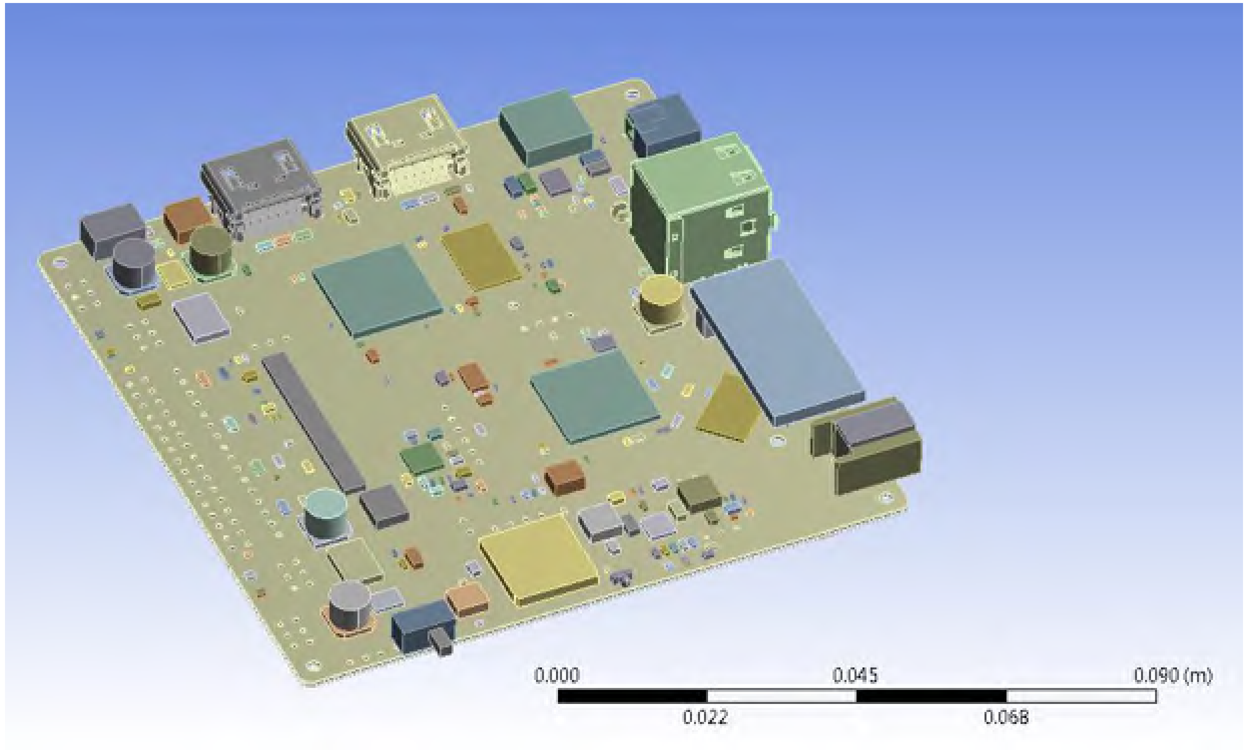
R&D Fellow

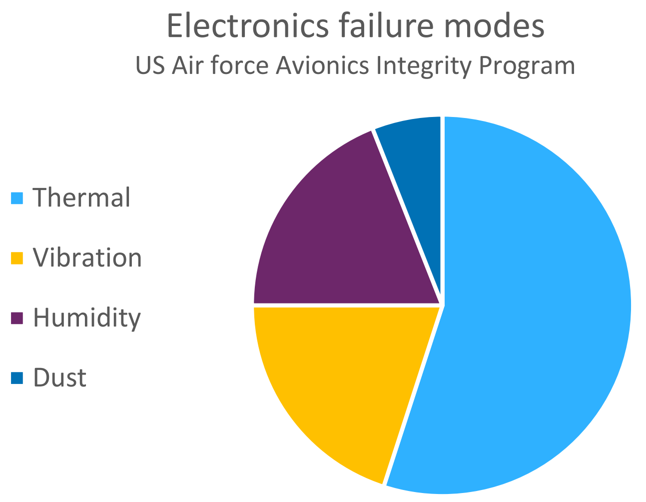
PCB Assembly Reliability Analysis

- PCB Assembly Failure Modes
- Challenges of modeling PCB Assemblies
- ANSYS Mechanical Workflow
  - Trace Mapping
  - Thermal Analysis – Joule Heating Hot Spot Detection
  - Solder Reflow – Board-Level Warpage Analysis
  - Vibration – Modal and Random Vibration Analyses
  - Automated Post-Processing
  - Thermal Cycling - Solder Joint Fatigue
- Conclusion



PCB Assembly Failures Modes

- **Mechanical failure of PCB assemblies are primarily due to thermal and vibration issues.**
- **As packages become thinner and boards become thicker, the risk of failure increases and becomes harder to predict using traditional design rules.**
- **ANSYS provides a full set of tools to model the entire PCB assembly efficiently. This allows engineers to foresee issues during the design process.**

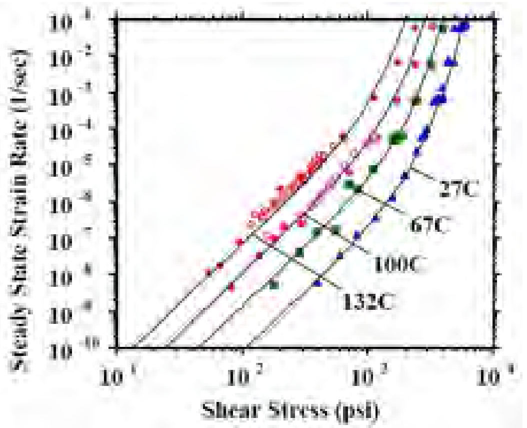


Challenges of Modeling PCB Assemblies

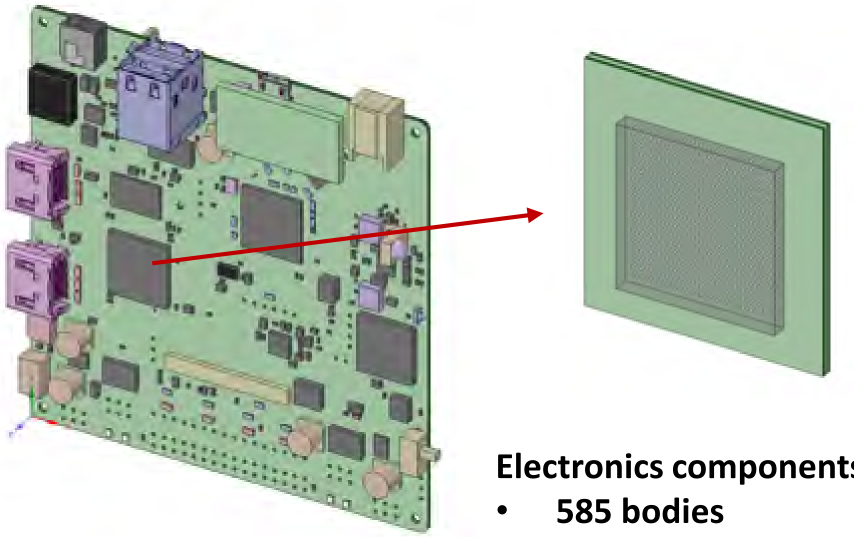
- **Geometry complexity**
  - **PCB**
  - **Electronics Components**
  - **Complex material models for solder**

PCB
- **11 layers**
- **21,000 bodies (including trace and via)**

Board design from:
https://kosagi.com/w/index.php?title=Kovan_Main_Page
open hardware robotics platform



Anand's Viscoplasticity model
R. Darveaux, "Effect of Simulation Methodology on Solder Joint Crack Growth Correlation", ECTC 2000



Electronics components
- **585 bodies**
- **324 solder bodies on one chip**

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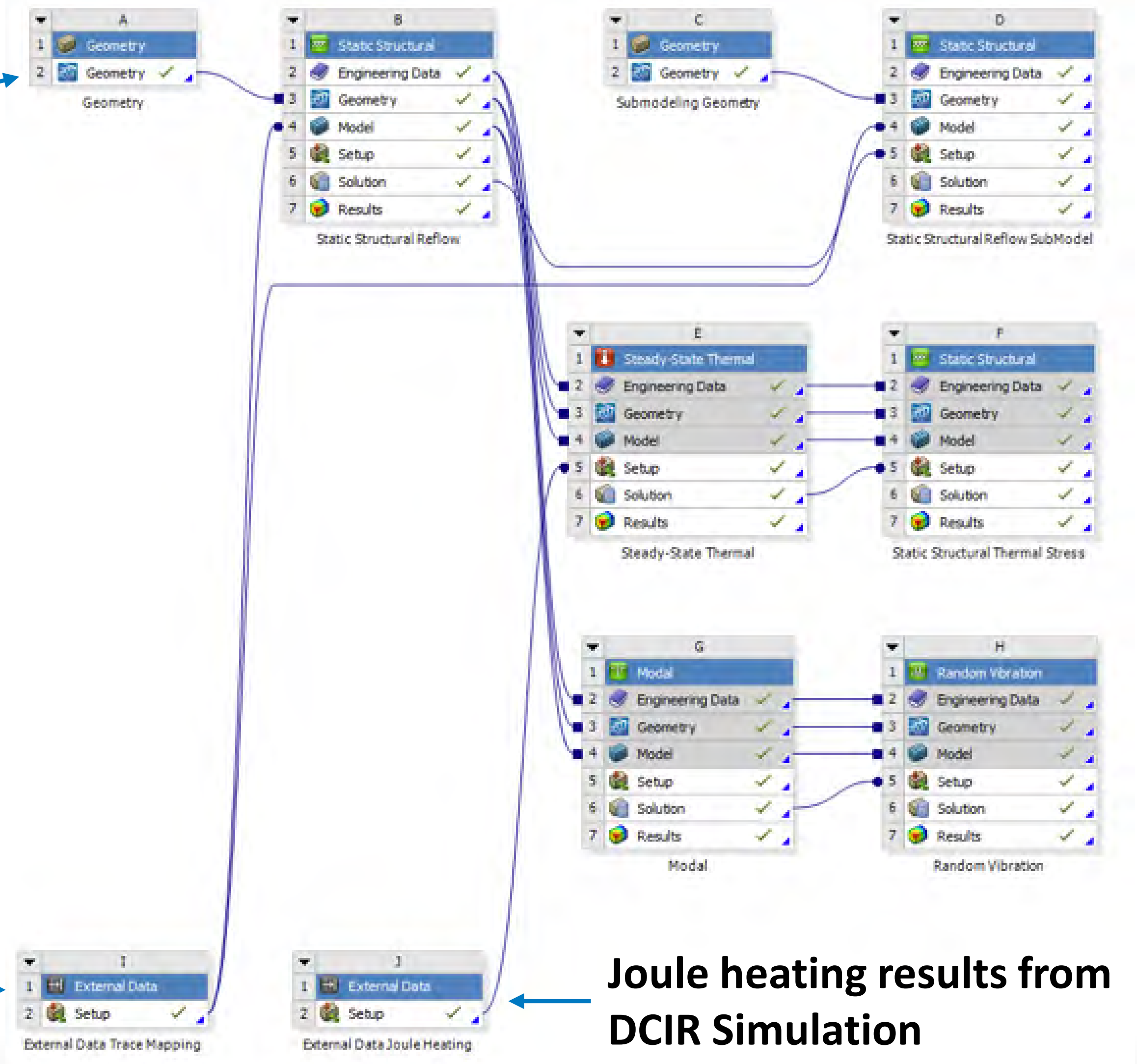
ANSYS Mechanical Workflow

Submodel of chip with solder balls

PCB assembly CAD
- PCB sliced so that each layer is a separate body (for trace mapping)



Solder reflow warpage simulation
- With submodeling of crucial components

Operating condition thermal stress simulation with joule heating

Model and random vibration analysis

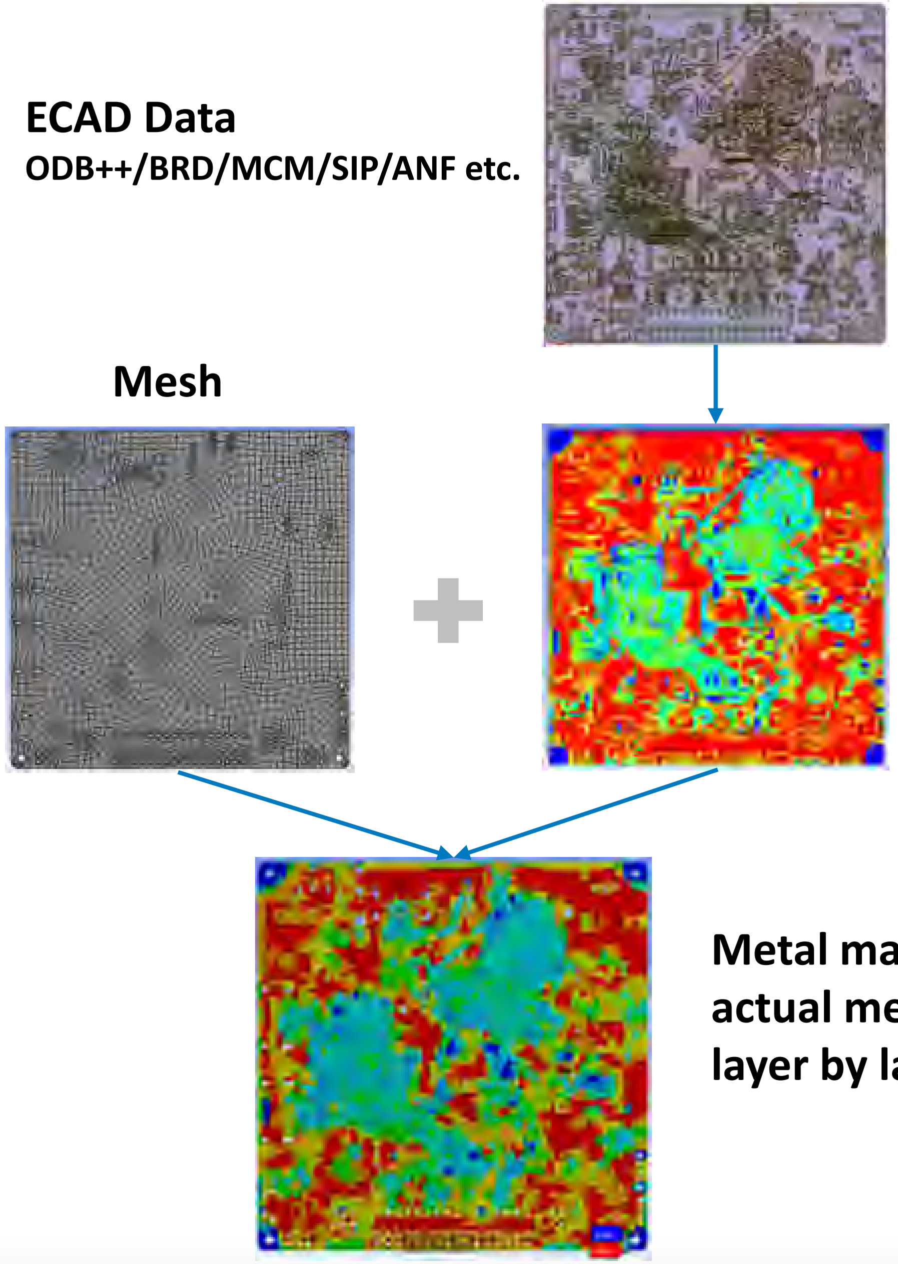
ODB++ layout file for trace mapping

Joule heating results from DCIR Simulation

ANSYS

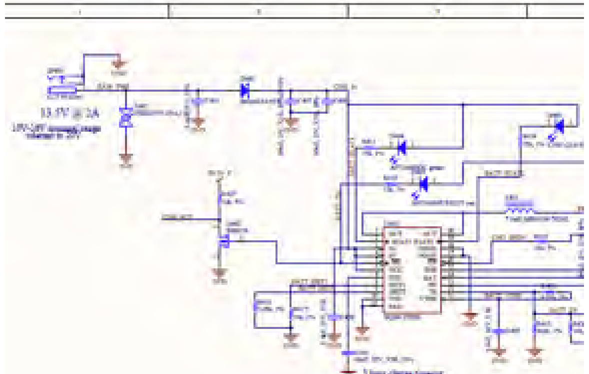
Trace Mapping

- The first step in accurate simulation of modern PCB assemblies is to capture the distribution of copper in each layer of the board.
- Trace mapping calculates an equivalent material property for each element in the PCB mesh based on the proportion of trace and substrate covered by the element.
- This leads to more accurate thermal, warpage and vibration simulation results.

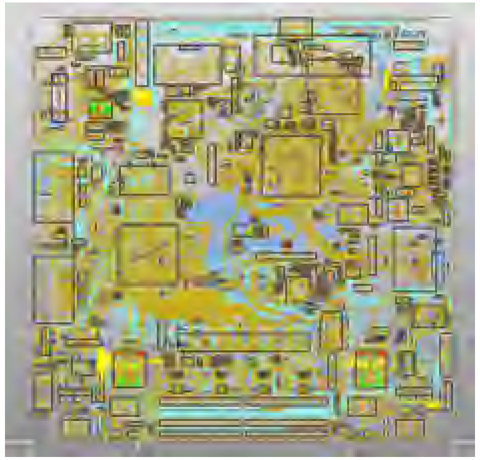


Thermal Analysis – Joule Heating Hot Spot Detection

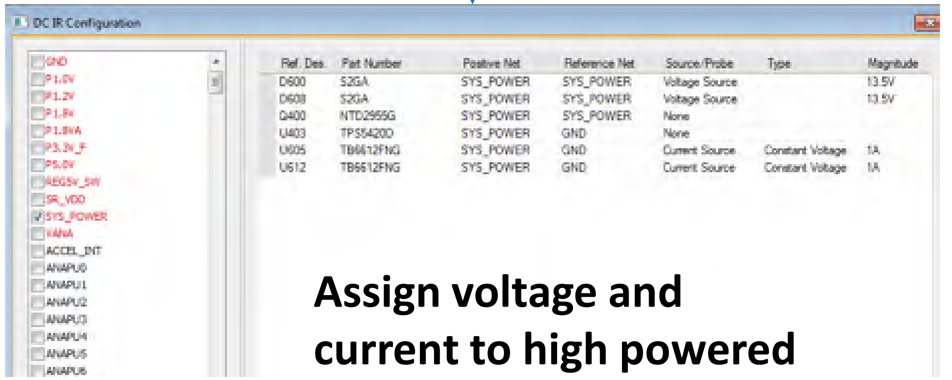
- **In high powered PCBs, joule heating inside the PCB can result in localized high temperature regions.**
- **High temperatures can cause PCB and nearby components to degrade over time, leading to failure.**
- **ANSYS SIWave provide an easy to use wizard that guides users in the setup of DCIR simulations.**



Electrical Schematic



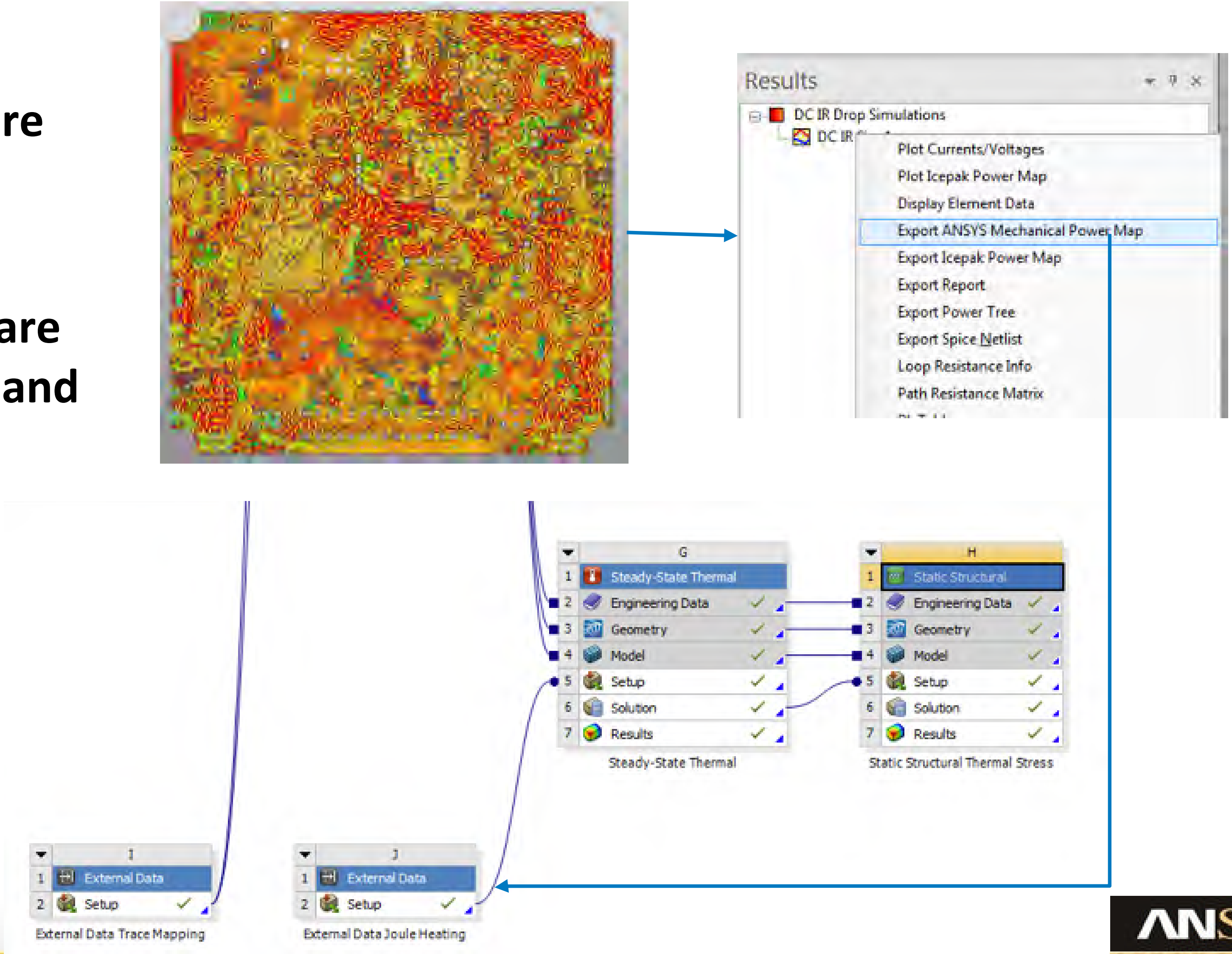
Load ECAD layout file



Assign voltage and current to high powered pins

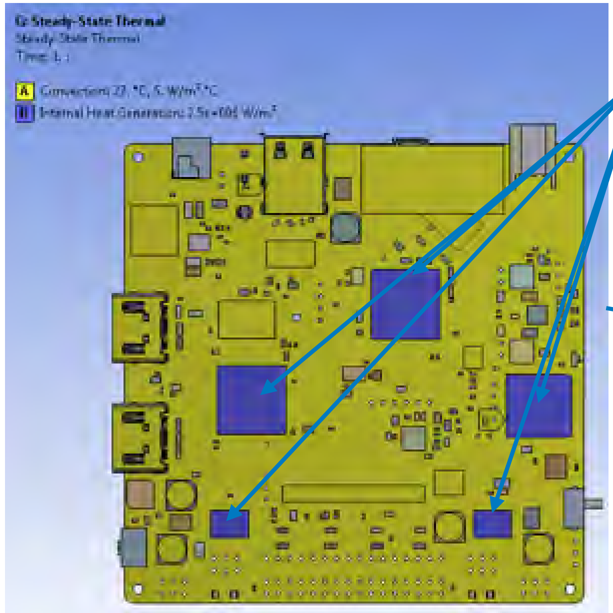
Thermal Analysis – Joule Heating Hot Spot Detection

- **Current, resistance and losses are calculated on the PCB for every electrical net.**
- **The electrical resistance losses are exported to ANSYS Mechanical and mapped on to the steady state thermal simulation**



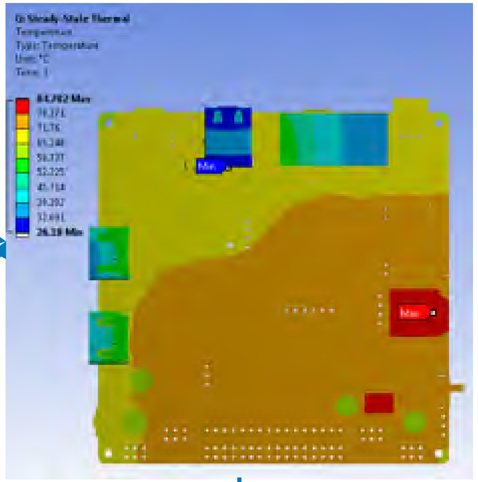
Thermal Analysis – Joule Heating Hot Spot Detection

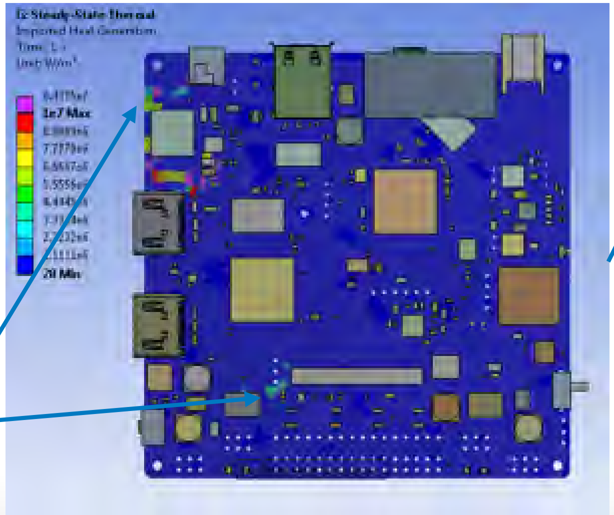
- In this thermal analysis we have:
  - 5 packages with high energy dissipation.
  - Convection boundary condition to simulate the effect of stagnant air.
  - Joule heating in the traces of the PCB



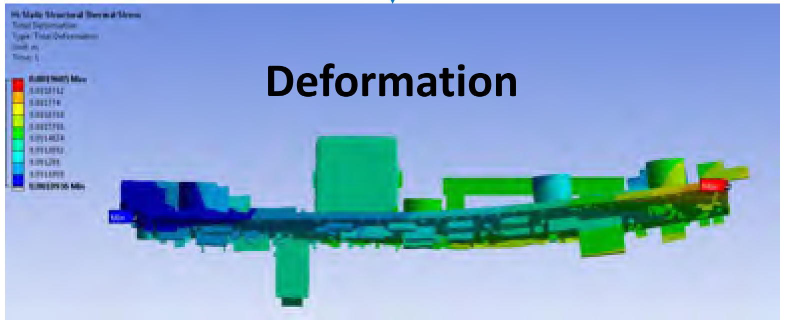
Hot Chips

Temperature





Deformation



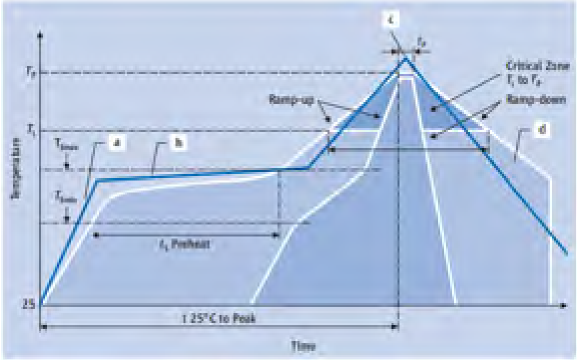
Joule heating locations

  July 26, 2017

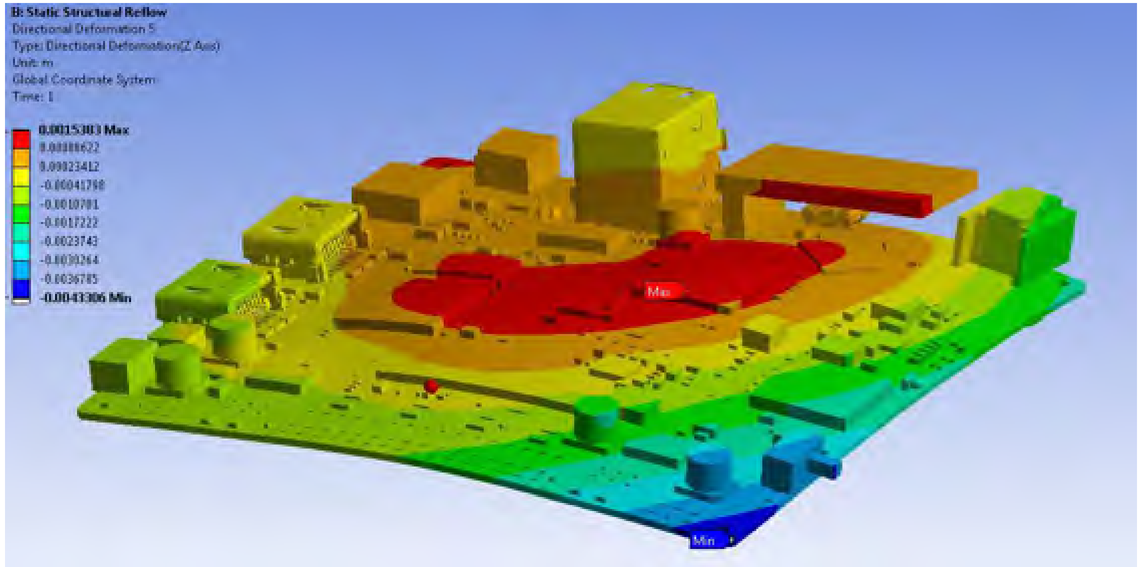
ANSYS

Solder Reflow – Board Level Warpage Analysis

- **In modern lead-free PCB assemblies, the solder reflow process can cause failure.**
- **The melting temperature of lead-free solder can be over 170° C. This can cause significant deformations due to mismatch of thermal expansion coefficients (CTE) between different materials.**



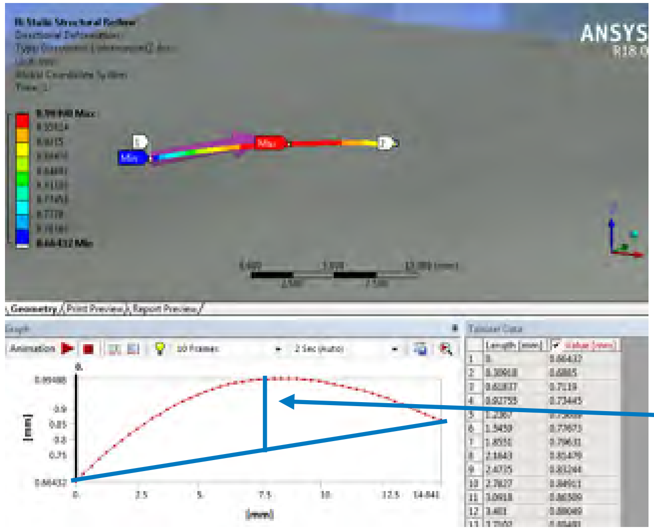
Solder reflow profile: p68
Handbook for Robustness Validation of Automotive Electrical/ Electronic Modules. ZVEI Die Electroindustrie



Warpage 170°C -> 22°C

Solder Reflow – Board Level Warpage Analysis

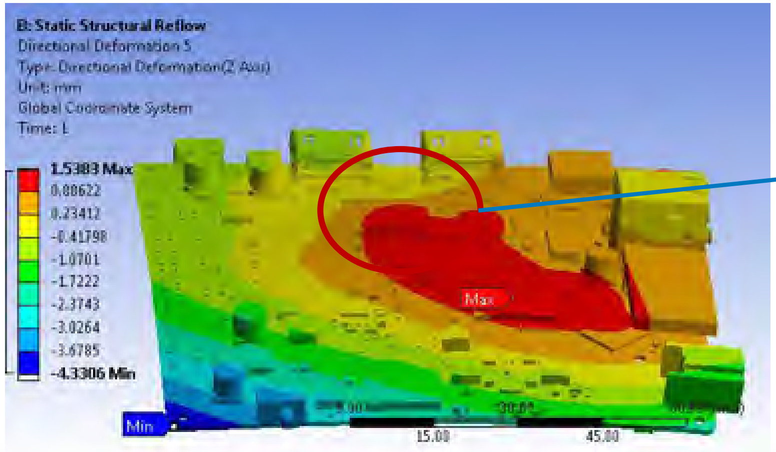
- **Failure of packages on the board is related to the warpage of the package.** **(Stienberg: Designing Electronics for high vibration and shock)**
- **Warpage of key packages are evaluated. Those with large warpage are selected for sub-modeling**

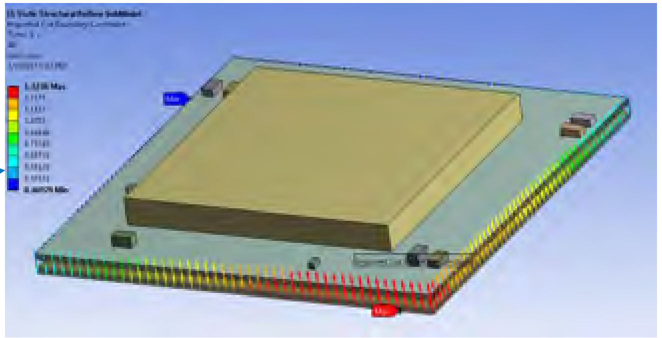


Plot of the z-direction warpage for package.

Warpage

In a sub-model, the deformation results from the global model is mapped on to the cut boundaries of the sub-model. Therefore the sub-model behaves as if it is a part of the global model.

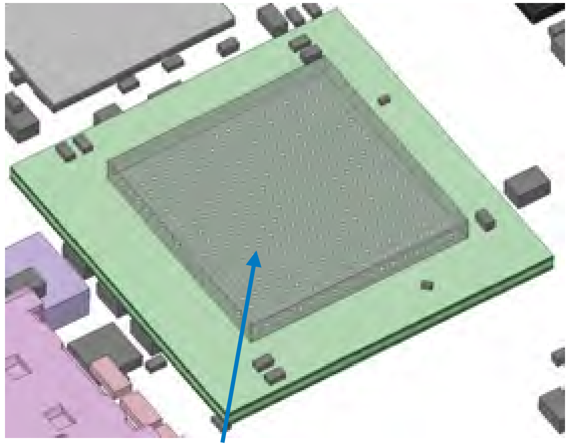




Solder Reflow – Board Level Warpage Analysis – Sub-Model

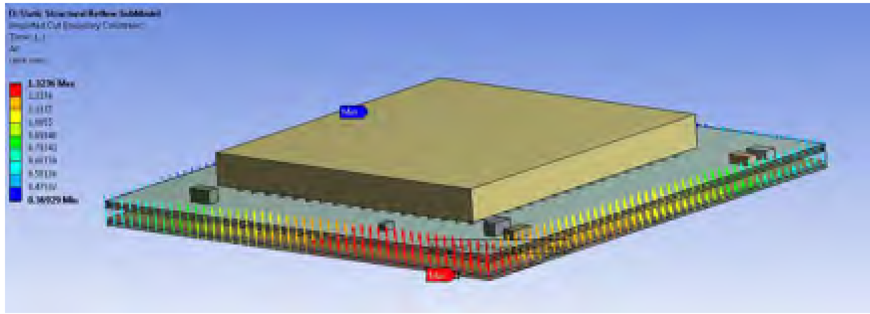
Sub-model allows additional details to be included.

- Solder balls automatically created based on ECAD Layout on selected packages. (324 bodies)

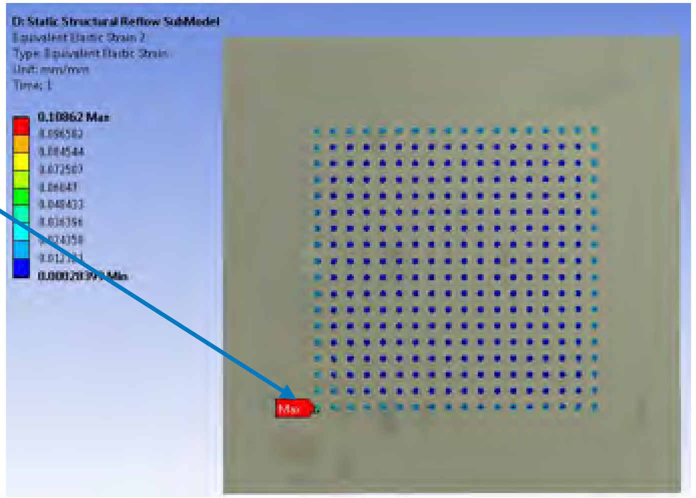


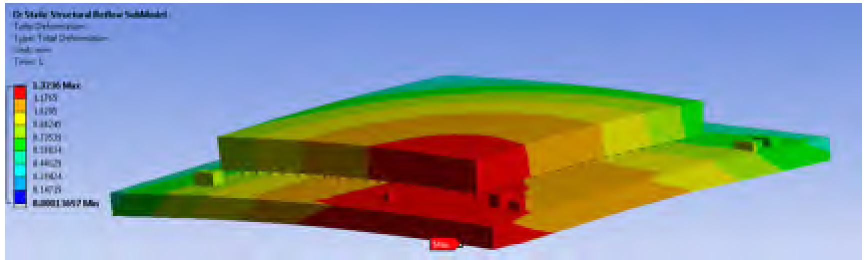
Solderballs

Boundary deformation from global model



Max strain on the solder ball can point to failure location.

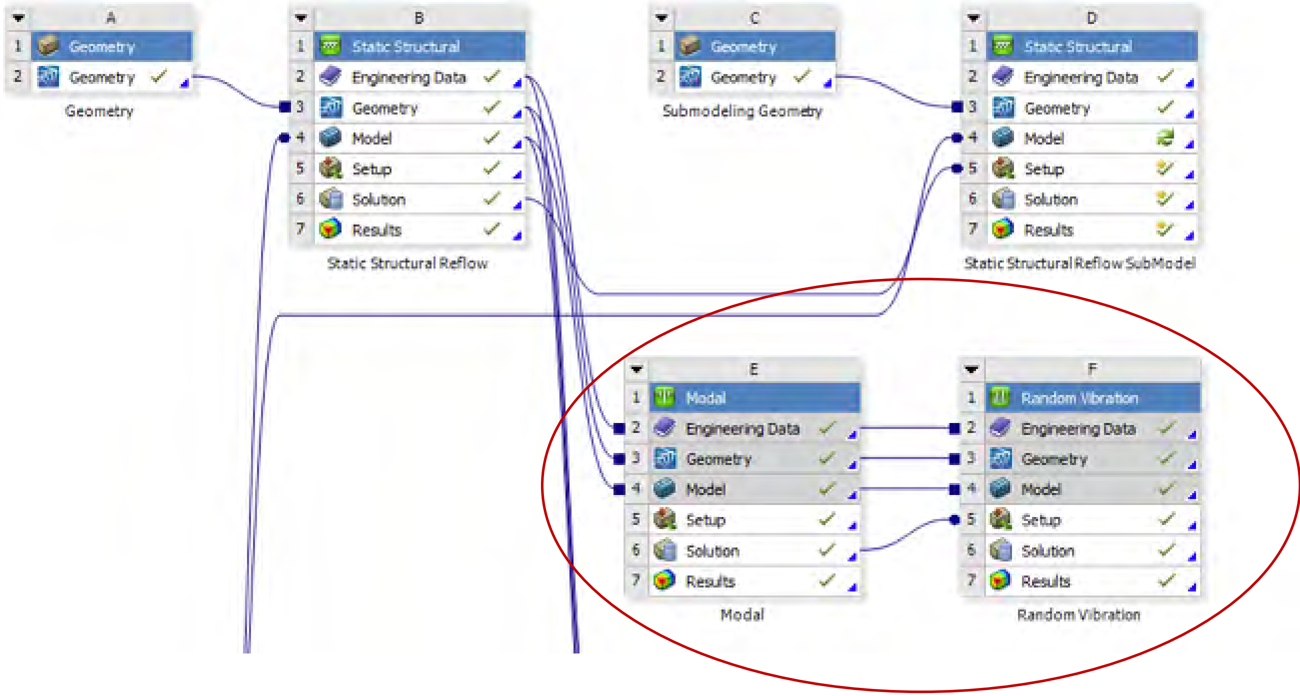




Submodel deformation

Vibration – Modal Analysis and Random Vibration Analysis

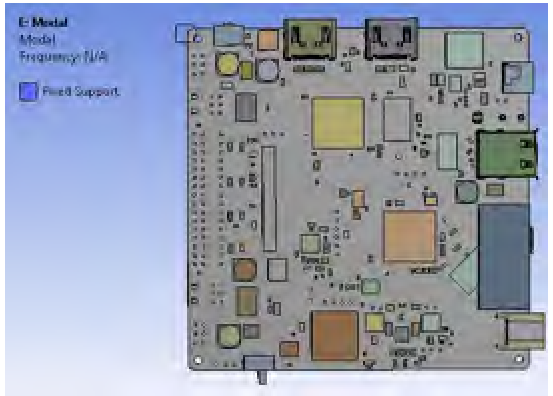
- Vibration can be a cause for PCB assembly failure.
- Simulation can be used to guide and evaluate the design to improve the chances for passing vibrations testing.
- Typical simulations are:
  - Modal – natural frequency
  - Random Vibration – vibration/fatigue during operations
  - Response Spectrum – Shock analysis (not shown in this presentation)

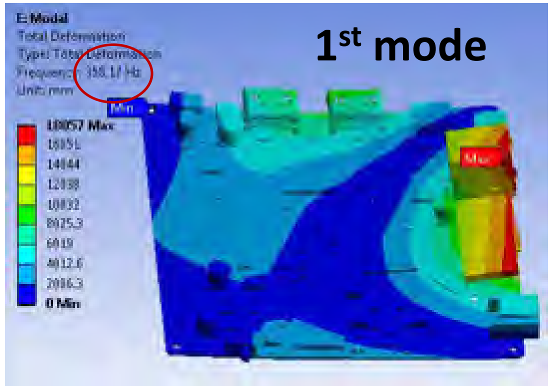


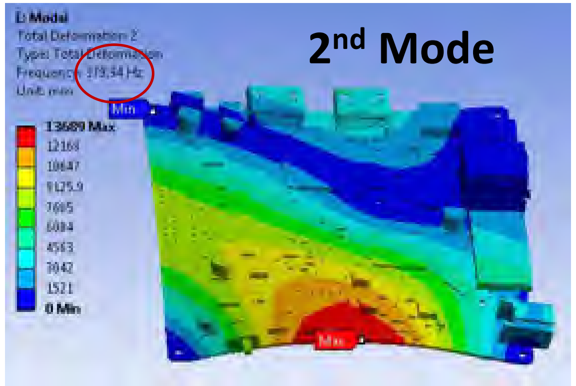
Vibration – Modal Analysis

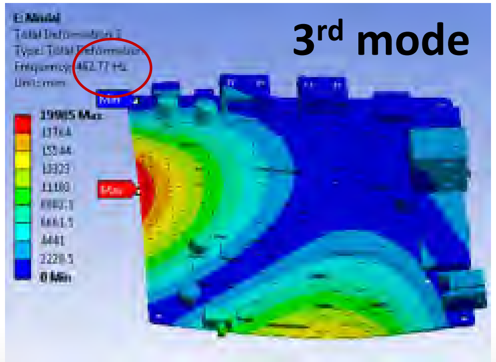
- **Modal analysis is the most basic of vibration analysis techniques.**
- **Commonly used during design to avoid vibration issues**

Use the model with trace mapping and assign support locations









Designing Electronics for High Vibration and Shock

Electronic equipment can be designed to withstand extreme mechanical stress, without the weight and cost penalties of overdesign

By Dave S. Steinberg, Steinberg & Associates, Westlake Village, CA 91361

For example, the natural frequency (resonant frequency) of the chassis must be a least one octave from the natural frequency of the PCB. Therefore if the PCB assembly has a frequency of 400 Hz, then the chassis must have a frequency no closer to 400 Hz than 200 Hz or 800 Hz.

Vibration – Random Vibration Analysis

- **Random vibrations analysis can be used to estimate fatigue life/failure due to vibrations.**
- **As with all fatigue calculations, accurate random vibrations simulations requires correlations with various tests.**
- **Steinberg through extensive testing, has formulated an equations to predict whether different electronics packages will pass certain random vibrations criteria.**
  - *Z* = single amplitude dynamic displacement, in.;
  - *L* = length of component, in.;
  - B and t = board length and thickness
  - c = 1.0 for standard DIP;
    - 1.26 for a DIP with side-brazed leads;
    - 1.26 for a pin-grid array with two parallel rows of pins;
    - 1.0 for a pin-grid array with four rows of pins
    - 2.25 for leadless chip carrier

Designing Electronics for High Vibration and Shock

Electronic equipment can be designed to withstand extreme mechanical stress, without the weight and cost penalties of overdesign.

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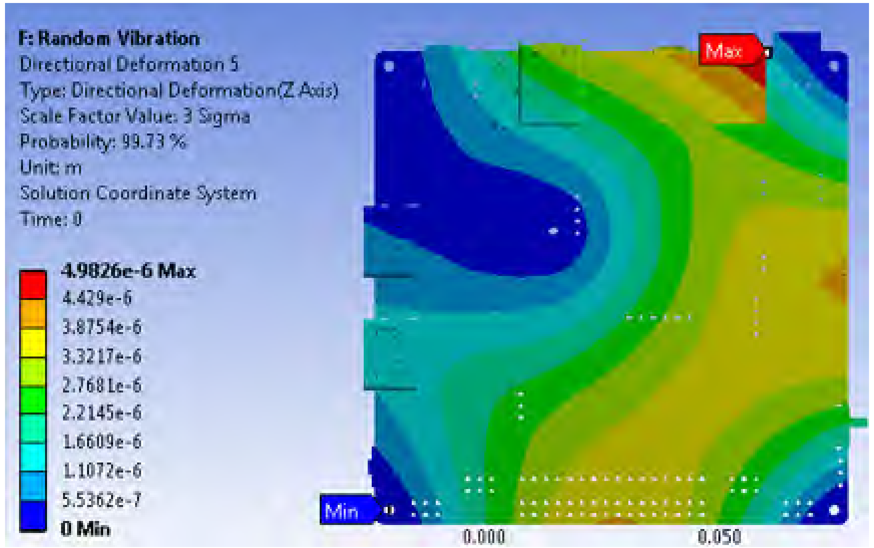
Vibration equations

Extensive PCB vibration testing has established that a fatigue life of about 10 million stress reversals under sinusoidal vibration can be achieved for lead wires and solder joints when the dynamic single amplitude displacement at the center of the board is limited to the value in Eq. 1. Similarly, about 20 million stress reversals can be achieved under random vibration.

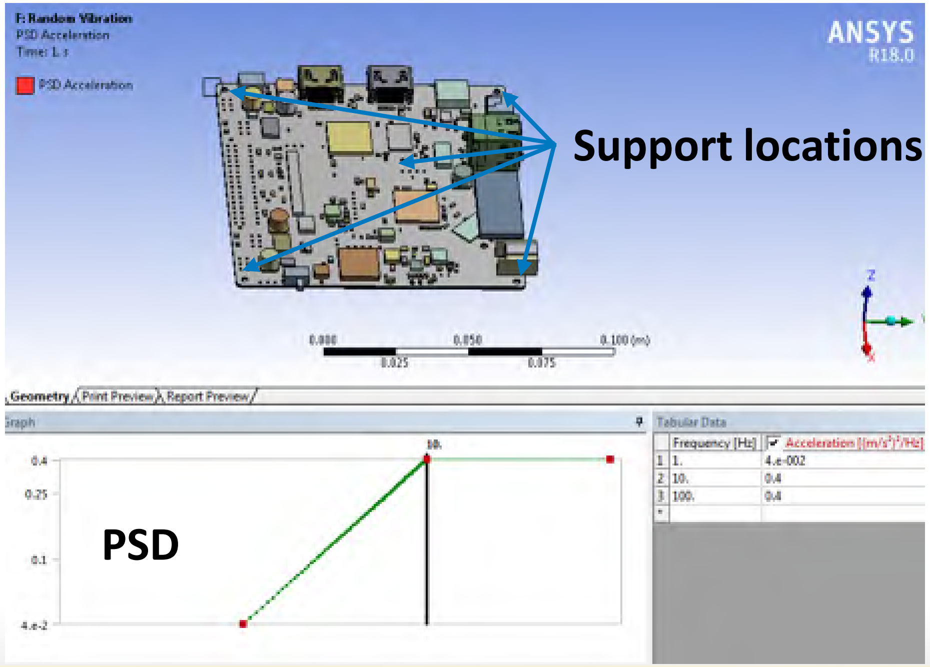
$$Z = \frac{0.00022B}{ct\sqrt{L}} \qquad (1)$$

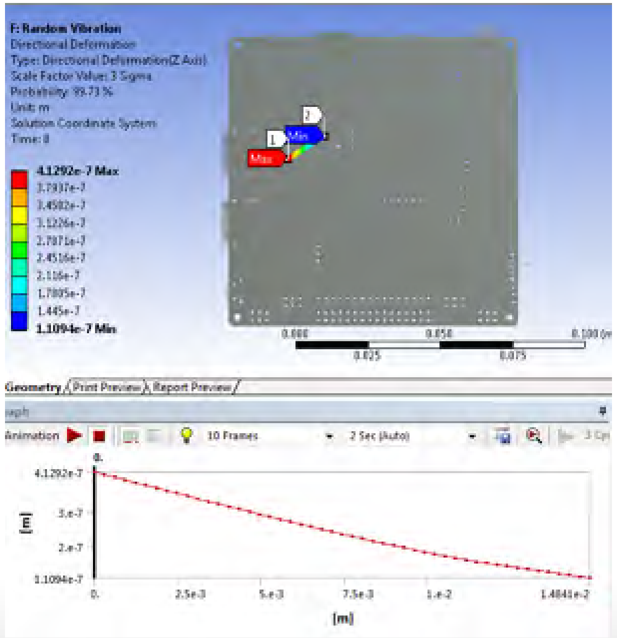
Vibration – Random Vibration Analysis

- In ANSYS, the appropriate Power Spectrum Density (PSD) load is applied to the supports of the PCB assembly.



3 Sigma deformation plot



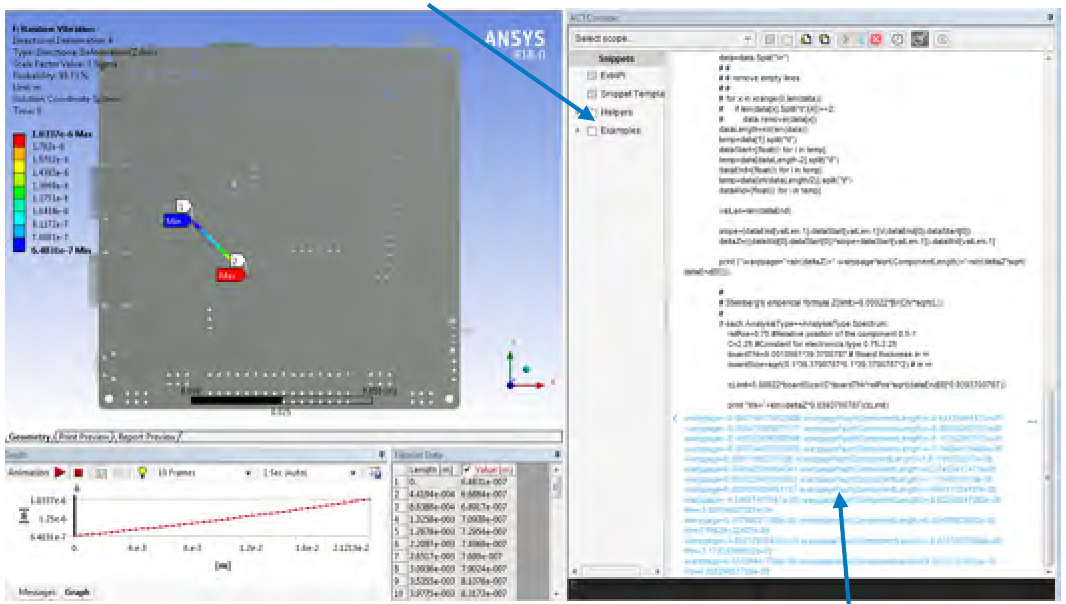


Calculate the deformation of each package.

Automation

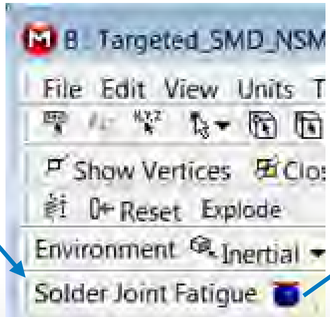
- **ANSYS Mechanical can be automated using scripting or extensions.**
- **A Python script is used here to automatically calculate the warpage of all bodies selected.**
- **In addition, scripts can be turned into GUI extensions for easier reuse.**

Python script



Warpage results

GUI Extension

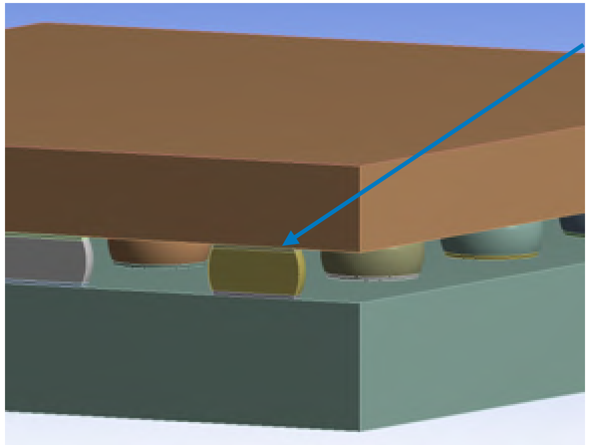


Details of "Solder Joint Fatigue"

Geometry	
Scoping Method	Geometry Selection
Geometry	
Fatigue Input Parameters	
K1	0 [cycles Pa^-k2]
K2	1
K3	0 [m cycles^-1 Pa^-k4]
K4	1
Number of Cycles	1
Cycle Time	1 [sec]
Solder Diameter at Joint	0.001 [m]
Fatigue Output Parameters	
	Fatigue output parameters will displayed in Table after evaluation

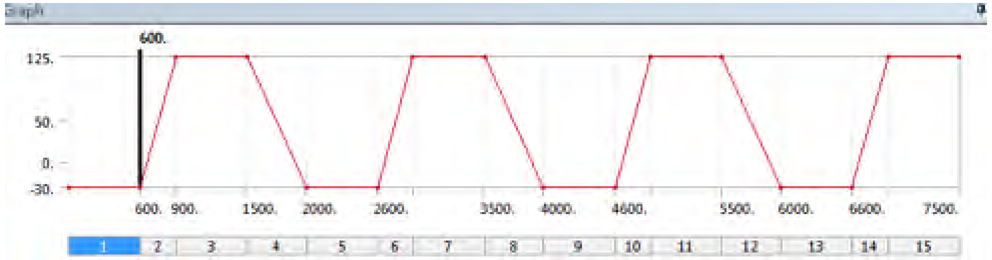
Thermal Cycle - Solder Joint Fatigue

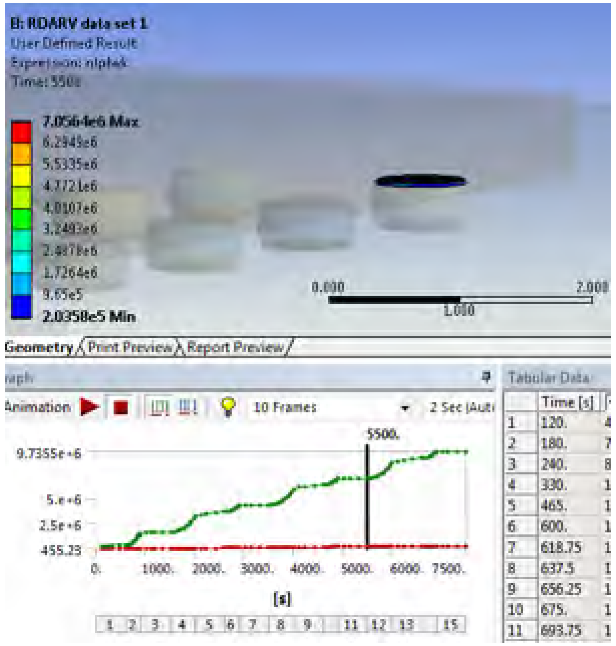
- **Solder joint fatigue due to thermal cycling can be predicted in ANSYS.**



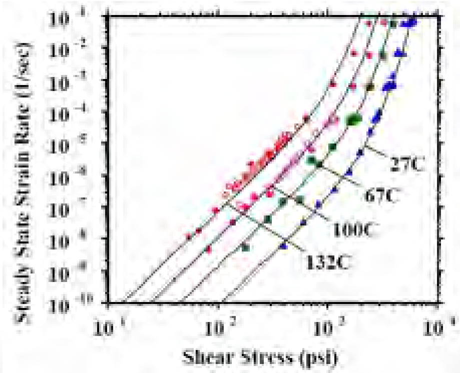
Area of the crack separated from the rest of the solder ball.

Simulate least 3 thermal cycles

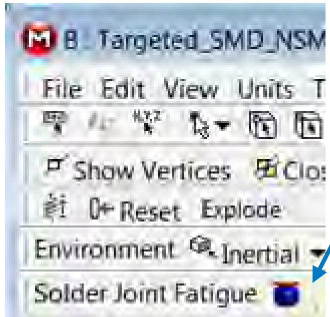




Calculate the accumulation of the volume-averaged nonlinear plastic work.



Anand viscoplasticity or the generalized Garofalo creep model used to model Solder



Automated fatigue calculations using a script extension.

Conclusion

- This presentation shows some of the key ways ANSYS Mechanical can be used to help predict failure in PCB assemblies.

- Different workflows are available for designers and analysts. Everyone can gain additional insight into PCB reliability through the use of simulation.

- This is a small selection PCB assembly simulations ANSYS has helped our customers perform. We are happy to discuss any additional issues you encounter.