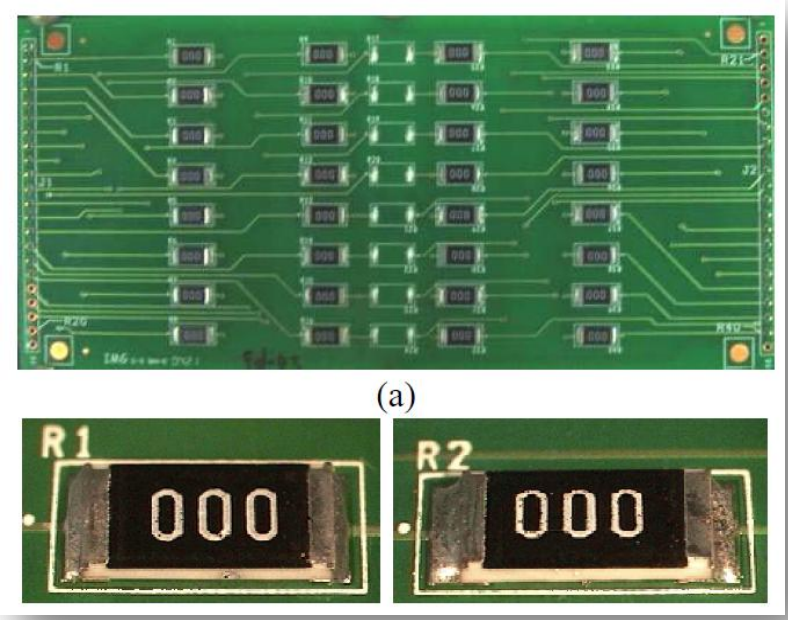
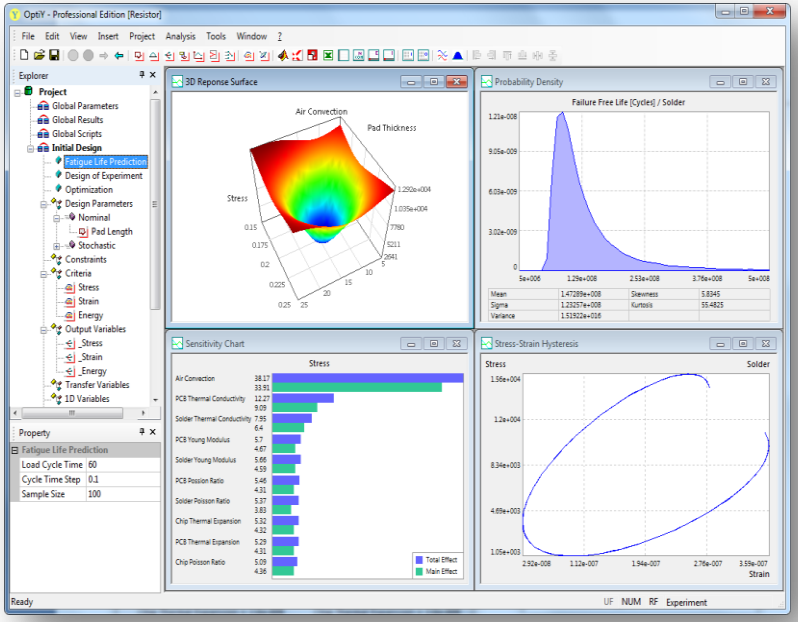
Probabilistic Fatigue Life Prediction of Microelectronic Components on the Example of a Chip Resistor

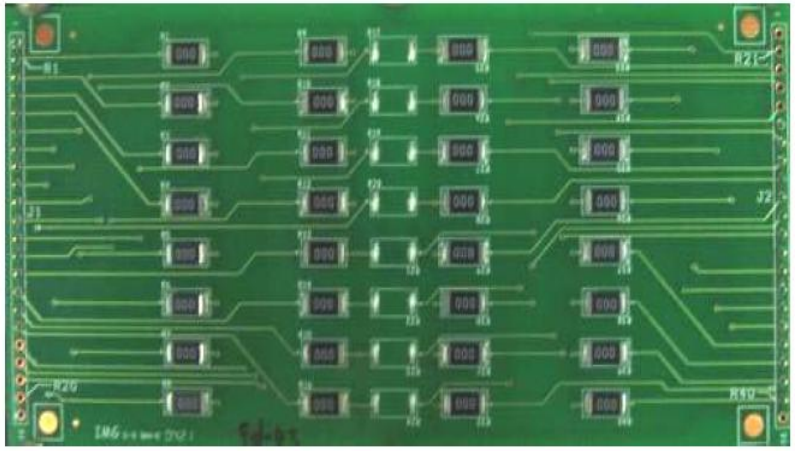




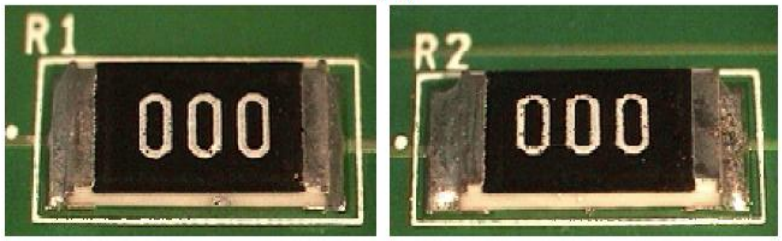
OptiY GmbH - Germany

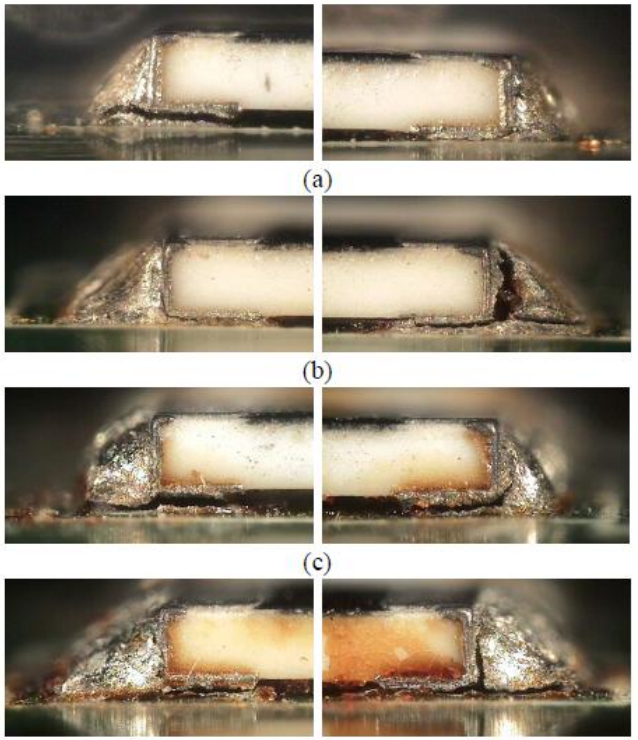
www.optiy.eu

Failure Modes of the Chip Resistor on PCB
Crack Initiation and Propagation of the Solder

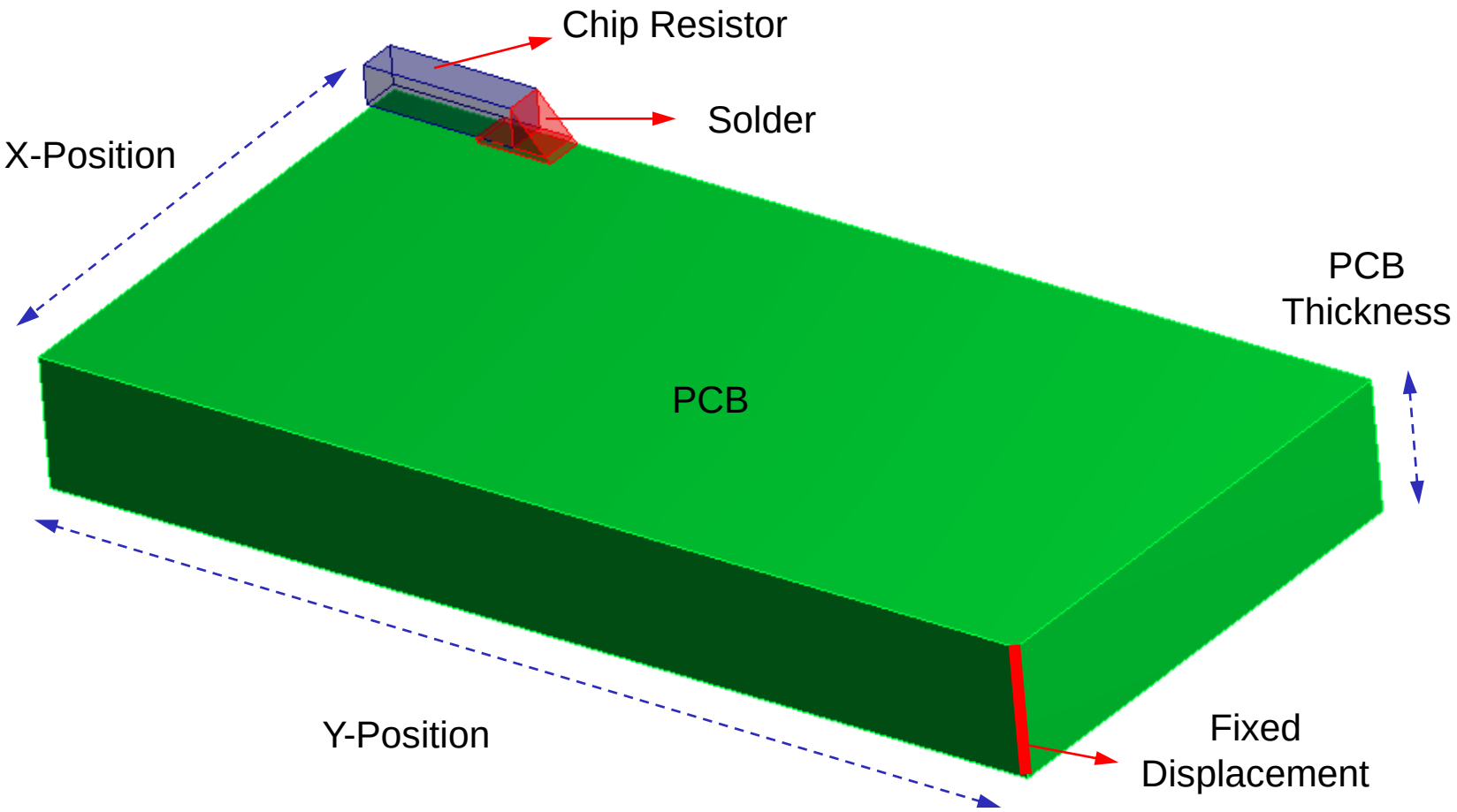


(a)

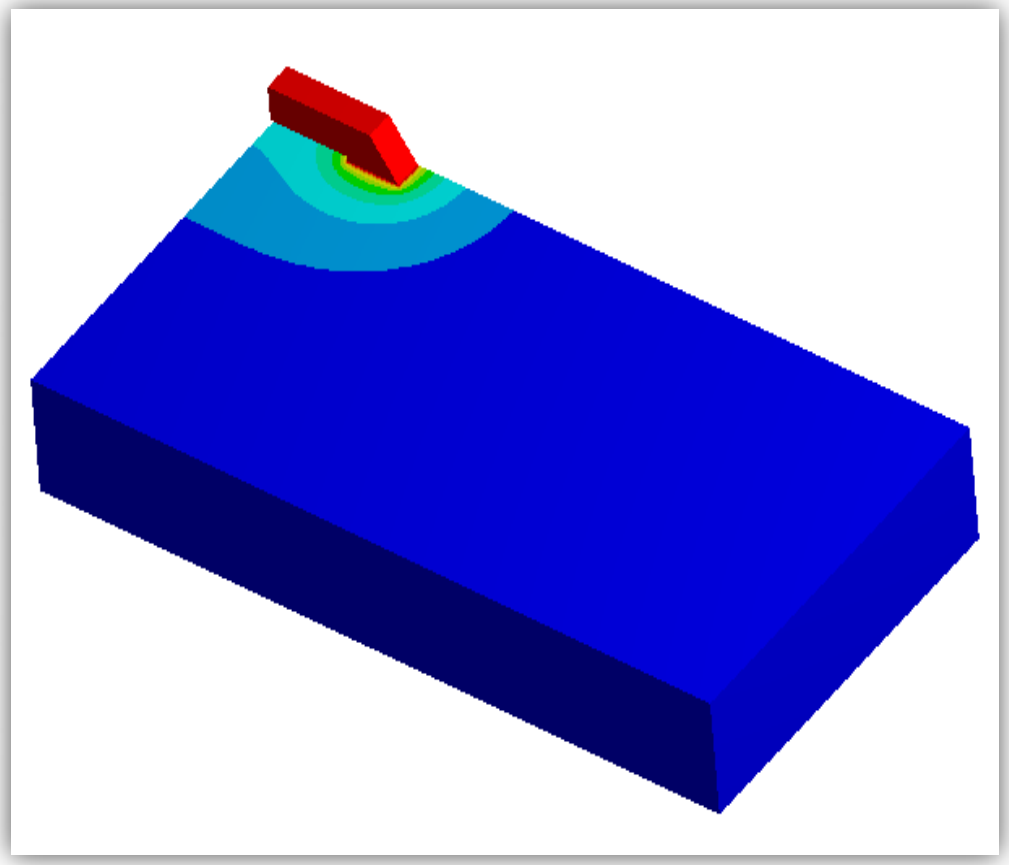




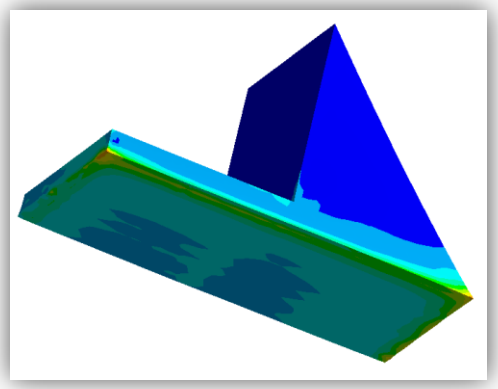
Chip Resistor on PCB Board



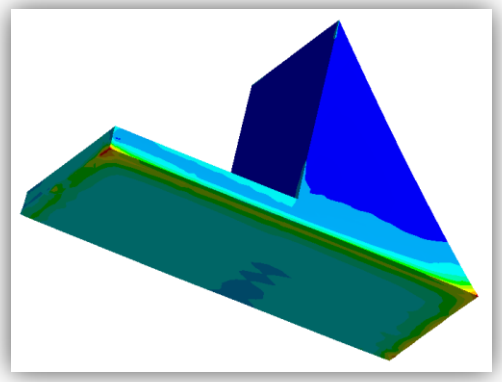
External FEA-Simulation



Chip Temperature Distribution on PCB



Solder Stress Distribution



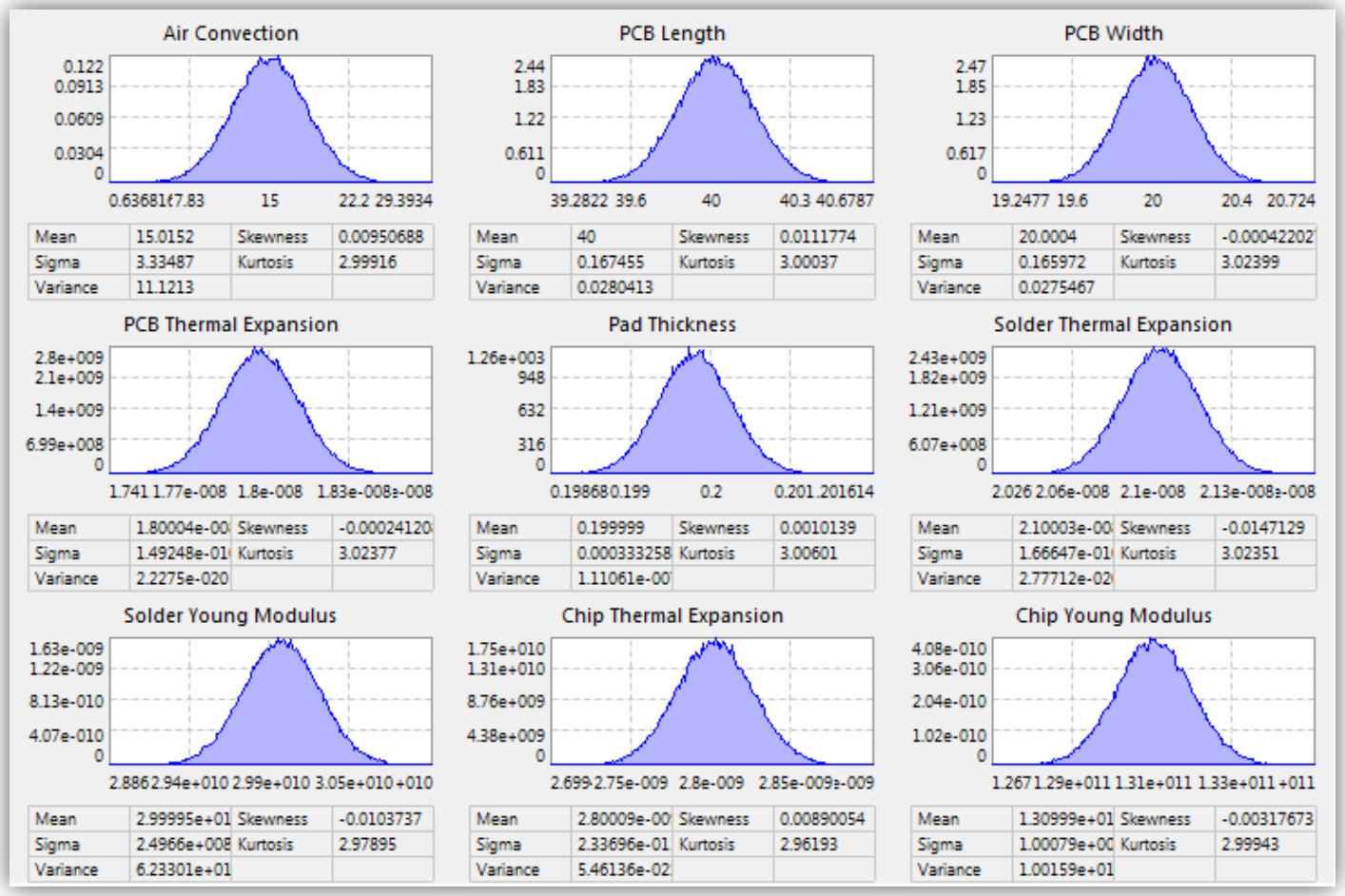
Solder Strain Distribution

Design, Environment and Manufacturing Parameters (Nominal and Tolerance)

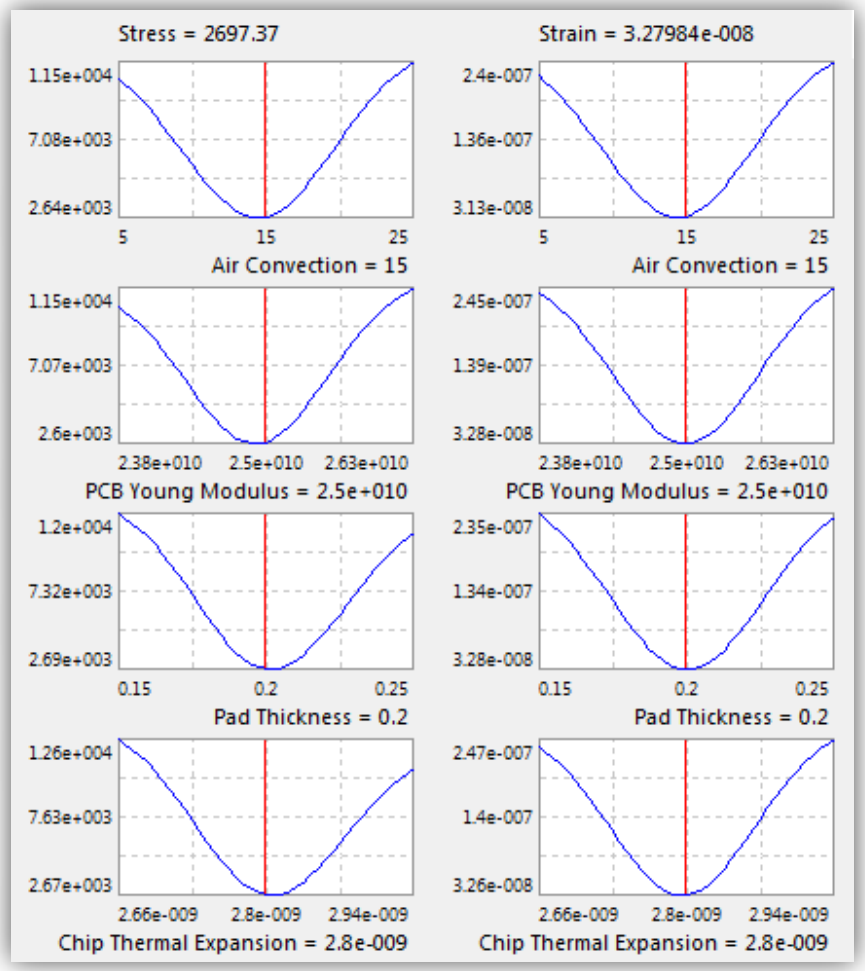
Design Parameters

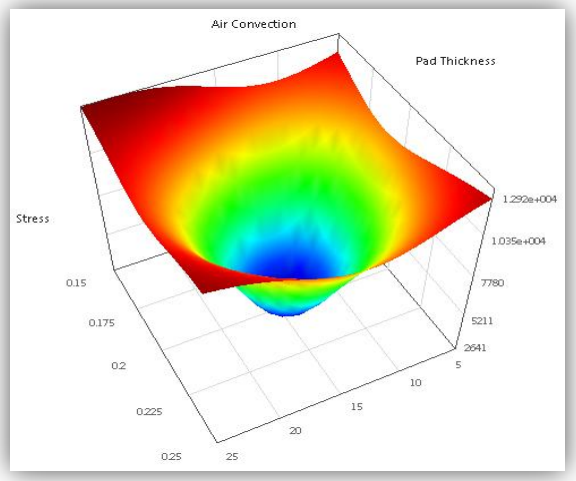
Name	Nominal	Tolerance	Unit
Temperature	25	1	C
Air Convection	15	20	Wm^-2C^-1
PCB Length	40	1	mm
PCB Thickness	5	1	mm
PCB Width	20	1	mm
PCB Thermal Expansion	1.8e-008	9e-010	C^-1
PCB Young Modulus	2.5e+010	1.25e+009	Pa
PCB Possion Ratio	0.3	0.015	
PCB Thermal Conductivity	0.294	0.014	Wm^-1C^-1
Pad Thickness	0.2	0.002	mm
Solder Thermal Expansion	2.1e-008	1e-009	C^-1
Solder Young Modulus	3e+010	1.5e+009	Pa
Solder Poisson Ratio	0.4	0.02	
Solder Thermal Conductivity	124	6	Wm^-1C^-1
Chip Length	6	0.1	mm
Chip Width	1.5	0.1	mm
Chip Thickness	1.5	0.1	mm
Chip Thermal Expansion	2.8e-009	1.4e-010	C^-1
Chip Young Modulus	1.31e+011	6e+009	Pa
Chip Poisson Ratio	0.3	0.015	
Chip Thermal Conductivity	124	6	Wm^-1C^-1

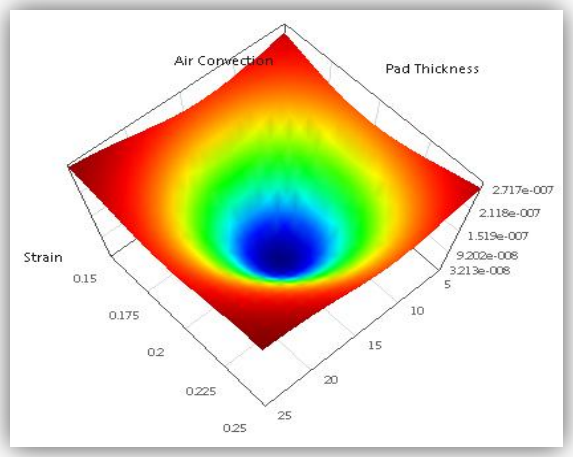
Parameter Uncertainties for Design, Environment and Manufacturing



Meta-Models of the Solder Stress and Strain







Fatigue Life Model of the Solder for Relative Prediction

Property

Strain Energy Density	
Name	Solder
Unit	
Comment	
Fatigue Life Data	
Total Crack Length	1.6
Crack Initiation Factor	69900
Crack Initiation Exponent	-1.55
Crack Growth Factor	0.00119
Crack Growth Exponent	1.3227
Weibull Shape Factor	2.6

Crack Initiation: $N_0 = K_1 * \Delta W^{K_2}$

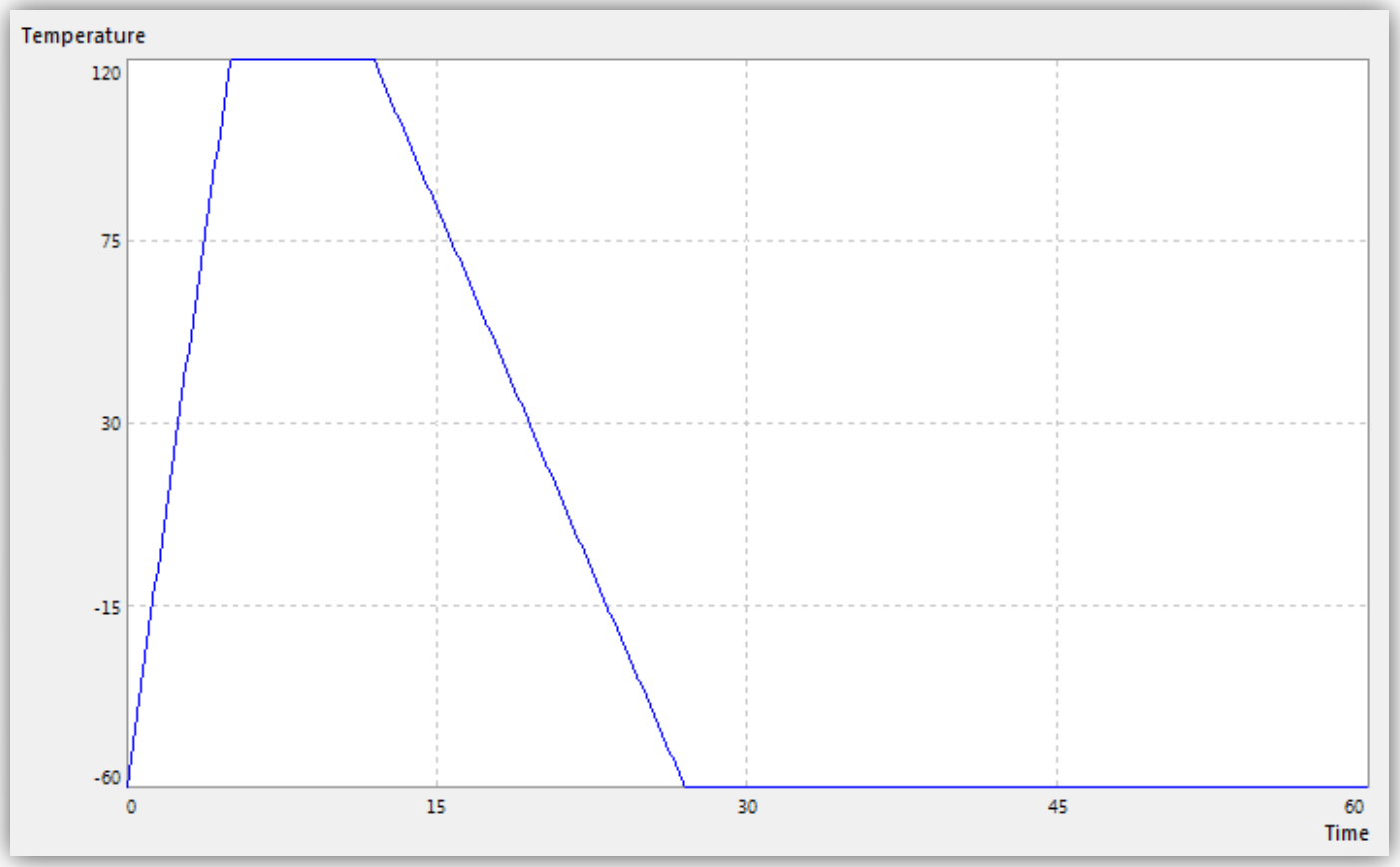
Crack Growth: $\frac{da}{dN} = K_3 * \Delta W^{K_4}$

Failure Probability on Load Cycles = F(N)

$$N = N_{ff} + (\alpha_w - N_{ff})(-ln(1 - F_0))^{\frac{1}{\alpha_w}}$$

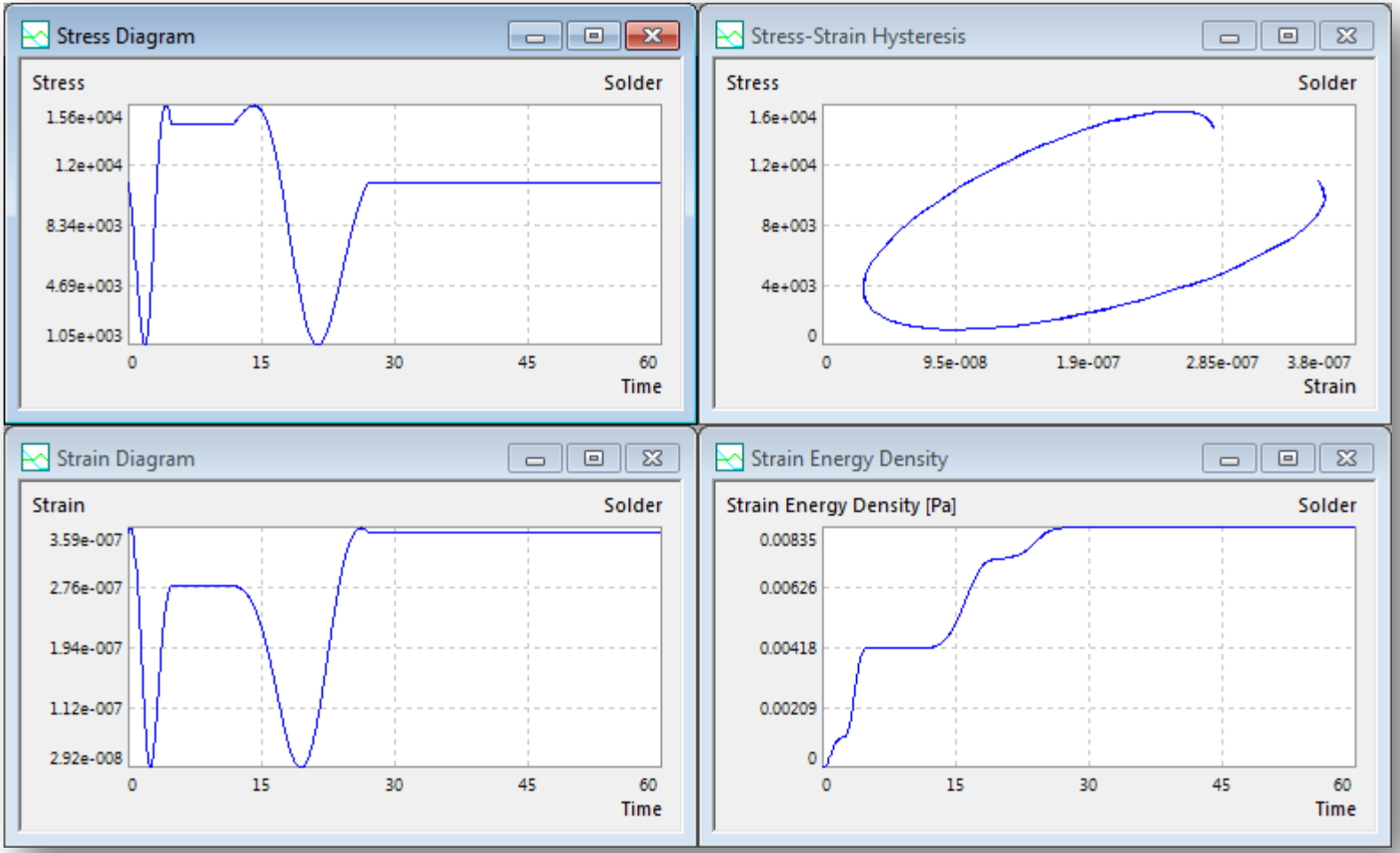
$$F = 1 - exp\left[-\left(\frac{N - N_{ff}}{\alpha_w - N_{ff}}\right)^{\beta_w}\right] \quad \text{for N} > N_{ff}$$

Load Cycle of the Chip Temperature



Temperature in [°C] / Time in [Minutes]

Stress-Strain Relationship of the Solder

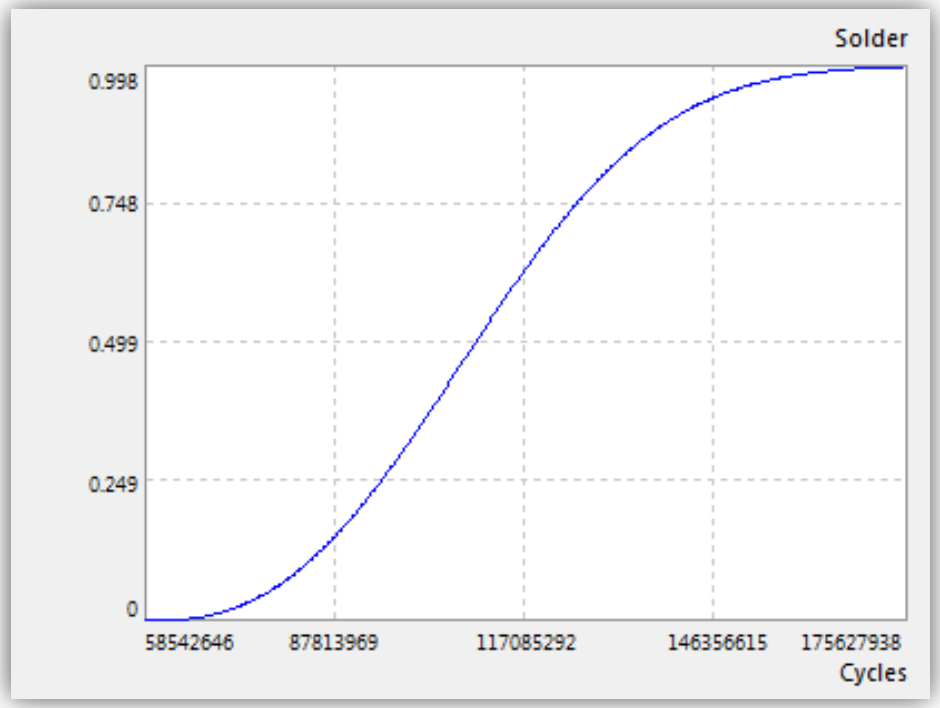


Nominal Fatigue Life Prediction

Fatigue Life Data

Name	Fatigue Life Data
Solder	
Strain Energy Density [Pa]	0.00835207
Crack Initiation [Cycles]	116331215
Crack Growth Rate [1/Cycle]	2.1218e-006
Failure Free Life [Cycles]	58542646
First Failure [Cycles]	67223872
63.2% Failure [Cycles]	117085292

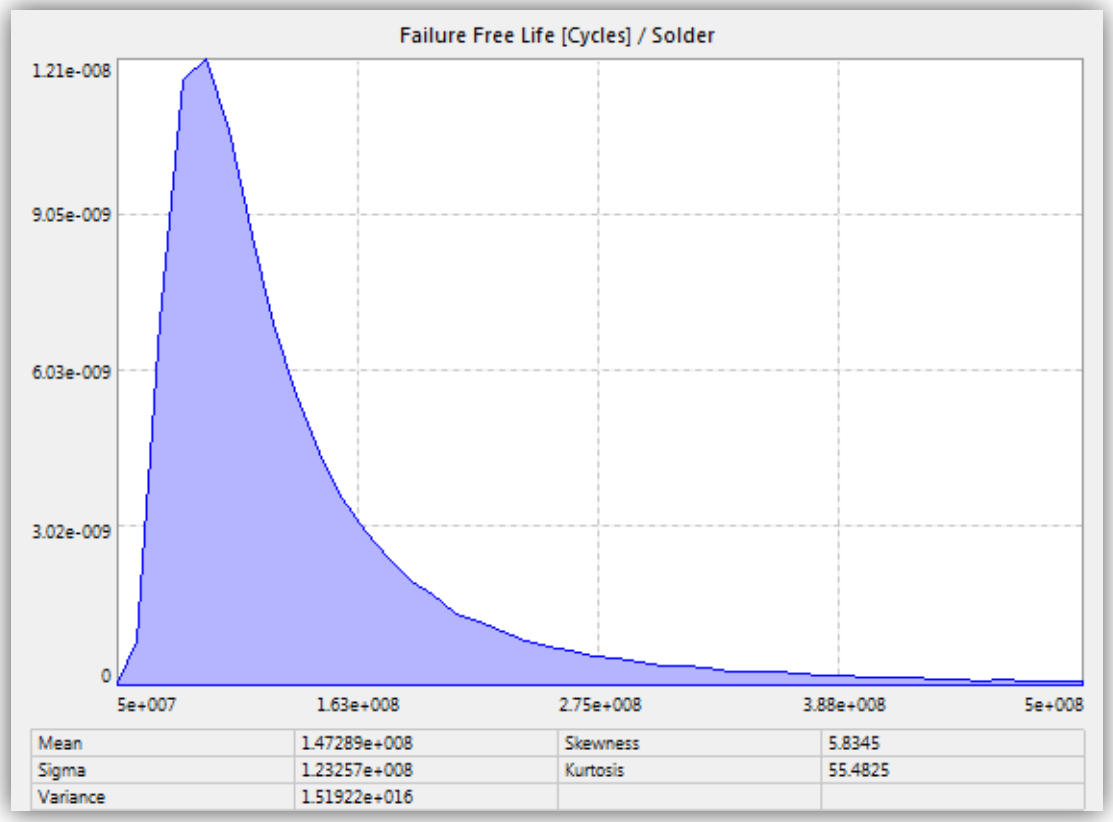
Nominal Fatigue Life
Characteristics of the Resistor



Cumulative Failure Probability Distribution
on the Number of Load Cycles

Failure Free Life = 58.542.646 Cycles
(2.439.276 Days)

Probabilistic Fatigue Life Prediction



Mean	1.47289e+008	Skewness	5.8345
Sigma	1.23257e+008	Kurtosis	55.4825
Variance	1.51922e+016		

Nominal Failure Free Life

Value = 58.542.646 Cycles

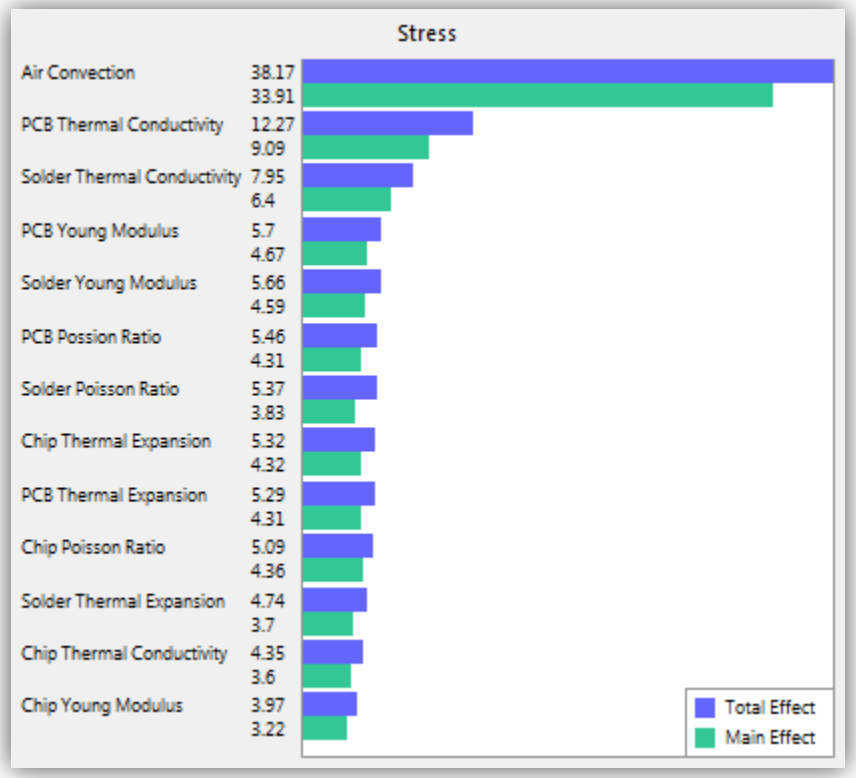
Probabilistic Failure Free Life

Min = 50.000.000 Cycles
Max = 500.000.000 Cycles

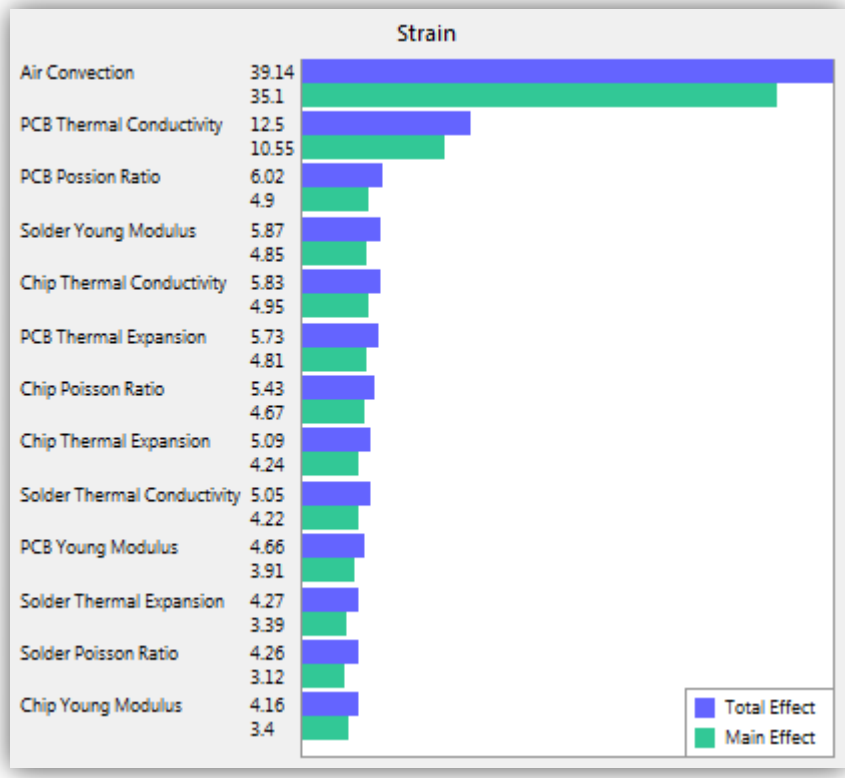
Probabilistic analysis can predict the failure free life most realistically because of design, environment and manufacturing uncertainties

Linear Correlation Matrix

Sensitivity Analysis of Stress and Strain



Stress Sensitivity

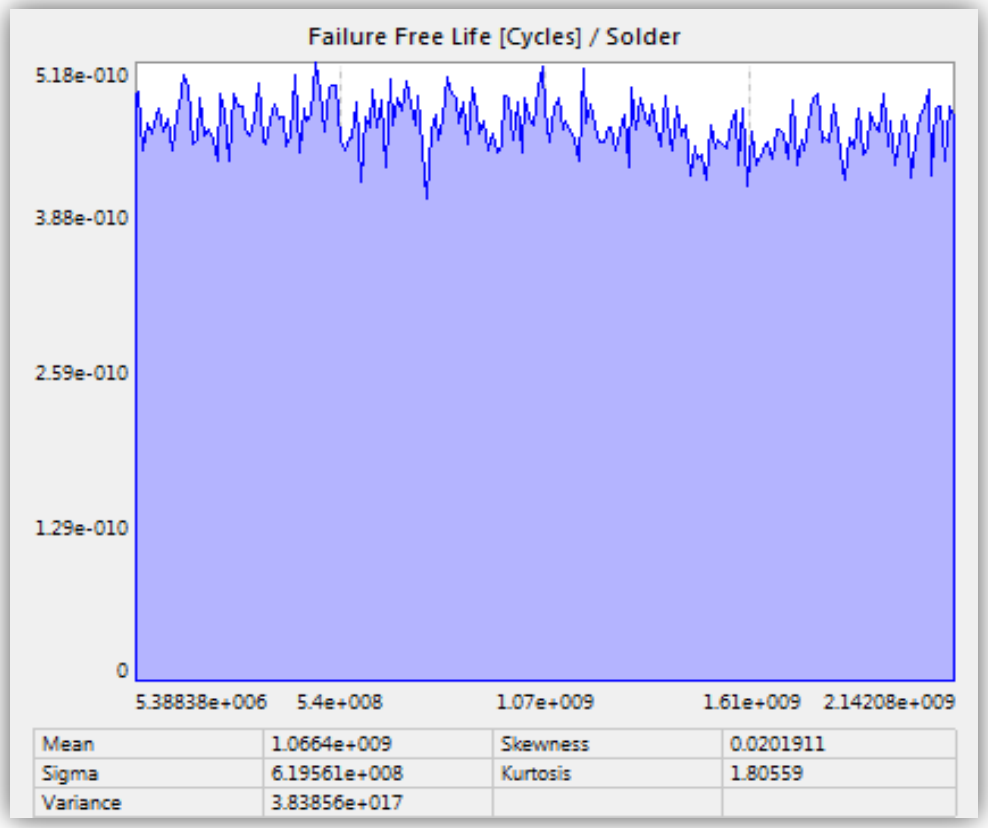


Strain Sensitivity

Change the variable Design Parameters to Maximize the Nominal Fatigue Life using numerical Optimization

Design Parameters	Initial Design	Optimized Design
X-Position Chip [mm]	20	16.64
Y-Position Chip [mm]	40	49.14
PCB Thickness [mm]	5	6.57
Pad Thickness [mm]	0.2	0.21
Failure Free Life [Cycles]	**58.542.646**	**2.138.649.499**

Design with Maximized Nominal Fatigue Life



Mean	1.0664e+009	Skewness	0.0201911
Sigma	6.19561e+008	Kurtosis	1.80559
Variance	3.83856e+017		

Fatigue Life Data

Name	Fatigue Life Data
Solder	
Strain Energy Density [Pa]	0.000818239
Crack Initiation [Cycles]	4261009561
Crack Growth Rate [1/Cycle]	9.82232e-008
Failure Free Life [Cycles]	2138649499
First Failure [Cycles]	2455787549
63.2% Failure [Cycles]	4277298998

Nominal Failure Free Life
Value = 2.138.649.499 Cycles

Probabilistic Failure Free Life
Min = 5.388.380 Cycles
Max = 2.142.080.000 Cycles

Probabilistic analysis shows the realistic life prediction:
this design is worse than the initial design related to the min. lifetime

Conclusion

Nominal design using classical nominal simulation cannot warranty the reliability and quality of the products, because the nominal parameters are only one fix value.

Robust design is a power-full tool for design of reliable and quality product in the early design stage without any cost. It considers the uncertainty parameters as stochastic distributions.

In the case of the chip resistor, the probabilistic analysis using meta modeling technology can predict the realistic fatigue life related to uncertainties of design, manufacturing and environment.

OptiY® is the leading software platform for robust design of all engineering fields using different commercial CAD/CAE-software or in-house codes.

References

1. R. Darveaux: *Effect of Simulation Methodology on Solder Joint Crack Growth Correlation*. Proceedings of 50th Electronic Components and Technology Conference, Las Vegas, May 2000, pp.1048-1058

2. Pham T.Q., Kamusella A., Neubert H.: *Auto-Extraction of Modelica Code from Finite Element Analysis or Measurement Data*. 8th International Modelica Conference, 20-22 March 2011 in Dresden.

3. C. Han, B. Song: *Development of Life Prediction Model for Lead-free Solder at Chip Resistor*. 2006 Electronics Packaging Technology Conference.

4. H. L. C. Bailey: *Modeling the Fatigue Life of Solder Joints for Surface Mount Resistors*. International Symposium on Elastic Materials and Packaging (EMAP 2000), 2000.