Complex Electronics Reliability and Life Modeling Based on Physics of Failure Simulation

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Complex System Reliability Modeling

- two approaches used to predict the reliability of a system or component.
  - **Statistics-Based**
    - A data-driven approach that uses statistical methods based on past performance data.
    - involves collecting data on the failure rates and patterns of similar systems or components
    - Useful for predicting the reliability of systems or components, where failure modes are well-understood and there is a large amount

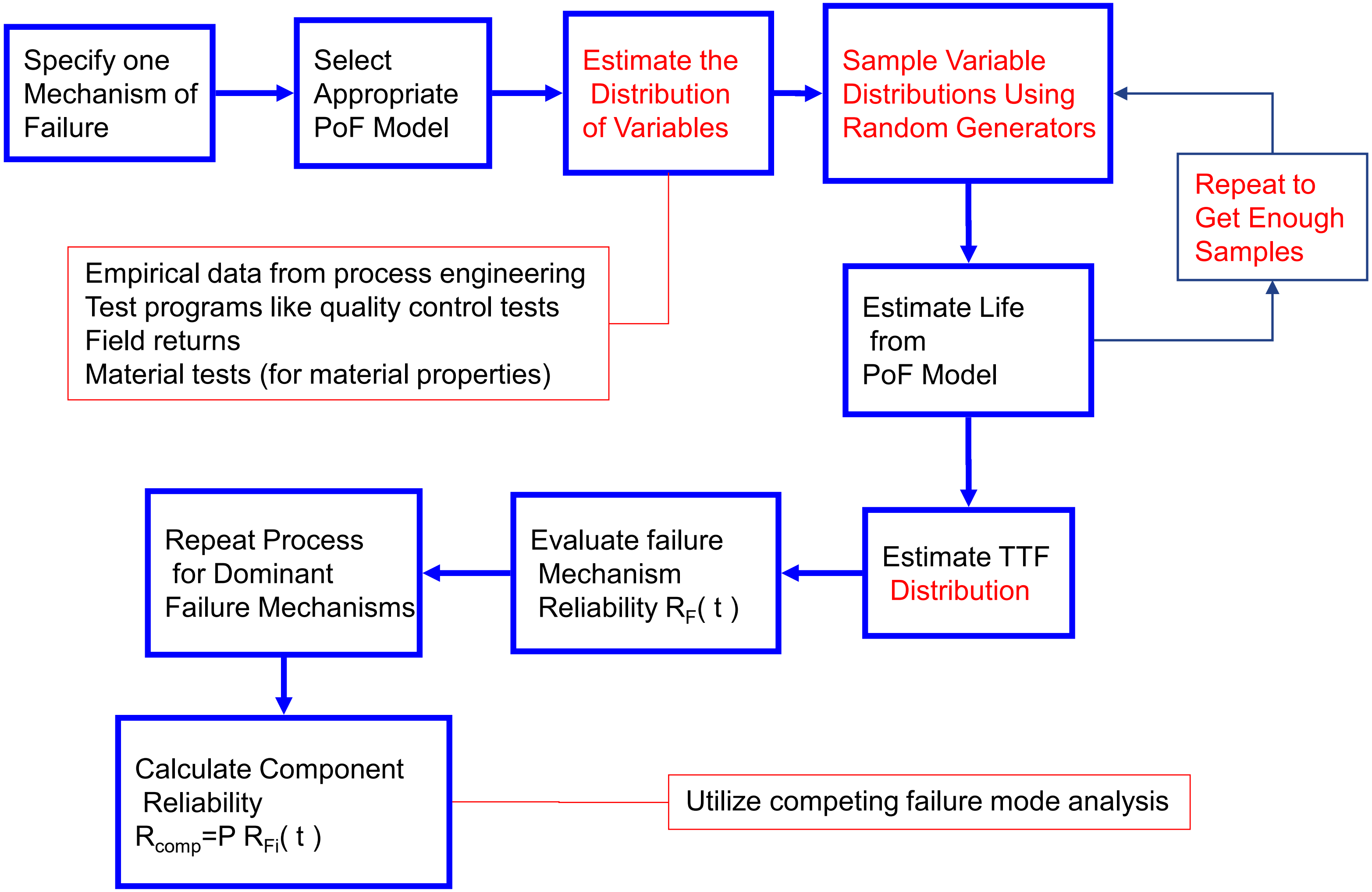
POF is an engineering approach to reliability assessment that uses simulation of the physical models of failures developed based on the science of failure mechanisms such as fatigue, fracture, wear, and corrosion

  - **Physics of Failure**
    - Detailed understanding of the physical processes and mechanisms causing a failure.
    - Identifying the potential failure modes, determining the root causes of failure, and developing mathematical models to simulate the failure mechanisms.
    - Models used to predict the probability of failure and estimate the remaining useful life.
    - Useful for predicting the reliability of complex systems or components, where failure can have catastrophic consequence
    - Cost Effective to cut on the test expenses

Why PoF-Based Modeling?

- To avoid repeating long and costly tests
  - Reduce the development time for fast release of the design
  - Cost reduction toward cheaper products
- Sometimes it is impossible to build several identical units for testing
  - Large Systems like buildings, space vehicles
    - This is the case for One-of-a-kind or highly expensive systems
  - The products that must work properly at the first time
- In design stage when there is no prototype to test
- Highly reliable products are hard to break
  - The lifetime is long
  - Internal control or safety related devices limit the stress
  - Higher stresses introduce other failure mechanisms
- Optimization purposes and need for a dynamic prediction
- Predicting the occurrence of rare or extreme events

Probabilistic POF Approach



Specify one Mechanism of Failure

Select Appropriate PoF Model

Estimate the Distribution of Variables

Sample Variable Distributions Using Random Generators

Empirical data from process engineering
Test programs like quality control tests
Field returns
Material tests (for material properties)

Estimate Life from PoF Model

Repeat to Get Enough Samples

Estimate TTF Distribution

Evaluate failure Mechanism Reliability $R_F(t)$

Repeat Process for Dominant Failure Mechanisms

Calculate Component Reliability R_{comp}=P $R_{Fi}(t)$

Utilize competing failure mode analysis

PoF Development for Solder fatigue-An Example

- Failure of solder joints due to thermo-mechanical fatigue is one of the primary wearout mechanisms in electronic products, primarily because inappropriate design, material selection, and use environments can result in relatively short times to failure.
- During changes in temperature, the component and printed board will expand or contract by dissimilar amounts due to differences in the coefficient of thermal expansion (CTE).
- This difference in expansion or contraction will place the second-level solder joint under a shear load.
- This load, or stress, is typically far below the strength of the solder joint. However, repeated exposure to temperature changes, such as power on/off or diurnal cycles, can introduce damage into the bulk solder.
- With each additional temperature cycle this damage accumulates, leading to crack propagation and eventual failure of the solder joint.

Drivers of Thermo-Mechanical Solder Joint Fatigue?

- Thermo-mechanical solder joint fatigue influenced by:
  - Maximum temperature,
  - Minimum temperature,
  - Dwell time at maximum temperature,
  - Component design (size, number of I/O, etc.),
  - Component material properties (cte, elastic modulus, etc.),
  - Solder joint geometry (size and shape),
  - Solder joint material (SnPb, SAC305, etc.),
  - Printed board thickness, and
  - Printed board in-plane material properties (cte, elastic modulus).

PoF Model for Thermo-Mechanical Solder Fatigue

- Estimation is done by a time to failure using strain energy
- Force exerted on a solder joint during a thermal cycle:

$$(\alpha_2-\alpha_1)\cdot\Delta T\cdot L_D=F\cdot\left(\frac{L_D}{E_1A_1}+\frac{L_D}{E_2A_2}+\frac{h_s}{A_sG_s}+\frac{h_c}{A_cG_c}+\left(\frac{2-\nu}{9\cdot G_b a}\right)\right)$$

α: CTE, T: temperature, L: one half component length, F: force, E: elastic modulus, A: effective solder joint area, G: shear modulus, h: thickness, v: Poisson ratio

- Strain range induced in the solder joint during the thermal cycle:

$$\Delta\gamma=C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

C: Equation accounts for the effect of operating temperatures and dwell times

- Stress on the solder joint determined using the computed forces combined with the strain to determine the energy dissipated by the solder during a thermal cycle :

$$\Delta W=0.5\cdot\Delta\gamma\cdot\frac{F}{A_s}$$

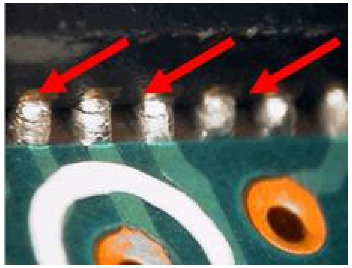
- Resulting strain energy is used to compute the number of cycles to failure for the component under temperature cycling using equations developed by Syed:

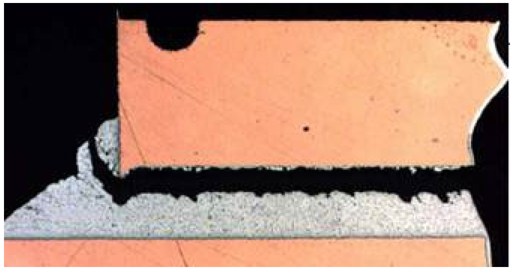
Sn3Ag0.5Cu -- $N_f=(0.0019\cdot\Delta W)^{-1}$

63Sn37Pb -- $N_f=(0.0006061\cdot\Delta W)^{-1}$

QFN Solder Cracks

- The IC started having solder joint failures after a couple years in the field.
- To analyze long term reliability due to thermal cycling for a QFN requires an Engelmaier model.

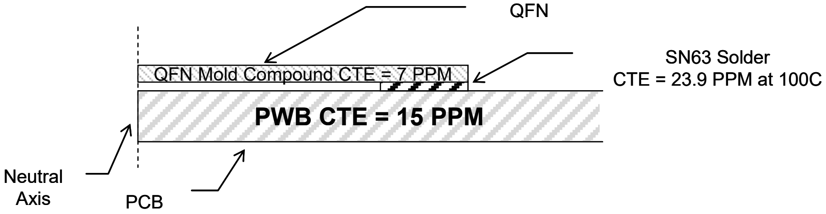




$$\gamma_G \leq \frac{L(\Delta CTE)(\Delta T)}{h_S}$$

$$\text{Global Stress}(\tau_G) = \gamma_G \times G$$

Test #	Thermal Cycling Range	Global Strain	Global Strain
1	-25 °C to 70 °C	8.4%	3.0%
2	0 °C to 100 °C	8.9%	3.2%
3	0 °C to 70 °C	6.2%	2.2%
4	20 °C to 31.5 °C	1.0%	



QFN

SN63 Solder
CTE = 23.9 PPM at 100C

QFN Mold Compound CTE = 7 PPM

PWB CTE = 15 PPM

Neutral
Axis

PCB

$$\text{local shear strain} = \gamma_L \leq \frac{L_{Solder}(CTE_{Solder} - CTE_{comp})(T_{Max} - T_{\min})}{h_S} + \frac{L(CTE_{Solder} - CTE_{PWB})(T_{Max} - T_{\min})}{h_S}$$

QFN Solder Cracks-cont

A PoF reliability model based on an Engelmaier model for a leadless device was manually calculated. The formula for solder joint reliability due to thermal cycling is:

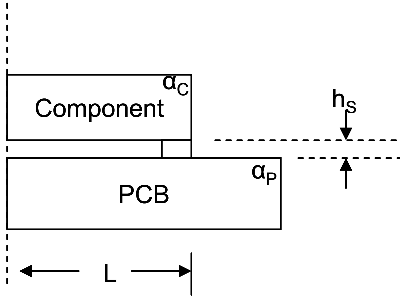
$$\underbrace{N_f(x\%) = \frac{1}{2}\left[\frac{F\Delta\gamma_{\max}}{2\varepsilon_f}\right]^{\frac{1}{c}}}_{\text{Engelmaier model}} \underbrace{\left[\frac{\ln(1-(0.01)(x))}{\ln(0.5)}\right]^{1/\beta}}_{\text{Weibull Distribution}}$$

Where:

$$\Delta\gamma_{\max}\ \text{(strain range)} = \frac{L\Delta\alpha\Delta T}{h_s}$$

$$\mathrm{c} = -0.442 - 6\times10^{-4}\,\mathrm{T_{sj}} + 1.74\times10^{-2}\ln\left(1+\frac{360}{t_D}\right)$$

$$2\varepsilon_f'\ \text{is a fatigue ductility coefficient} = 0.65\ (60\text{Sn}/40\text{Pb}\ \&\ 63\text{Sn}/37\text{Pb})$$



QFN Solder Cracks-cont.

Thermal Cycle profile:

High temperature: 70°C
Low temperature: 0°C
Dwell time at set point: 20 minutes
Temperature ramp rate: 60°C/minute

$$\text{Global shear strain} = \gamma_G \leq \frac{L\left(CTE_{PWB} - CTE_{comp}\right)\left(T_{Max} - T_{\min}\right)}{h_S}$$

$$\gamma_G \leq \frac{0.2783\left(15\times10^{-6} - 7\times10^{-6}\right)\left(70-(0)\right)}{0.0025} = 62.339\times10^{-3} = 6.2\%$$

$$\text{Shear Stress}\left(\tau_G\right) = \gamma\times G = \left(8.908\times10^{-3}\right)\left(6909\,MPa\right) = 61.53\,MPa > \text{yield stress } 9.6 \text{ MPA}$$

$$\text{local shear strain} = \gamma_L \leq \frac{L_{Solder}\left(CTE_{Solder} - CTE_{comp}\right)\left(T_{Max} - T_{\min}\right)}{h_S} + \frac{L\left(CTE_{Solder} - CTE_{PWB}\right)\left(T_{Max} - T_{\min}\right)}{h_S}$$

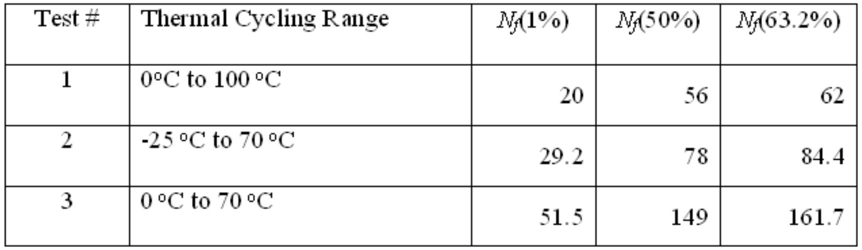
$$\gamma_L \leq \frac{0.0308\left(23.9\times10^{-6} - 7\times10^{-6}\right)\left(70\right)}{0.0025} + \frac{0.0308\left(23.9\times10^{-6} - 15\times10^{-6}\right)\left(70\right)}{0.0025} =$$

$$= 0.01457 + 0.00768 = 22.25\times10^{-3} = 2.2\%$$

$$\text{Shear Stress}\left(\tau_L\right) = \gamma\times G = \left(3.1046\times10^{-3}\right)\left(6909\,MPa\right) = 21.45 \text{ MPa} > \text{yield stress } 9.6\text{MPA}$$

QFN Solder Cracks-cont.

Modeling long-term solder joint reliability showed that the CTE mismatch was significant enough to impact product life.



Test #	Thermal Cycling Range	$N_f(1\%)$	$N_f(50\%)$	$N_f(63.2\%)$
1	0°C to 100 °C	20	56	62
2	-25 °C to 70 °C	29.2	78	84.4
3	0 °C to 70 °C	51.5	149	161.7

For thermal Cycling test #2 (0° C to 70° C) :

$$T_{sj} = \frac{0+70}{2} = 35 \qquad c = -0.41177 \qquad \Delta\gamma_{max} = 62.339\times10^{-3}$$

$$N_f(1\%) = \frac{1}{2}\left[\frac{77.924\times10^{-3}}{0.65}\right]^{\frac{1}{-0.41177}}\left[\frac{\ln(1-(0.01)(1))}{\ln(0.5)}\right]^{1/4} = 51.5$$

$$N_f(50\%) = \frac{1}{2}\left[\frac{77.924\times10^{-3}}{0.65}\right]^{\frac{1}{-0.41177}} = 148.5$$

$$N_f(63.2\%) = \frac{1}{2}\left[\frac{77.924\times10^{-3}}{0.65}\right]^{\frac{1}{-0.41177}}\left[\frac{\ln(1-(0.01)(62.3))}{\ln(0.5)}\right]^{1/4} = 161.7$$

Ansys Sherlock Applications

1. **Failure analysis:** Sherlock uses various failure analysis techniques such as thermal, vibration, and shock analysis to predict potential failure modes in electronic products.
2. **Physics of failure analysis:** physics of failure (PoF) approach to analyze the root cause of failure in electronic components and systems.

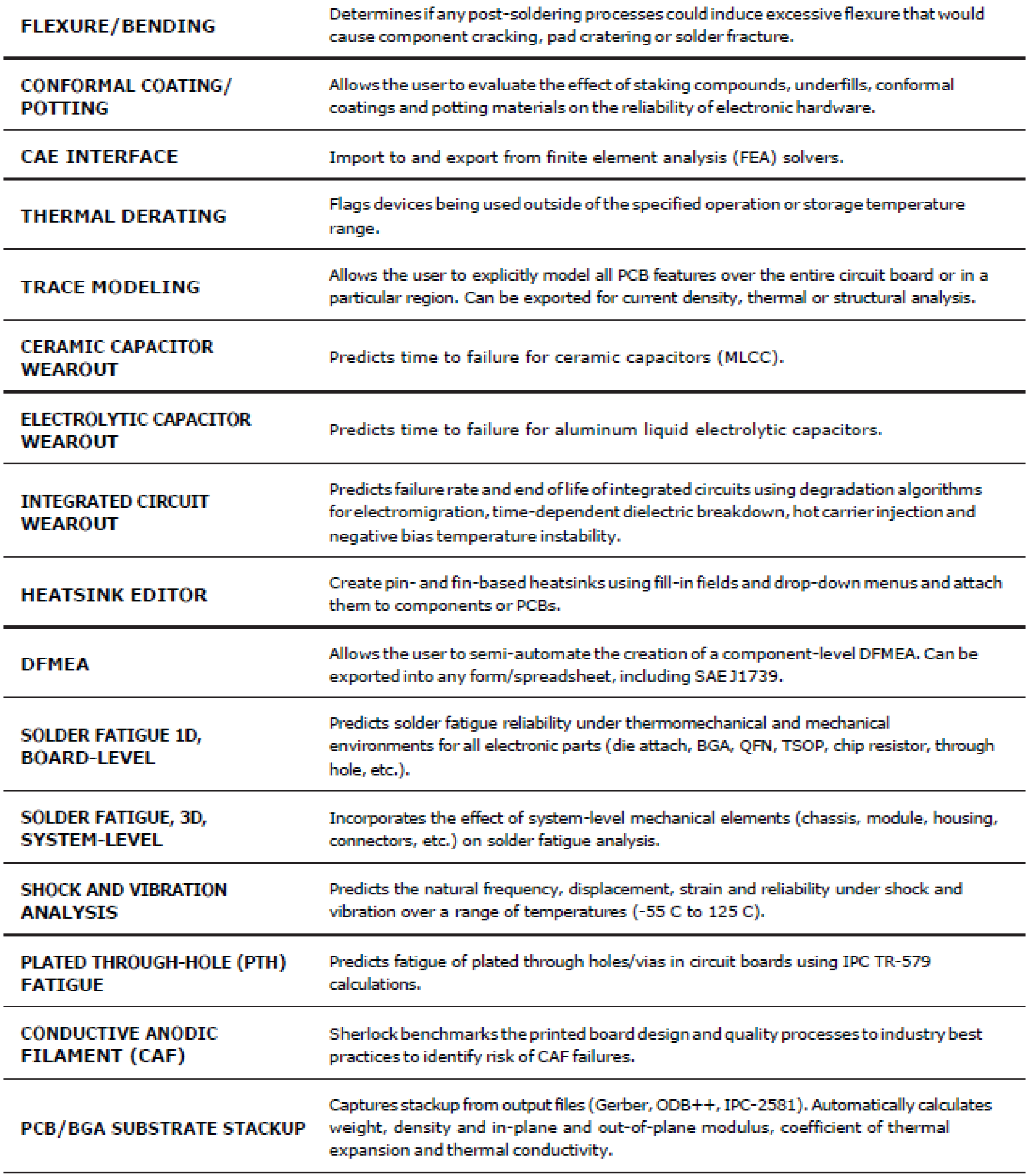
   -combines physics-based models with empirical data to simulate the life

3. **Design analysis:** Sherlock provides various design analysis features such as component derating, margin analysis, and accelerated life testing to optimize the design of electronic products for reliability and durability.

4. **Material analysis:** can analyze the impact of materials on the reliability and durability of electronic products.

   -It includes analyzing the thermal and mechanical properties of materials to determine their suitability for specific applications.

- ✓ CAF Failure
- ✓ Component Failure Mechanism
- ✓ DFMEA
- ✓ Harmonic Vibe
- ✓ ICT Analysis
- ✓ Mechanical Shock
- ✓ Natural Freq
- ✓ PTH Fatigue
- ✓ Part Validation
- ✓ Random Vibe
- ✓ Semiconductor Wearout
- ✓ Solder Fatigue
- ✓ Thermal Derating
- ✓ Thermal Mech



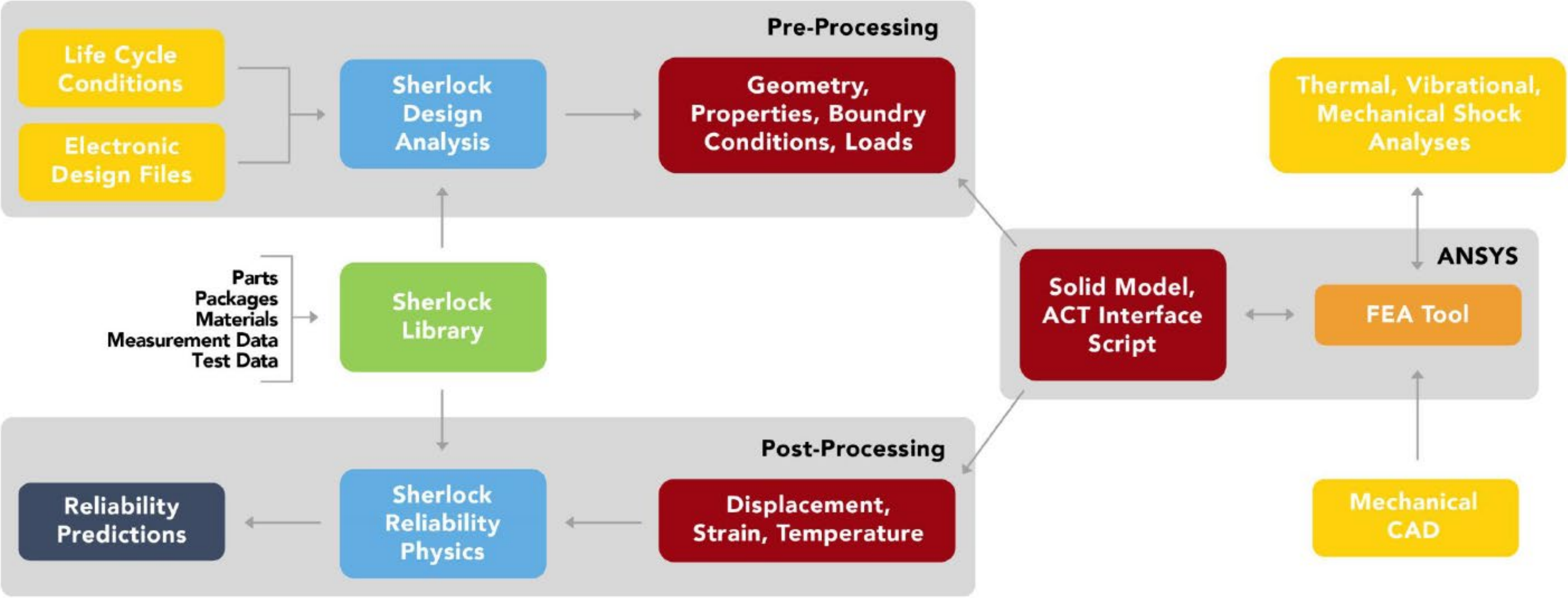
FLEXURE/BENDING	Determines if any post-soldering processes could induce excessive flexure that would cause component cracking, pad cratering or solder fracture.
CONFORMAL COATING/ POTTING	Allows the user to evaluate the effect of staking compounds, underfills, conformal coatings and potting materials on the reliability of electronic hardware.
CAE INTERFACE	Import to and export from finite element analysis (FEA) solvers.
THERMAL DERATING	Flags devices being used outside of the specified operation or storage temperature range.
TRACE MODELING	Allows the user to explicitly model all PCB features over the entire circuit board or in a particular region. Can be exported for current density, thermal or structural analysis.
CERAMIC CAPACITOR WEAROUT	Predicts time to failure for ceramic capacitors (MLCC).
ELECTROLYTIC CAPACITOR WEAROUT	Predicts time to failure for aluminum liquid electrolytic capacitors.
INTEGRATED CIRCUIT WEAROUT	Predicts failure rate and end of life of integrated circuits using degradation algorithms for electromigration, time-dependent dielectric breakdown, hot carrier injection and negative bias temperature instability.
HEATSINK EDITOR	Create pin- and fin-based heatsinks using fill-in fields and drop-down menus and attach them to components or PCBs.
DFMEA	Allows the user to semi-automate the creation of a component-level DFMEA. Can be exported into any form/spreadsheet, including SAE J1739.
SOLDER FATIGUE 1D, BOARD-LEVEL	Predicts solder fatigue reliability under thermomechanical and mechanical environments for all electronic parts (die attach, BGA, QFN, TSOP, chip resistor, through hole, etc.).
SOLDER FATIGUE, 3D, SYSTEM-LEVEL	Incorporates the effect of system-level mechanical elements (chassis, module, housing, connectors, etc.) on solder fatigue analysis.
SHOCK AND VIBRATION ANALYSIS	Predicts the natural frequency, displacement, strain and reliability under shock and vibration over a range of temperatures (-55 C to 125 C).
PLATED THROUGH-HOLE (PTH) FATIGUE	Predicts fatigue of plated through holes/vias in circuit boards using IPC TR-579 calculations.
CONDUCTIVE ANODIC FILAMENT (CAF)	Sherlock benchmarks the printed board design and quality processes to industry best practices to identify risk of CAF failures.
PCB/BGA SUBSTRATE STACKUP	Captures stackup from output files (Gerber, ODB++, IPC-2581). Automatically calculates weight, density and in-plane and out-of-plane modulus, coefficient of thermal expansion and thermal conductivity.

Modeling Steps

The modeling process consists of two parts:

1) **Pre-processing** pulls in the PCB artwork (e.g., ODB+) and components to create a model.
2) **Post-processing** calculates strains from stress due to CTE differences and mechanical flexure displacements. The strains are then fed into Sherlock's physics of failure (PoF) reliability models to evaluate long term reliability.

There is an appendix at the end with the PoF reliability model for a QFN package and the validation work behind the model. Each package type has its own PoF model and validation.



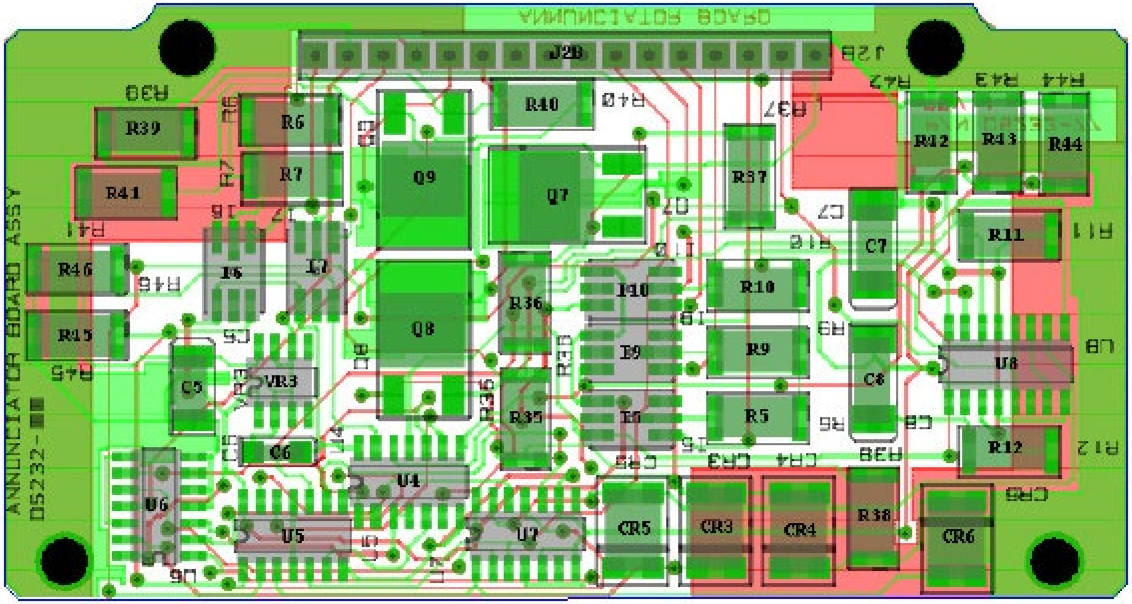
The pre-processed model

√ Component details and placement

√ PCB outline & stack-up

√ Drill hole file with mount points

√ Metal layers, silkscreen and solder mask layers

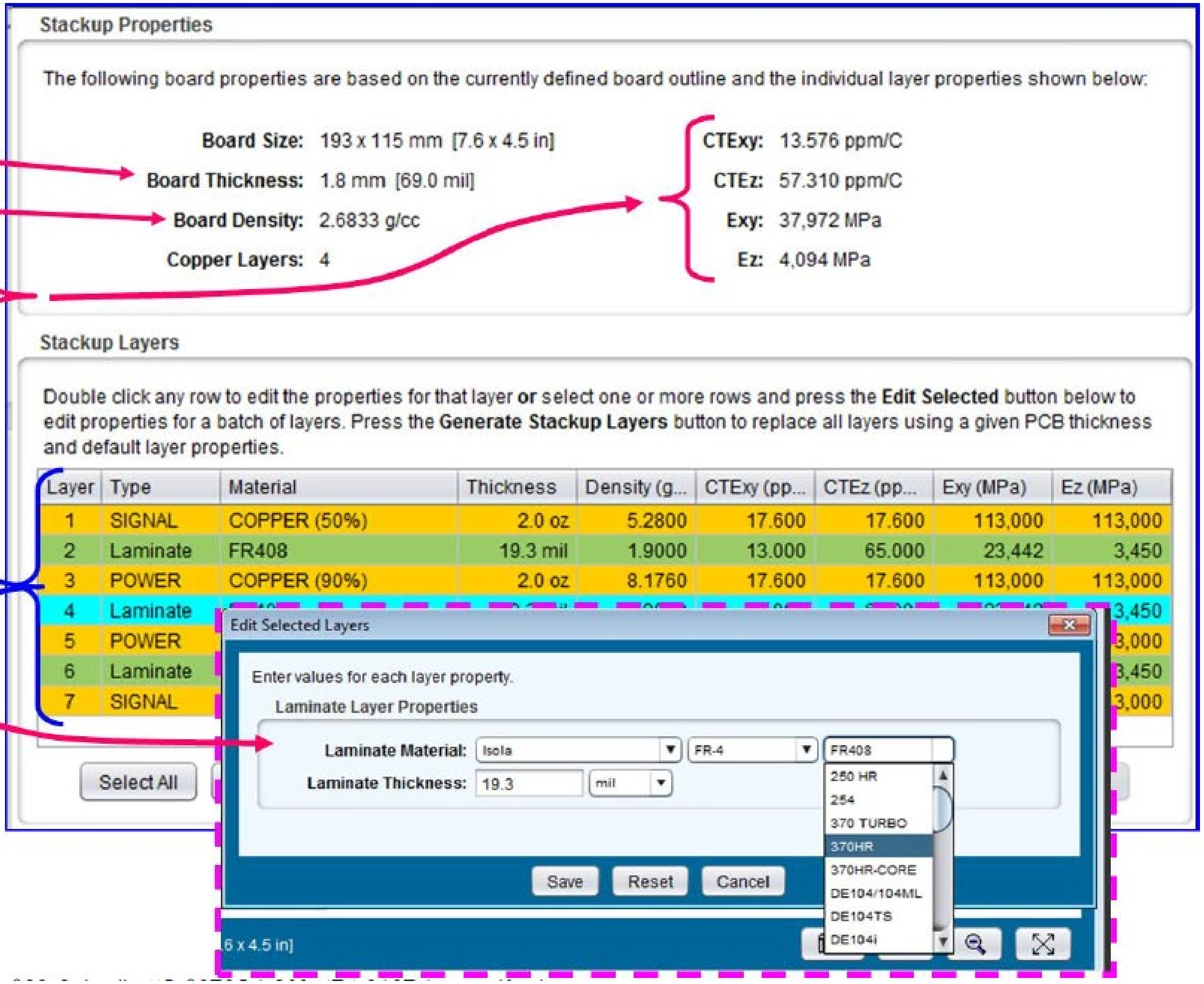


PCB Material Properties

All the relevant PCB material properties for each layer of the PCB are pulled in from the ODB files.

Calculates

- **Thickness**
- **Density**
- **CTE x-y**
- **CTE z**
- **Modulus x-y**
- **Modulus z**
- **From the material properties of each layer**
- **Using the Built in Laminate Data Library**



Stackup Properties

The following board properties are based on the currently defined board outline and the individual layer properties shown below:

Board Size: 193 x 115 mm [7.6 x 4.5 in]
Board Thickness: 1.8 mm [69.0 mil]
Board Density: 2.6833 g/cc
Copper Layers: 4

CTExy: 13.576 ppm/C
CTEz: 57.310 ppm/C
Exy: 37,972 MPa
Ez: 4,094 MPa

Stackup Layers

Double click any row to edit the properties for that layer **or** select one or more rows and press the **Edit Selected** button below to edit properties for a batch of layers. Press the **Generate Stackup Layers** button to replace all layers using a given PCB thickness and default layer properties.

Layer	Type	Material	Thickness	Density (g...	CTExy (pp...	CTEz (pp...	Exy (MPa)	Ez (MPa)
1	SIGNAL	COPPER (50%)	2.0 oz	5.2800	17.600	17.600	113,000	113,000
2	Laminate	FR408	19.3 mil	1.9000	13.000	65.000	23,442	3,450
3	POWER	COPPER (90%)	2.0 oz	8.1760	17.600	17.600	113,000	113,000
4	Laminate							3,450
5	POWER							3,000
6	Laminate							3,450
7	SIGNAL							3,000

Edit Selected Layers

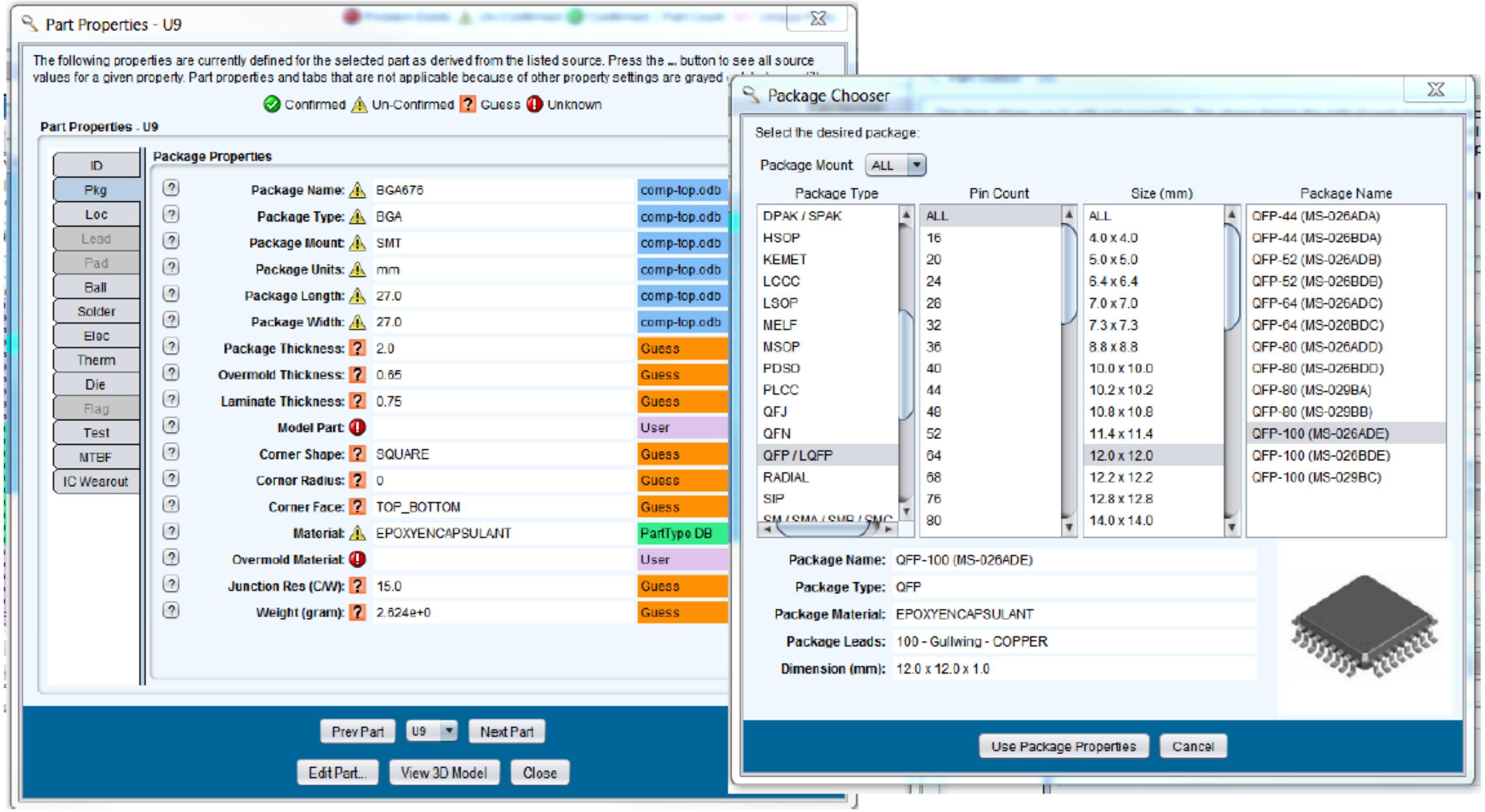
Enter values for each layer property.

Laminate Layer Properties

Laminate Material: Isola FR-4 FR408
Laminate Thickness: 19.3 mil

Ansys Part Model Library

- The part Library contains all the relevant information needed to create a 3D mesh model.
- If the part doesn't exist in Sherlock Global Parts library, they will create a new model for that part and add it to the Ansys library.
- Limitation for Current Version: Ansys doesn’t model connectors, custom ASICs and some unique parts where the manufacturer doesn’t share package material information.



Part Properties - U9

The following properties are currently defined for the selected part as derived from the listed source. Press the ... button to see all source values for a given property. Part properties and tabs that are not applicable because of other property settings are grayed

✅ Confirmed ⚠ Un-Confirmed ? Guess ❗ Unknown

Part Properties - U9

Package Properties

Property		Value	Source
Package Name:	⚠	BGA676	comp-top.odb
Package Type:	⚠	BGA	comp-top.odb
Package Mount:	⚠	SMT	comp-top.odb
Package Units:	⚠	mm	comp-top.odb
Package Length:	⚠	27.0	comp-top.odb
Package Width:	⚠	27.0	comp-top.odb
Package Thickness:	?	2.0	Guess
Overmold Thickness:	?	0.65	Guess
Laminate Thickness:	?	0.75	Guess
Model Part:	❗		User
Corner Shape:	?	SQUARE	Guess
Corner Radius:	?	0	Guess
Corner Face:	?	TOP_BOTTOM	Guess
Material:	⚠	EPOXYENCAPSULANT	PartType DB
Overmold Material:	❗		User
Junction Res (C/W):	?	15.0	Guess
Weight (gram):	?	2.624e+0	Guess

Package Chooser

Select the desired package:

Package Mount: ALL

Package Type:
DPAK / SPAK
HSOP
KEMET
LCCC
LSOP
MELF
MSOP
PDSO
PLCC
QFJ
QFN
QFP / LQFP
RADIAL
SIP
SM / SMA / SMB / SMC

Pin Count:
ALL
16
20
24
28
32
36
40
44
48
52
64
68
76
80

Size (mm):
ALL
4.0 x 4.0
5.0 x 5.0
6.4 x 6.4
7.0 x 7.0
7.3 x 7.3
8.8 x 8.8
10.0 x 10.0
10.2 x 10.2
10.8 x 10.8
11.4 x 11.4
12.0 x 12.0
12.2 x 12.2
12.8 x 12.8
14.0 x 14.0

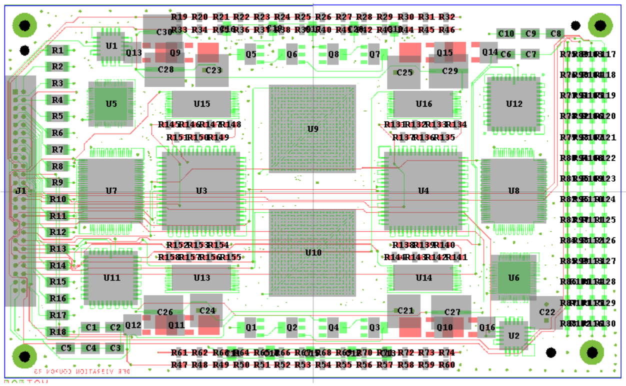
Package Name:
QFP-44 (MS-026ADA)
QFP-44 (MS-026BDA)
QFP-52 (MS-026ADB)
QFP-52 (MS-026BDB)
QFP-64 (MS-026ADC)
QFP-64 (MS-026BDC)
QFP-80 (MS-026ADD)
QFP-80 (MS-026BDD)
QFP-80 (MS-029BA)
QFP-80 (MS-029BB)
QFP-100 (MS-026ADE)
QFP-100 (MS-026BDE)
QFP-100 (MS-029BC)

Package Name: QFP-100 (MS-026ADE)
Package Type: QFP
Package Material: EPOXYENCAPSULANT
Package Leads: 100 - Gullwing - COPPER
Dimension (mm): 12.0 x 12.0 x 1.0

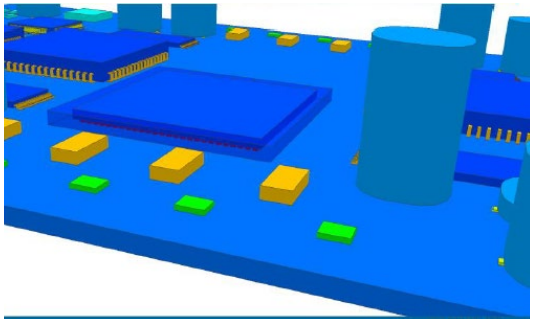
FEA Analysis

- For PTH and Solder Fatigue, CAF Analysis, Derating, Part Stress Analysis, the simulations are based on the Non-FEA models.
- After uploading the PCB CAD files and the 3D components from the Ansys parts library, the PCBA is meshed for finite element modeling.
- The size of the components to mesh, mesh type and number of elements are defined.
- Small components like chip resistors and capacitors, can be omitted to reduce simulation time.

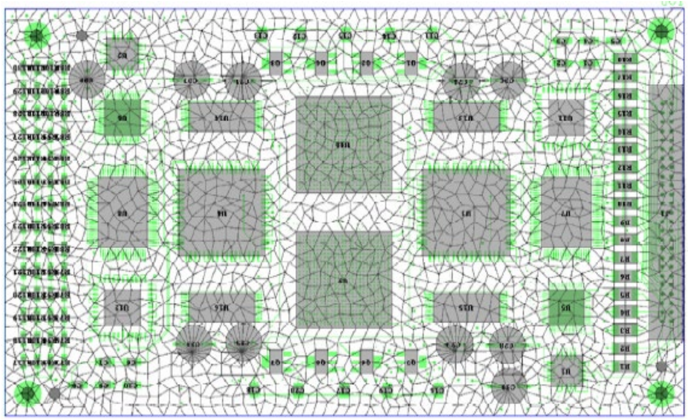
Upload ECAD Design



Add the 3D Component Models



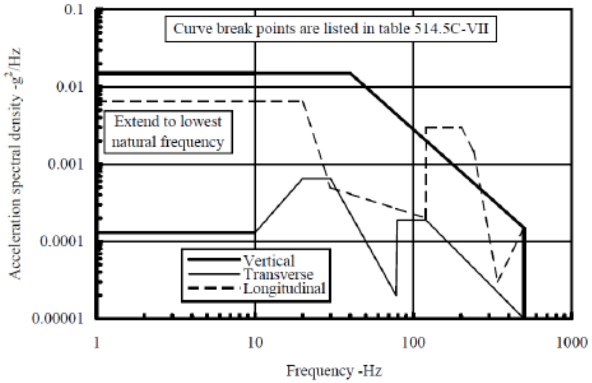
Mesh the network



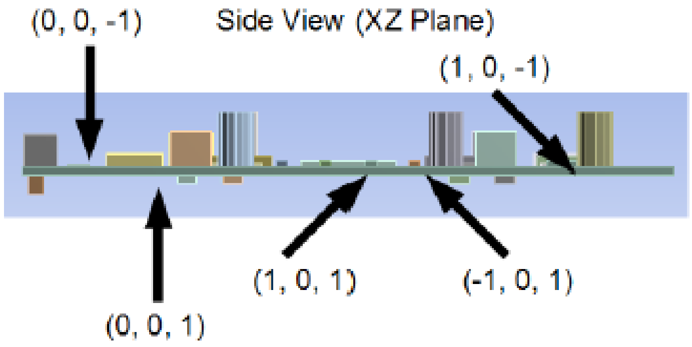
Example of Vibration Cycles Profile

Below is an example of a defined vibration profile to simulate shipping in accordance with MIL-STD810 for 60 minutes (simulate 1000 miles travel distance).

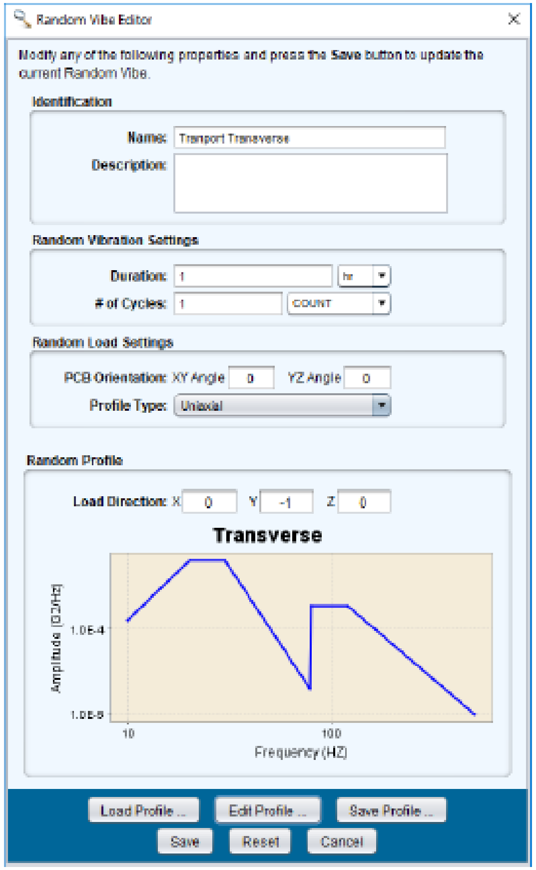
Vibration Spec per MIL-STD-810



Vibration profile Orientation



Vibration transverse profile


Random Vibe Editor

Modify any of the following properties and press the **Save** button to update the current Random Vibe.

Identification

Name: Tranport Transverse

Description:

Random Vibration Settings

Duration: 1 hr

# of Cycles: 1 COUNT

Random Load Settings

PCB Orientation: XY Angle 0 YZ Angle 0

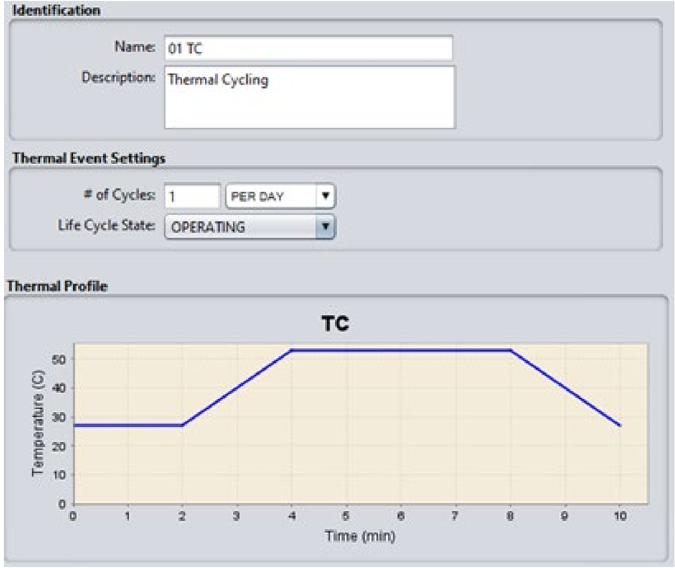
Profile Type: Uniaxial

Random Profile

Load Direction: X 0 Y -1 Z 0

Example-Thermal Cycling Profiles

- The sample board was modeled using Ansys Sherlock for Solder Joint reliability.
- The PCBA was analyzed for long term temperature cycling between 27 °C and 53 °C once/day.
- A thermal image was taken for worst case power consumption, and the thermal image was overlayed to the PCB.



Identification

Name: 01 TC

Description: Thermal Cycling

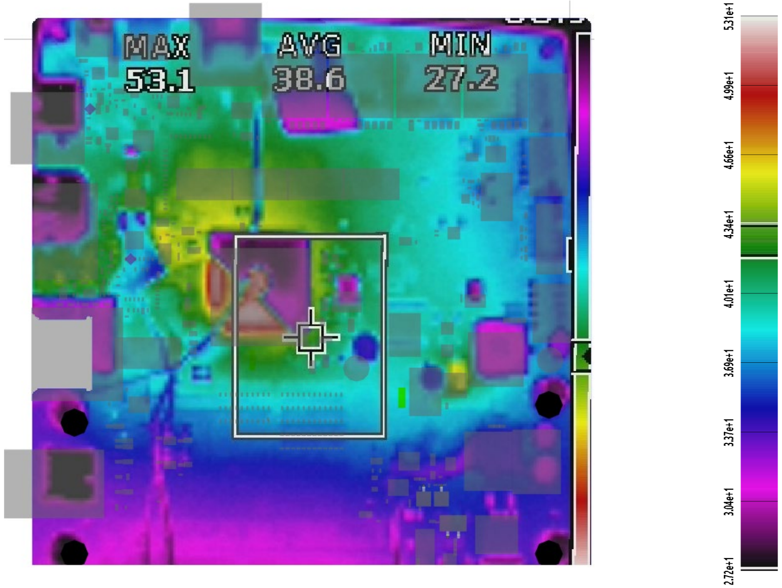
Thermal Event Settings

# of Cycles: 1 PER DAY

Life Cycle State: OPERATING

Thermal Profile

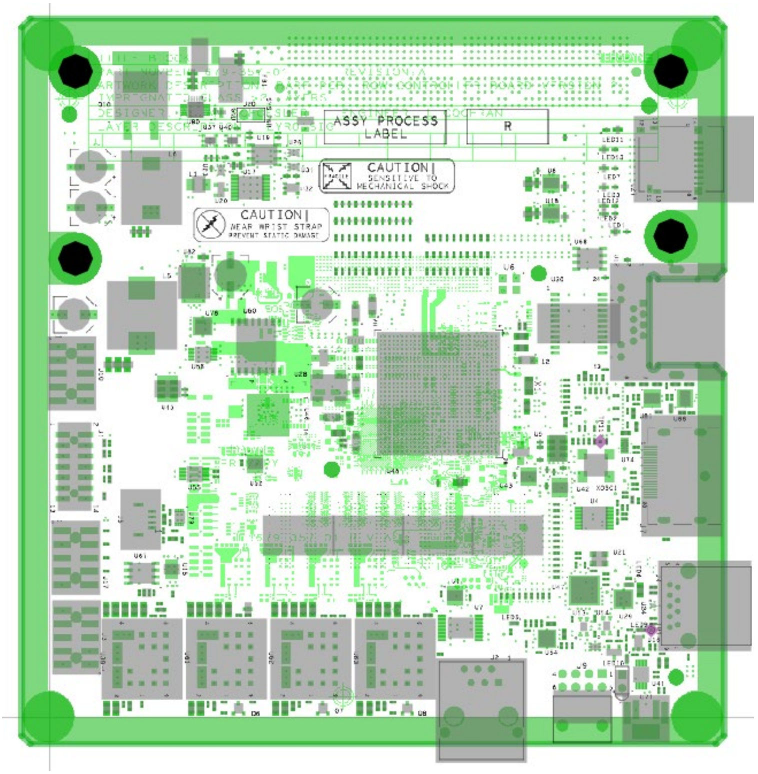
Defined Thermal cycle



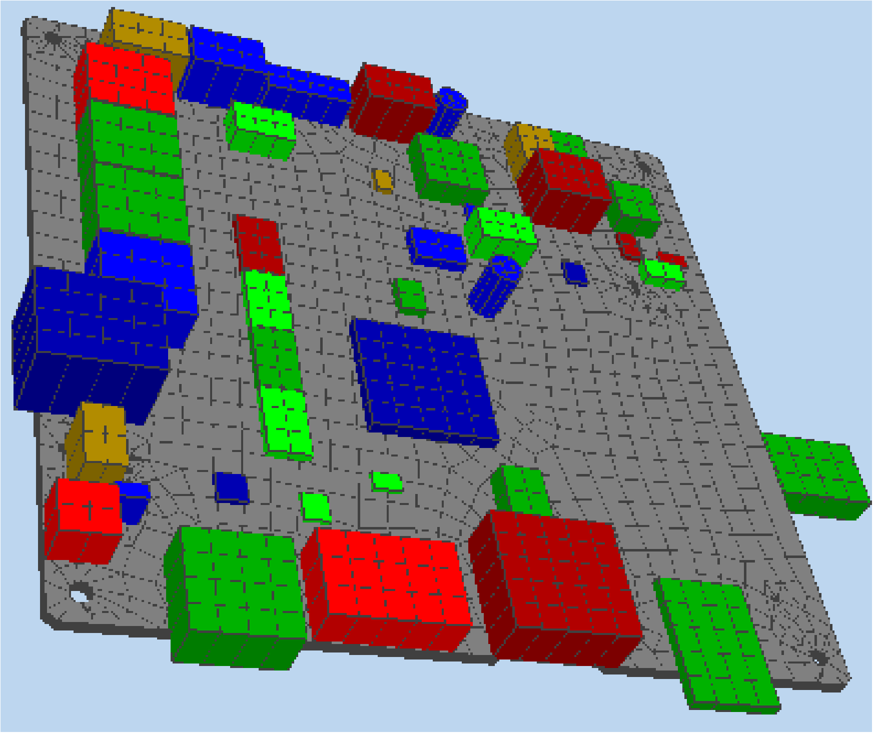
IR image

Board Solder Joint Reliability

- The 2D and 3D models created in Sherlock are shown below:



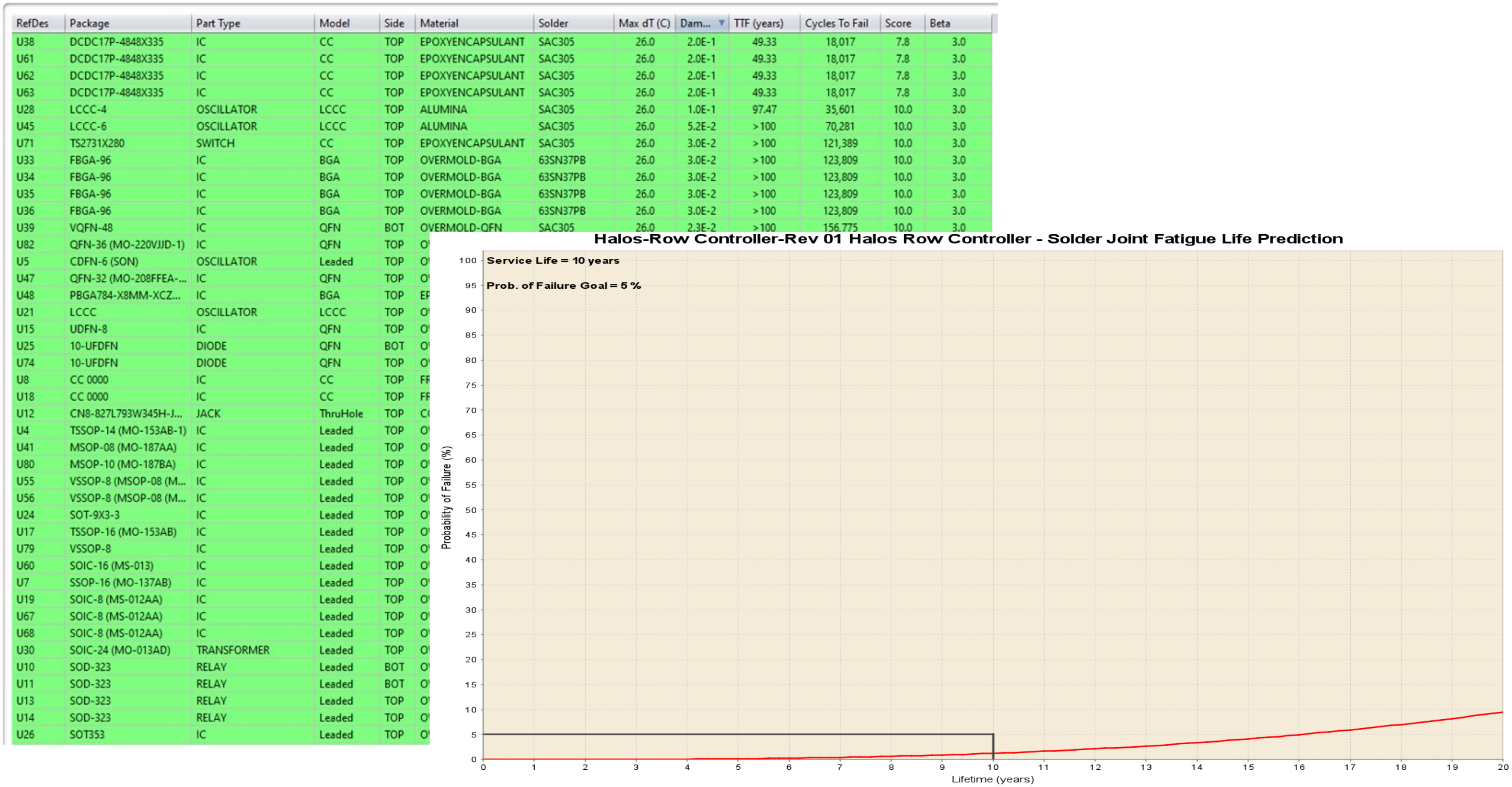
2D Model with Artwork



3D Meshed Model

Board Solder Joint Reliability-cont

Reliability modeling showed that all components in the assembly exceed the minimum 10-year life requirement. The software calculates the number of cycles to a predefined percent failure. In this case we defined it as a 5% failure rate in 10 years.



RefDes	Package	Part Type	Model	Side	Material	Solder	Max dT (C)	Dam... ▼	TTF (years)	Cycles To Fail	Score	Beta
U38	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U61	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U62	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U63	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U28	LCCC-4	OSCILLATOR	LCCC	TOP	ALUMINA	SAC305	26.0	1.0E-1	97.47	35,601	10.0	3.0
U45	LCCC-6	OSCILLATOR	LCCC	TOP	ALUMINA	SAC305	26.0	5.2E-2	>100	70,281	10.0	3.0
U71	TS2731X280	SWITCH	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	3.0E-2	>100	121,389	10.0	3.0
U33	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U34	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U35	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U36	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U39	VQFN-48	IC	QFN	BOT	OVERMOLD-QFN	SAC305	26.0	2.3E-2	>100	156,775	10.0	3.0
U82	QFN-36 (MO-220VJJD-1)	IC	QFN	TOP	O							
U5	CDFN-6 (SON)	OSCILLATOR	Leaded	TOP	O							
U47	QFN-32 (MO-208FFEA-...	IC	QFN	TOP	O							
U48	PBGA784-X8MM-XCZ...	IC	BGA	TOP	EP							
U21	LCCC	OSCILLATOR	LCCC	TOP	O							
U15	UDFN-8	IC	QFN	TOP	O							
U25	10-UFDFN	DIODE	QFN	BOT	O							
U74	10-UFDFN	DIODE	QFN	TOP	O							
U8	CC 0000	IC	CC	TOP	FR							
U18	CC 0000	IC	CC	TOP	FR							
U12	CN8-827L793W345H-J...	JACK	ThruHole	TOP	C							
U4	TSSOP-14 (MO-153AB-1)	IC	Leaded	TOP	O							
U41	MSOP-08 (MO-187AA)	IC	Leaded	TOP	O							
U80	MSOP-10 (MO-187BA)	IC	Leaded	TOP	O							
U55	VSSOP-8 (MSOP-08 (M...	IC	Leaded	TOP	O							
U56	VSSOP-8 (MSOP-08 (M...	IC	Leaded	TOP	O							
U24	SOT-9X3-3	IC	Leaded	TOP	O							
U17	TSSOP-16 (MO-153AB)	IC	Leaded	TOP	O							
U79	VSSOP-8	IC	Leaded	TOP	O							
U60	SOIC-16 (MS-013)	IC	Leaded	TOP	O							
U7	SSOP-16 (MO-137AB)	IC	Leaded	TOP	O							
U19	SOIC-8 (MS-012AA)	IC	Leaded	TOP	O							
U67	SOIC-8 (MS-012AA)	IC	Leaded	TOP	O							
U68	SOIC-8 (MS-012AA)	IC	Leaded	TOP	O							
U30	SOIC-24 (MO-013AD)	TRANSFORMER	Leaded	TOP	O							
U10	SOD-323	RELAY	Leaded	BOT	O							
U11	SOD-323	RELAY	Leaded	BOT	O							
U13	SOD-323	RELAY	Leaded	TOP	O							
U14	SOD-323	RELAY	Leaded	TOP	O							
U26	SOT353	IC	Leaded	TOP	O							

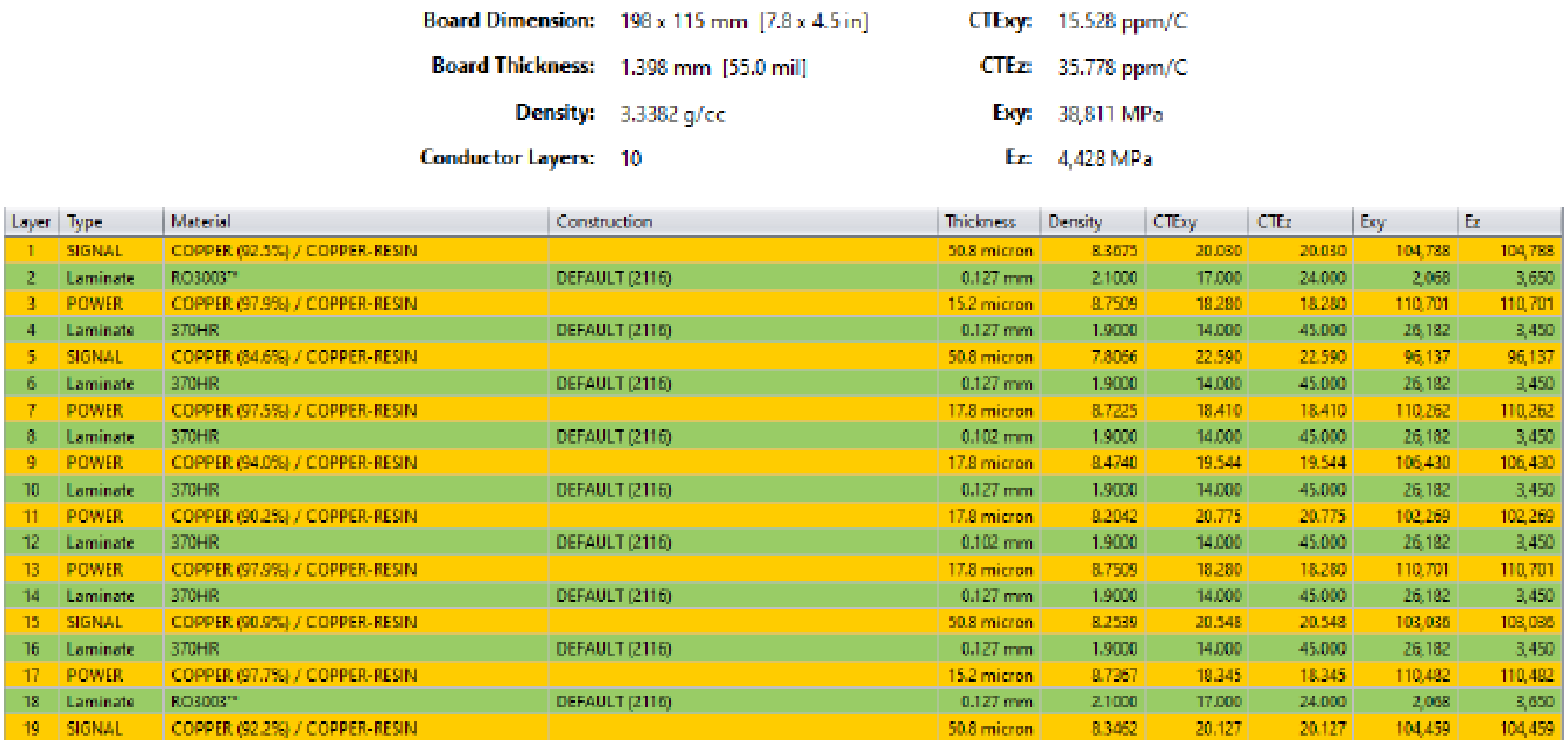
Halos-Row Controller-Rev 01 Halos Row Controller - Solder Joint Fatigue Life Prediction

Modeling Board Strain during Mechanical Attachments attachment Stresses

Ansys Mechanical to Model Board Strain due to Mechanical Assembly of a Cover onto a RF Module

Ansys Sherlock works with Ansys Mechanical to simulate board strain during lid attachment of the RFM module and the results from Ansys Mechanical are sent back to Sherlock for post-processing reliability analysis.

1) The process starts by Sherlock pulling in the ODB files for the PCB (including all layers, traces, vias, solder mask and laminate material information) for the RFM module.

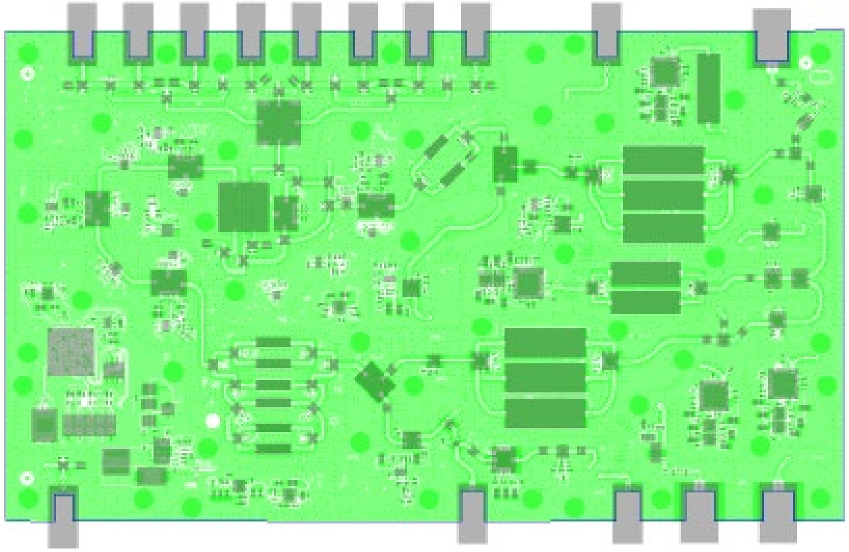


Board Dimension:	198 x 115 mm [7.8 x 4.5 in]	**CTExy:**	15.528 ppm/C
Board Thickness:	1.398 mm [55.0 mil]	**CTEz:**	35.778 ppm/C
Density:	3.3382 g/cc	**Exy:**	38,811 MPa
Conductor Layers:	10	**Ez:**	4,428 MPa

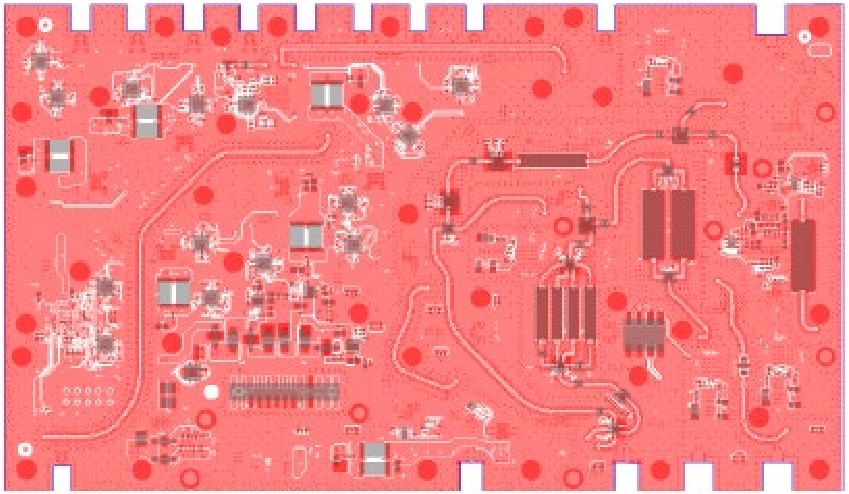
Layer	Type	Material	Construction	Thickness	Density	CTExy	CTEz	Exy	Ez
1	SIGNAL	COPPER (92.5%) / COPPER-RESIN		50.8 micron	8.3675	20.030	20.030	104,788	104,788
2	Laminate	RO3003™	DEFAULT (2116)	0.127 mm	2.1000	17.000	24.000	2,068	3,650
3	POWER	COPPER (97.9%) / COPPER-RESIN		15.2 micron	8.7509	18.280	18.280	110,701	110,701
4	Laminate	370HR	DEFAULT (2116)	0.127 mm	1.9000	14.000	45.000	26,182	3,450
5	SIGNAL	COPPER (84.6%) / COPPER-RESIN		50.8 micron	7.8066	22.590	22.590	96,137	96,137
6	Laminate	370HR	DEFAULT (2116)	0.127 mm	1.9000	14.000	45.000	26,182	3,450
7	POWER	COPPER (97.5%) / COPPER-RESIN		17.8 micron	8.7225	18.410	18.410	110,262	110,262
8	Laminate	370HR	DEFAULT (2116)	0.102 mm	1.9000	14.000	45.000	26,182	3,450
9	POWER	COPPER (94.0%) / COPPER-RESIN		17.8 micron	8.4740	19.544	19.544	106,430	106,430
10	Laminate	370HR	DEFAULT (2116)	0.127 mm	1.9000	14.000	45.000	26,182	3,450
11	POWER	COPPER (90.2%) / COPPER-RESIN		17.8 micron	8.2042	20.775	20.775	102,269	102,269
12	Laminate	370HR	DEFAULT (2116)	0.102 mm	1.9000	14.000	45.000	26,182	3,450
13	POWER	COPPER (97.9%) / COPPER-RESIN		17.8 micron	8.7509	18.280	18.280	110,701	110,701
14	Laminate	370HR	DEFAULT (2116)	0.127 mm	1.9000	14.000	45.000	26,182	3,450
15	SIGNAL	COPPER (90.9%) / COPPER-RESIN		50.8 micron	8.2539	20.548	20.548	103,036	103,036
16	Laminate	370HR	DEFAULT (2116)	0.127 mm	1.9000	14.000	45.000	26,182	3,450
17	POWER	COPPER (97.7%) / COPPER-RESIN		15.2 micron	8.7367	18.345	18.345	110,482	110,482
18	Laminate	RO3003™	DEFAULT (2116)	0.127 mm	2.1000	17.000	24.000	2,068	3,650
19	SIGNAL	COPPER (92.2%) / COPPER-RESIN		50.8 micron	8.3462	20.127	20.127	104,459	104,459

Using Ansys to Model RFM Module

2) Sherlock then pulls in the BOM, and the component 3D models from the part library.



Top Side RFM Module



Bottom Side RFM Module

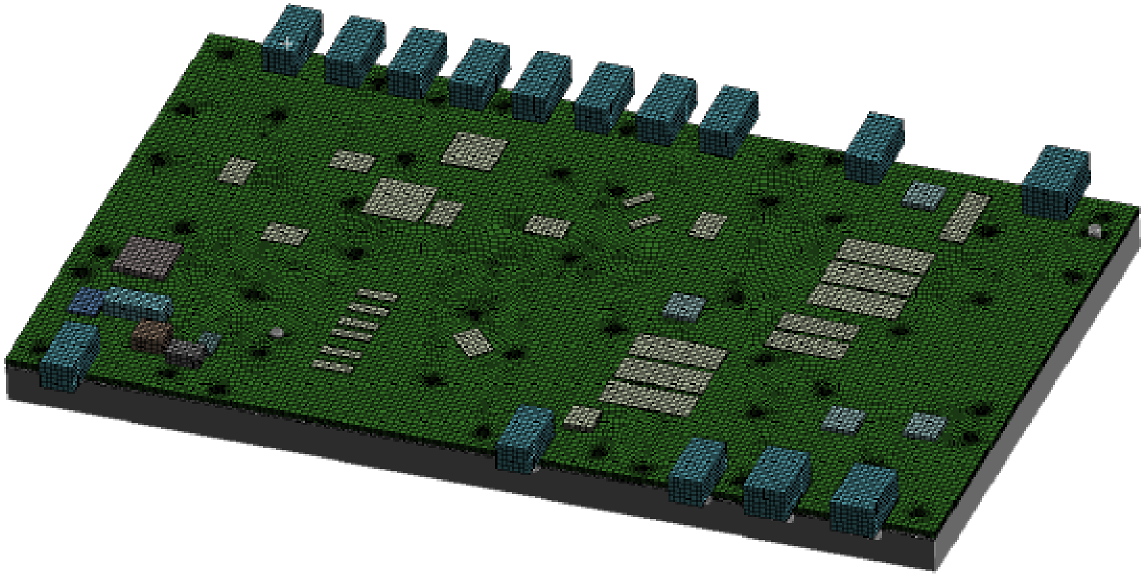
Using Ansys to Model RFM module

3) Sherlock then creates a mesh network for the PCB assembly.

Proper Meshing is Determined for the PCBA, Housing, Gasket and TIM materials (Quadratic, primarily hexahedral elements were used to mesh the PCB, gaskets, and TIM material.

- Elements through the thickness of the PCB (minimum 3) were included to ensure bending stiffness was captured approximately.

The housing was approximated as a rigid body because it was expected to be far stiffer than the PCB, gaskets, and housing.



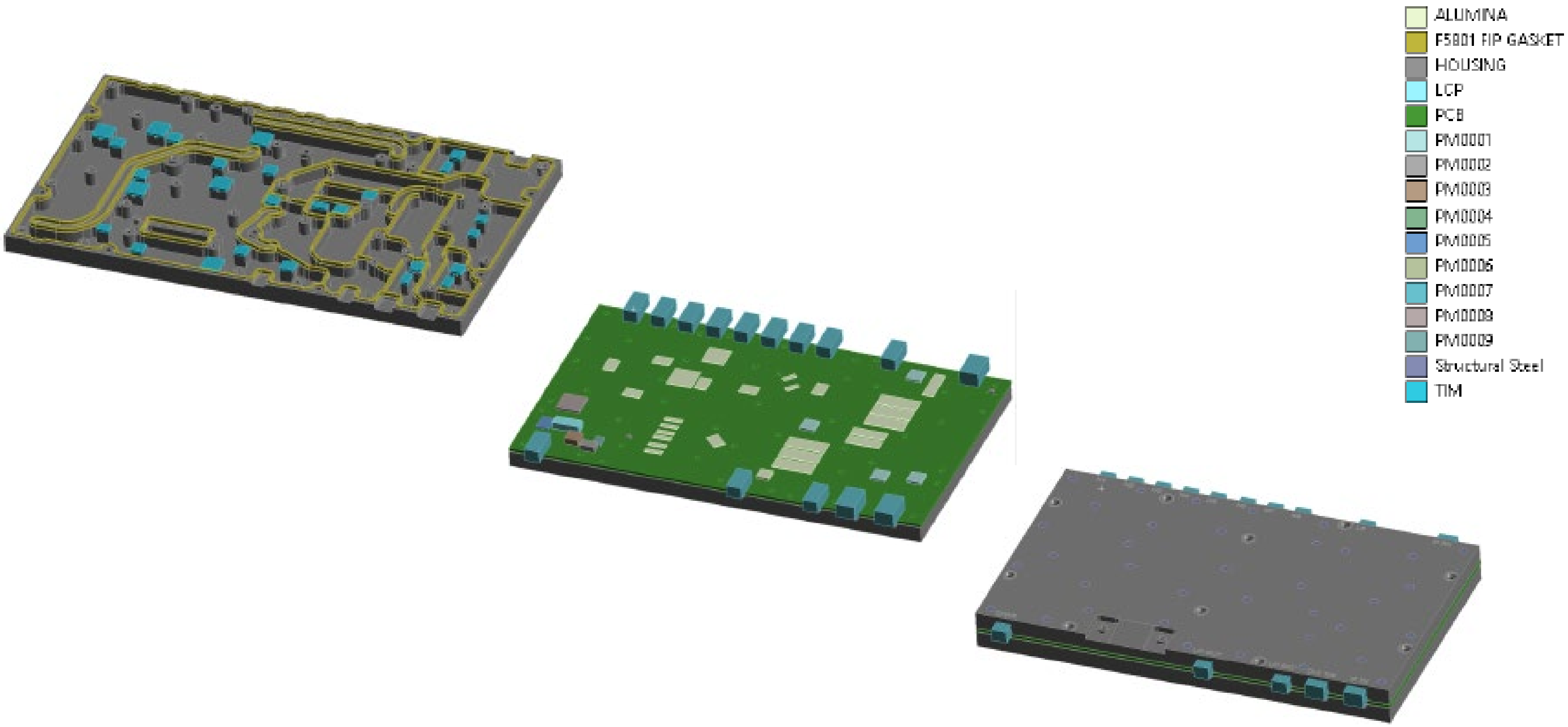
Mesh through PCB

Using Ansys to Model RFM module

4) Using Ansys SpaceClaim and Ansys Workbench the Teradyne 3D mechanical files from Solidworks were pulled in for the housing, RF gasket, TIM and align to the PCBA.

A mesh network was created for the mechanical parts that have been pulled in from Solidworks.

Once the assembly is meshed, Ansys can simulate the process of torquing the screws in a predefined torque sequential sequence and measure strain during the mechanical attachment process.



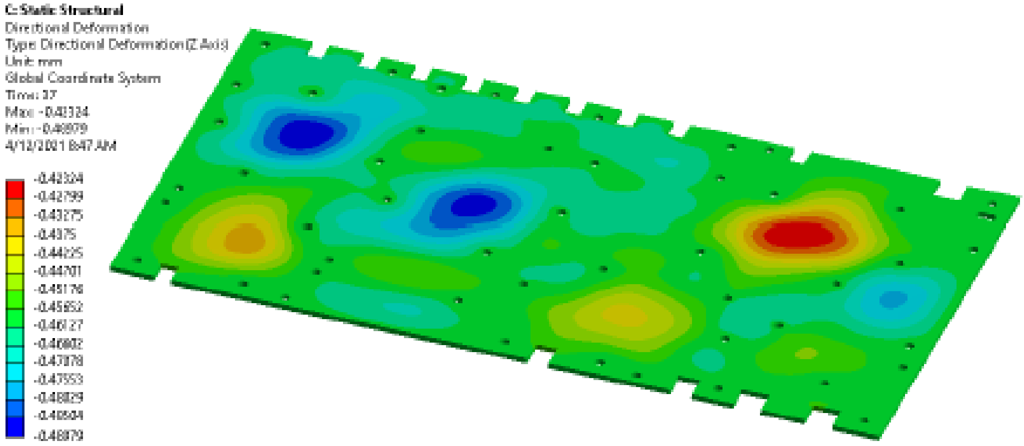
Define the Boundary Conditions & the Torque Sequence

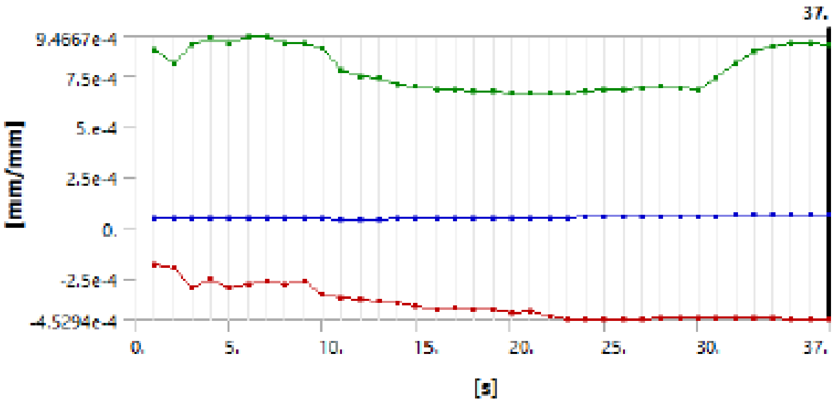
The bottom face of the housing was fixed to the outside world to prevent rigid body motion during simulation.

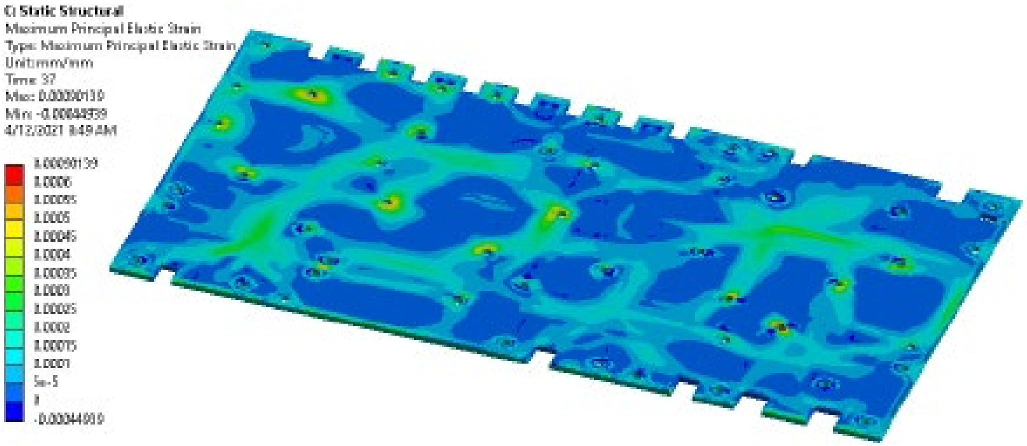
- A 37-step, sequential bolt pretension process was used to approximate the board assembly. The bolting sequence for the screws is shown below and number from 1 to 37.
- A 1695N bolt pretension load was applied to all bolts in order. Bolts were free prior to application of the pretension and locked after application.

Module Board Strain Results

- Final out-of-plane board deflection and maximum principal strain after application of all bolts are shown on the right.
- Maximum, minimum, and average board strains tracked during the application process are shown in the below plot.

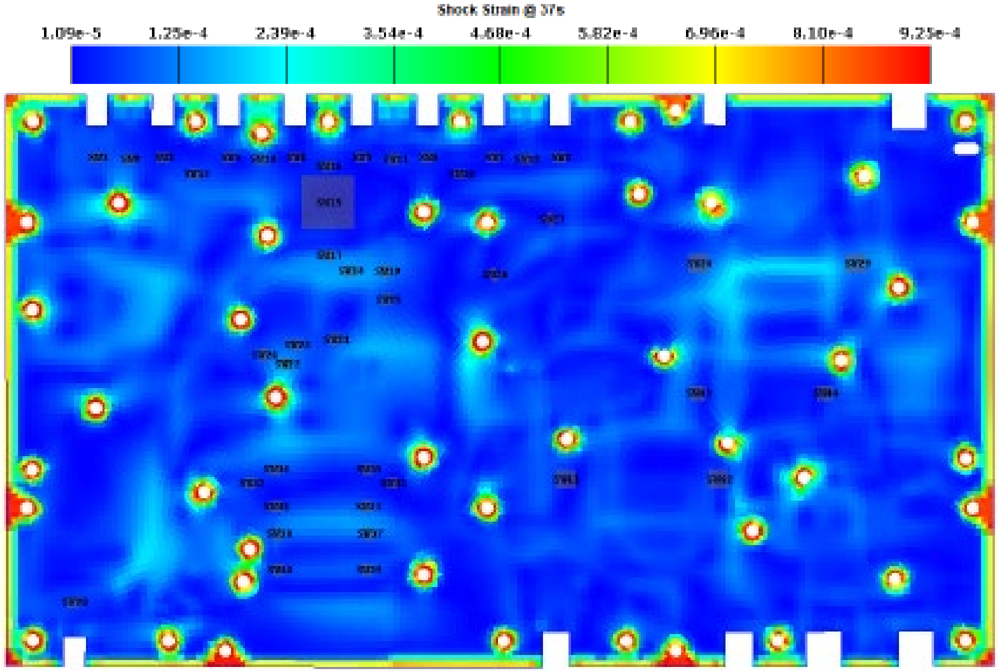


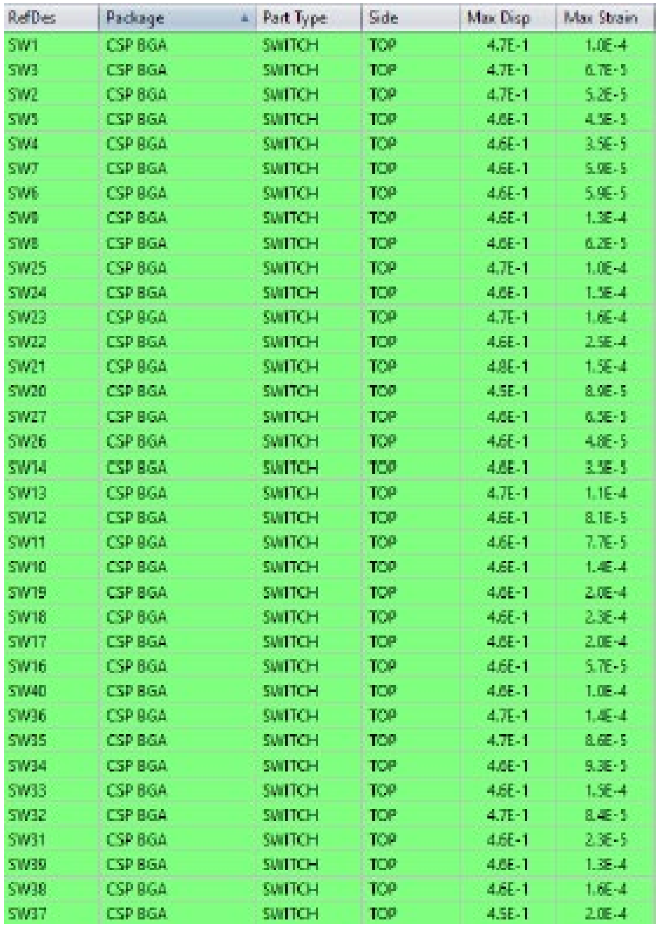




Using Ansys to Model RFM module

- The results were then imported to Sherlock to identify the peak board deflection condition and associated strain in the board regions.
  - Sherlock identified the final assembled state as the peak deflection condition.
- Peak strains observed on any of the regions were approximately 250$\mu\varepsilon$.

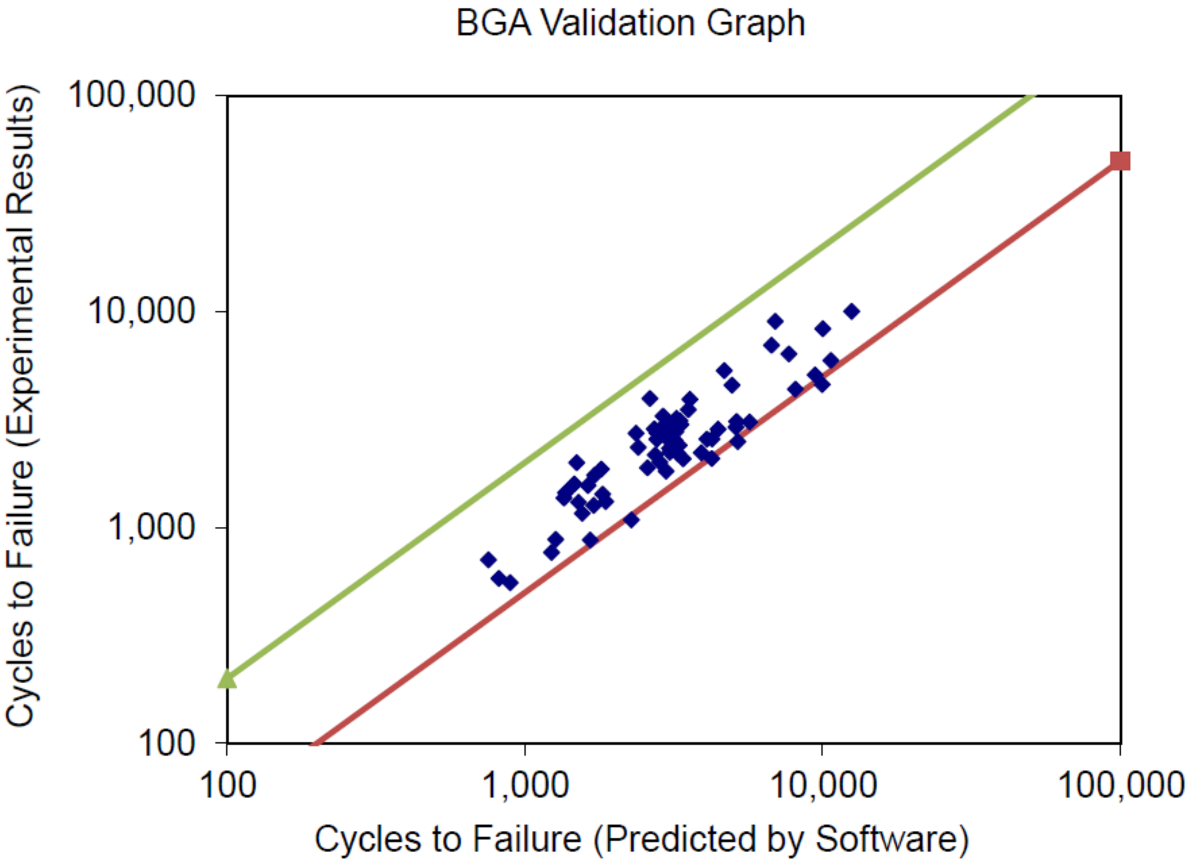




RefDes	Package	Part Type	Side	Max Disp	Max Strain
SW1	CSP BGA	SWITCH	TOP	4.7E-1	1.0E-4
SW3	CSP BGA	SWITCH	TOP	4.7E-1	6.7E-5
SW2	CSP BGA	SWITCH	TOP	4.7E-1	5.2E-5
SW5	CSP BGA	SWITCH	TOP	4.8E-1	4.5E-5
SW4	CSP BGA	SWITCH	TOP	4.6E-1	3.5E-5
SW7	CSP BGA	SWITCH	TOP	4.6E-1	5.9E-5
SW6	CSP BGA	SWITCH	TOP	4.6E-1	5.9E-5
SW9	CSP BGA	SWITCH	TOP	4.6E-1	1.3E-4
SW8	CSP BGA	SWITCH	TOP	4.6E-1	6.2E-5
SW25	CSP BGA	SWITCH	TOP	4.7E-1	1.0E-4
SW24	CSP BGA	SWITCH	TOP	4.8E-1	1.3E-4
SW23	CSP BGA	SWITCH	TOP	4.7E-1	1.6E-4
SW22	CSP BGA	SWITCH	TOP	4.6E-1	2.5E-4
SW21	CSP BGA	SWITCH	TOP	4.8E-1	1.5E-4
SW20	CSP BGA	SWITCH	TOP	4.5E-1	8.9E-5
SW27	CSP BGA	SWITCH	TOP	4.6E-1	6.5E-5
SW26	CSP BGA	SWITCH	TOP	4.6E-1	4.8E-5
SW14	CSP BGA	SWITCH	TOP	4.8E-1	3.5E-5
SW13	CSP BGA	SWITCH	TOP	4.7E-1	1.1E-4
SW12	CSP BGA	SWITCH	TOP	4.6E-1	8.1E-5
SW11	CSP BGA	SWITCH	TOP	4.6E-1	7.7E-5
SW10	CSP BGA	SWITCH	TOP	4.6E-1	1.4E-4
SW19	CSP BGA	SWITCH	TOP	4.6E-1	2.0E-4
SW18	CSP BGA	SWITCH	TOP	4.6E-1	2.3E-4
SW17	CSP BGA	SWITCH	TOP	4.8E-1	2.0E-4
SW16	CSP BGA	SWITCH	TOP	4.6E-1	5.7E-5
SW40	CSP BGA	SWITCH	TOP	4.8E-1	1.0E-4
SW36	CSP BGA	SWITCH	TOP	4.7E-1	1.4E-4
SW35	CSP BGA	SWITCH	TOP	4.7E-1	8.6E-5
SW34	CSP BGA	SWITCH	TOP	4.6E-1	9.3E-5
SW33	CSP BGA	SWITCH	TOP	4.6E-1	1.5E-4
SW32	CSP BGA	SWITCH	TOP	4.7E-1	8.4E-5
SW31	CSP BGA	SWITCH	TOP	4.6E-1	2.3E-5
SW39	CSP BGA	SWITCH	TOP	4.8E-1	1.3E-4
SW38	CSP BGA	SWITCH	TOP	4.6E-1	1.6E-4
SW37	CSP BGA	SWITCH	TOP	4.5E-1	2.0E-4

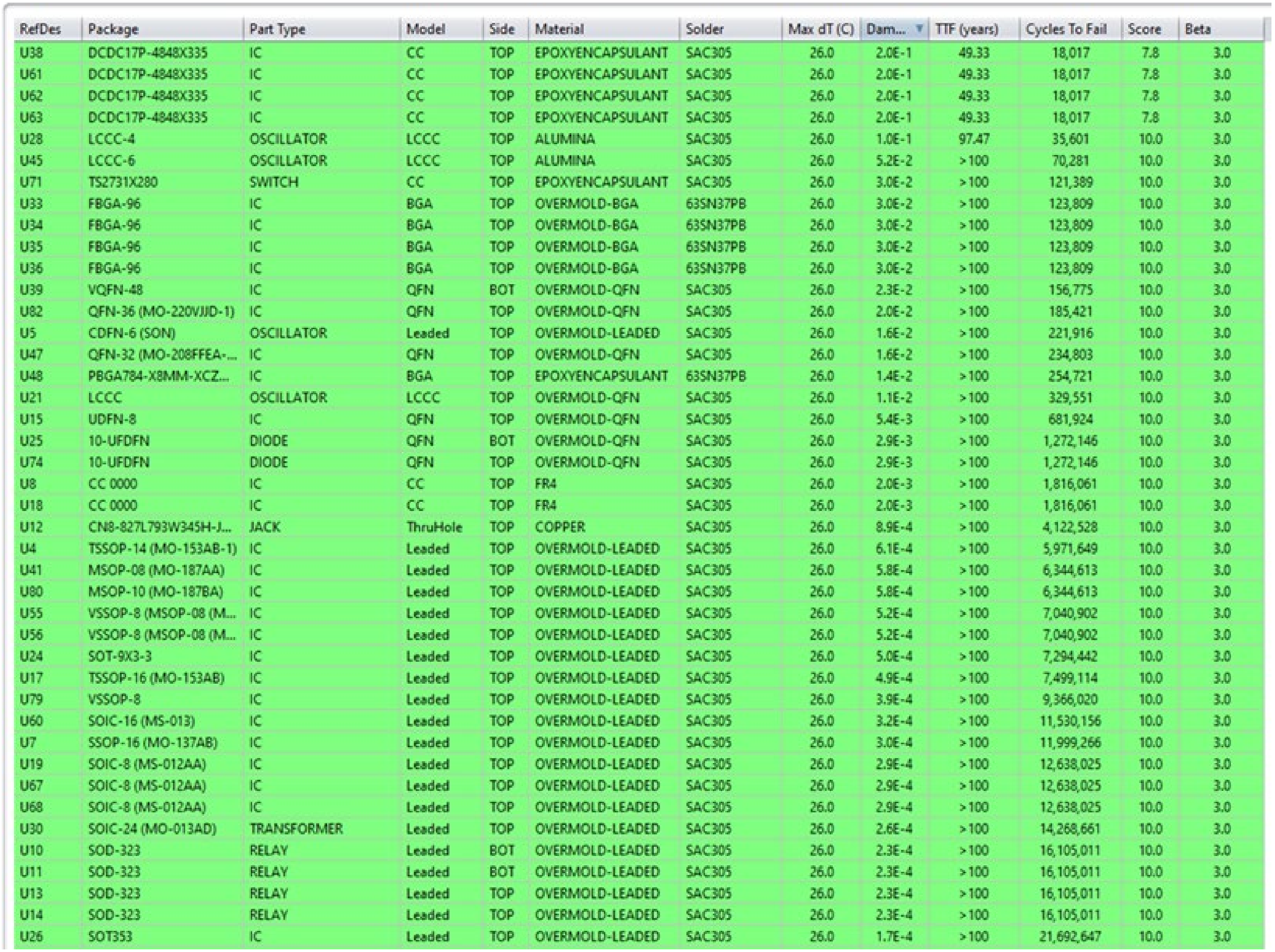
Validation and Application

- How Accurate Are the Results?
  - DfR gathered over seventy (70) examples of temperature cycling data for a variety of overmolded plastic ball grid array (BGA) and chip scale (CSP) packages.
  - Packages were soldered to a printed board with either SnPb or SAC305.



Application Accuracy and Acceptance

- If the parts meet the design life
- If a part is area of concern



RefDes	Package	Part Type	Model	Side	Material	Solder	Max dT (C)	Dam...	TTF (years)	Cycles To Fail	Score	Beta
U38	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U61	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U62	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U63	DCDC17P-4848X335	IC	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	2.0E-1	49.33	18,017	7.8	3.0
U28	LCCC-4	OSCILLATOR	LCCC	TOP	ALUMINA	SAC305	26.0	1.0E-1	97.47	35,601	10.0	3.0
U45	LCCC-6	OSCILLATOR	LCCC	TOP	ALUMINA	SAC305	26.0	5.2E-2	>100	70,281	10.0	3.0
U71	TS2731X280	SWITCH	CC	TOP	EPOXYENCAPSULANT	SAC305	26.0	3.0E-2	>100	121,389	10.0	3.0
U33	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U34	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U35	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U36	FBGA-96	IC	BGA	TOP	OVERMOLD-BGA	63SN37PB	26.0	3.0E-2	>100	123,809	10.0	3.0
U39	VQFN-48	IC	QFN	BOT	OVERMOLD-QFN	SAC305	26.0	2.3E-2	>100	156,775	10.0	3.0
U82	QFN-36 (MO-220VJJD-1)	IC	QFN	TOP	OVERMOLD-QFN	SAC305	26.0	2.0E-2	>100	185,421	10.0	3.0
U5	CDFN-6 (SON)	OSCILLATOR	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	1.6E-2	>100	221,916	10.0	3.0
U47	QFN-32 (MO-208FFEA-...	IC	QFN	TOP	OVERMOLD-QFN	SAC305	26.0	1.6E-2	>100	234,803	10.0	3.0
U48	PBGA784-X8MM-XCZ...	IC	BGA	TOP	EPOXYENCAPSULANT	63SN37PB	26.0	1.4E-2	>100	254,721	10.0	3.0
U21	LCCC	OSCILLATOR	LCCC	TOP	OVERMOLD-QFN	SAC305	26.0	1.1E-2	>100	329,551	10.0	3.0
U15	UDFN-8	IC	QFN	TOP	OVERMOLD-QFN	SAC305	26.0	5.4E-3	>100	681,924	10.0	3.0
U25	10-UFDFN	DIODE	QFN	BOT	OVERMOLD-QFN	SAC305	26.0	2.9E-3	>100	1,272,146	10.0	3.0
U74	10-UFDFN	DIODE	QFN	TOP	OVERMOLD-QFN	SAC305	26.0	2.9E-3	>100	1,272,146	10.0	3.0
U8	CC 0000	IC	CC	TOP	FR4	SAC305	26.0	2.0E-3	>100	1,816,061	10.0	3.0
U18	CC 0000	IC	CC	TOP	FR4	SAC305	26.0	2.0E-3	>100	1,816,061	10.0	3.0
U12	CN8-827L793W345H-J...	JACK	ThruHole	TOP	COPPER	SAC305	26.0	8.9E-4	>100	4,122,528	10.0	3.0
U4	TSSOP-14 (MO-153AB-1)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	6.1E-4	>100	5,971,649	10.0	3.0
U41	MSOP-08 (MO-187AA)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	5.8E-4	>100	6,344,613	10.0	3.0
U80	MSOP-10 (MO-187BA)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	5.8E-4	>100	6,344,613	10.0	3.0
U55	VSSOP-8 (MSOP-08 (M...	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	5.2E-4	>100	7,040,902	10.0	3.0
U56	VSSOP-8 (MSOP-08 (M...	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	5.2E-4	>100	7,040,902	10.0	3.0
U24	SOT-9X3-3	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	5.0E-4	>100	7,294,442	10.0	3.0
U17	TSSOP-16 (MO-153AB)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	4.9E-4	>100	7,499,114	10.0	3.0
U79	VSSOP-8	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	3.9E-4	>100	9,366,020	10.0	3.0
U60	SOIC-16 (MS-013)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	3.2E-4	>100	11,530,156	10.0	3.0
U7	SSOP-16 (MO-137AB)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	3.0E-4	>100	11,999,266	10.0	3.0
U19	SOIC-8 (MS-012AA)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.9E-4	>100	12,638,025	10.0	3.0
U67	SOIC-8 (MS-012AA)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.9E-4	>100	12,638,025	10.0	3.0
U68	SOIC-8 (MS-012AA)	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.9E-4	>100	12,638,025	10.0	3.0
U30	SOIC-24 (MO-013AD)	TRANSFORMER	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.6E-4	>100	14,268,661	10.0	3.0
U10	SOD-323	RELAY	Leaded	BOT	OVERMOLD-LEADED	SAC305	26.0	2.3E-4	>100	16,105,011	10.0	3.0
U11	SOD-323	RELAY	Leaded	BOT	OVERMOLD-LEADED	SAC305	26.0	2.3E-4	>100	16,105,011	10.0	3.0
U13	SOD-323	RELAY	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.3E-4	>100	16,105,011	10.0	3.0
U14	SOD-323	RELAY	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	2.3E-4	>100	16,105,011	10.0	3.0
U26	SOT353	IC	Leaded	TOP	OVERMOLD-LEADED	SAC305	26.0	1.7E-4	>100	21,692,647	10.0	3.0

Concluding Remarks

- Modeling and results are only as reliable as the accuracy of the models and the quality of the provided inputs.
- The obtained results exhibit a range of variability, typically within +/- 20% to 25%, particularly noticeable in solder fatigue simulations.
- Experimental results, on other hand especially for fatigue Testing, display significant scatter.
- Continuous refinement of models and input data is essential for enhancing accuracy and reducing uncertainties in reliability predictions.
- Ongoing research and development efforts are crucial for advancing our understanding of the physics of failure, enabling more precise and reliable life modeling in complex electronic systems.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