

DfR Solutions

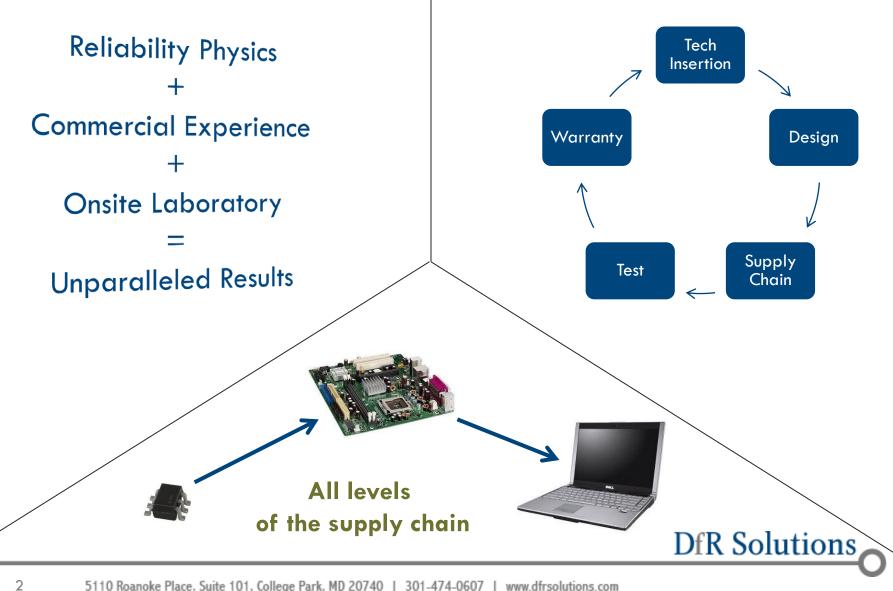
Enhanced Reliability through Automated

Design Analysis[™] for the Electronics Industry

Gregg Kittlesen gkittlesen@dfrsolutions.com October 12, 2011



Focus on Quality/Reliability/Durability of Electronics



5110 Roanoke Place, Suite 101, College Park, MD 20740 | 301-474-0607 | www.dfrsolutions.com

DfR Solutions – Senior Experts

• Dr. Craig Hillman, CEO and Managing Partner

- <u>Expertise</u>: Design for Reliability (DfR), Pb-free Transition, Supplier Benchmarking, Passive Components, Printed Circuit Board
- PhD, Material Science (UCSB)

Dr. Nathan Blattau, Senior Vice President

- <u>Expertise</u>: Power Devices, DfR, Nonlinear Finite Element Analysis (FEA), Solder Joint Reliability, Fracture, Fatigue Mechanics.
- PhD, Mechanical Eng. (University of Maryland)

Walt Tomczykowski, Vice President, CRE

- <u>Expertise</u>: Systems Eng., Life Cycle Management (including obsolescence), Spares Analysis, Counterfeit Mitigation, Failure Analysis
- M.S., Reliability Eng. (University of Maryland)

• Cheryl Tulkoff, CRE

- <u>Expertise</u>: Pb-Free Transition, PCB and PCBA Fabrication, IC Fabrication, RCA (8D and Red X)
- B.S., Mechanical Engineering (Georgia Tech)

• Dr. Ron Wunderlich

- <u>Expertise</u>: Design for EMI/EMC, Power Supply Design, Analog Circuit Design, Spice Model Development, Monte Carlo Circuit Simulation
- PhD, Electrical Engineering (SUNY Binghamton)

• Greg Caswell

3

- <u>Expertise</u>: Nanotechnology CMOS, CMOS/SOS, Input Protection Networks / ESD, SMT, Pb-free
- B.S., Electrical Engineering (Rutgers)

- Dr. Randy Schueller
- <u>Expertise</u>: IC Fabrication, IC Packaging, Pb-Free Transition Activities, Supplier Benchmarking, Corrosion Mechanisms
- PhD, Material Science (University of Virginia)

• Dr. Gregg Kittlesen

- <u>Expertise</u>: Semiconductor Lasers and Integrated Modules, Photonic and RF Technologies, IC Process Development and Qualification, Supply Chain Management
- PhD, Inorganic Chemistry (MIT)

• James McLeish, CRE

- <u>Expertise</u>: FMEA, Root-Cause Analysis, Warranty Analysis, Automotive Electronics, Physics of Failure, Battery Technology
- M.S., Electrical Eng. (Wayne State University)

• Norm Anderson

- <u>Expertise</u>: Avionics, Product Qualification, Safety Criticality Assessment, FTA, FMEA, Component Uprating, Obsolescence
- B.S., Electrical Engineering (Iowa State University)

• Anne Marie Neufelder

- <u>Expertise</u>: Software Reliability Prediction, Best Practices in Software Risk Management
- B.S., Systems Engineering (Georgia Tech)



Purpose

- Early assessment of assembly level reliability
- Uniform design for reliability process
- Design trade-off analysis
 - Include reliability assessment

Presentation Outline

- Analyses
- Methodology
- Design Assessment
- Hardware Capability Assessment

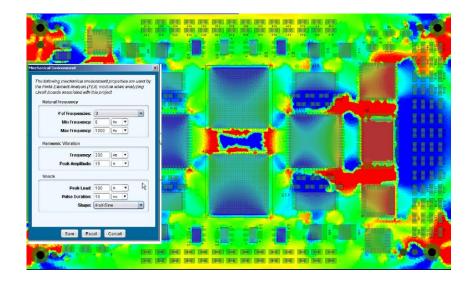


Analyses

Capabilities

- Virtual Shock Testing
- Virtual Vibration Testing
- Virtual Thermal Cycling
- Virtual CAF Testing
 - Conductive Anodic Filament

Shock Strain Example





Methodology - Inputs

Input Data Sources

• ODB++ archive

• ODB XML archive

• Files

- o Layers
- Drill holes
- o BOM
- Pick and place
- Thermal map

Environmental Stresses

- Mechanical Shock
- Random Vibration
- Harmonic Vibration
- Thermal Cycle



Methodology - Input Review

Parts List

8

Stack-up

		iew all properties associated		
	Sources: User	PartsDB BOM	PickPlace Guess	
	🕕 Problem Exists 🛕 U	in-Confirmed 🥝 Confirme	d Part Count: 221 Unique Part	s; 17
Filters				
Ref Des	Part Number	Part Type	Packaging Lo	ration
	1.0011.0001.0001	- on the		
Parts Listing				
Ref Des 🔺	Part Number	Part Type	Packaging	Location
Q C1	TMC1CBTTE106M	CAPACITOR	SMT C-8END-3528-12	TOP 4
Q C2	TMC1CBTTE106M	CAPACITOR	SMT C-BEND-3528-12	TOP
00	TMC1CBTTE116M	CAPACITOR	SMT C-BEND-3528-12	O TOP
Q C4	TMC1CBTTE106M	CAPACITOR	SMT C-8END-3528-12	TOP
CS CS	TMC1CBTTE106M	CAPACITOR	SMT C-BEND-3528-12	O TOP
📿 C6	C TMC1CBTTE106M	CAPACITOR	SMT C-BEND-3528-12	O TOP
🧭 C7	TMC1CBTTE106M	CAPACITOR	SMT C-BEND-3528-12	O TOP
🕗 CB	O TMC1CBTTE106M	CAPACITOR	SMT C-BEND-3528-12	O TOP
🕗 C9	C TMC1CBTTE106M	CAPACITOR	SMT C-8END-3528-12	🕗 тор

The for	newing Board	properties are based	I ON THE CARTING	s cethed boa	e autice and	the individual	layer property	es shewn
below								
	B	00505 101×1150	and the second second		arrest de	2.214 gpm/C		
	Board The	charess: 2.1 rent (R)	CR OIL		CTER 6	i8.782 gpm/C		
	Exact	Density: 1.8217 pts			Eqt. 3	1,323 MPa		
	CORDIN	Layers: 6			E2 3	16471626		
to edit	properties to	r to exit the properties r a batch of layers. Pre						
to edit	properties to Iss and defa		na the General		yers butten to		vers using a g	
to edit thickne Layer	properties to Iss and defa	a batch of layers. Pro ut layer properties.	na the General	le Stackap La Density	one outen te	CTE2	evenusing a g	Er
to edit thickne Layer	properties to Iss and defa Type	r a batch of layers. Pre uit layer properties. Material	Thickness	le Stackap La Density	one outen te	CTR2 22.195	evenusing a g	Er
to edit thickne Layer 1 2	properties to so and defa Type SIGNAL	r a batch of Leyers. Pre uit leyer properties. Material COPPER (14 JPA)	Thickness E5 ct	Cencity 2.0579 1.9500	CTExy 22.195 17.000	CTE2 22.195 70.000	Exy Exy 25,784 24,884	Ann PCB Ez 29,794 3,490
to edit thickne Layer 1 2	properties to ss and defa Type SIGNAL Lawrinade	a batch of Levers. Pro utilizer properties. Material COPPER 0.4 INNO Denem PRI 4	Thickness E.S. ct. 15.4 mil	Cencity 2.0579 1.9500	CTExy 22.195 17.000	0152 0152 12,195 70,000 12,736	Eey 28,784 24,884 16,684	Aren PER Ez 28,784 3,490 18,641
to edit thickne Lager 1 2 3 4	properties to tot and defa Type SCHAL Lawrende Power	a batt h of layers. Pro ut layer properties. Material COPPER (3.4.9%) Denets (76.4 COPPER (3.9%)	Thickness Biscon Biscon Thickness Biscon Thickness Thickness Thickness	Censity 2.0179 1.0000 2.1479 1.9000	CTExp 22.195 17.000 22.736 17.000	01E2 01E2 22,195 20,000 22,736 70,000	Exy 28,784 28,784 28,084 18,684 29,084	Aren PER Ez 28,784 3,490 18,661 3,490
to edit thickne Lager 1 2 3 4	properties to so and defail Type SIGNAL Lawrende POWER Lawrende	a batch of layers. Pro ut layer properties. Material COPPER (3.9%) Denesis PR-8 COPPER (3.9%) Denesis FR-8	Thickness B Soc 19.4 cm 10.00 10.00 10.00	Censily 2.0170 1.9000 3.1476 1.9000 1.9100	CTEap 22.195 17.000 32.736 17.000 32.914	0152 0152 22,195 79,080 32,736 79,080 32,936 79,080 22,944	Ev 28,784 28,784 28,088 18,688 29,688 13,221	Aven PCB Ez 28,784 3,490 18,642 3,490 13,201
to eat thicker Layer 1 2 3 4 5 6	properties to compared with Type School Lawrinste Powerk Lawrinste School	a batch of layers. Pro ut layer properties. Material COPPER (3.9%) Denenic FR-8 COPPER (3.9%) Denenic FR-8 COPPER (3.6%)	Thickness B Scc 19.4 val 10.00 10.00 10.00 10.00 10.00 10.00 10.00	Centify 2.8579 1.9500 3.1479 1.9500 1.9126 1.9126 1.9126	CTEAP 22.195 17.000 32.736 17.000 32.914 17.000	egisce al la CTG2 22,195 79,080 33,736 79,080 32,914 79,080	Env 29,794 29,794 29,098 10,098 10,201 29,094	Aven PCB Er 28,784 3,490 16,682 3,450 13,201 3,450
to eat thicker Layer 1 2 3 4 5 6	properties to consider the Type Schedu Lancade Schedu Lancade Schedu Lancade	a batti of layers. Pro ut layer proporties. Material COPPER (3.4.9%) Denesis (FR-8 COPPER (3.6%) Denesis (FR-8 COPPER (1.6%) Denesis (FR-4	Thickness Bischess Bisch Bisches Bisches Bisch Bisch Bisch Bisch	Density 2,8979 1,9999 2,1479 1,9999 1,9136 1,9136 1,9999	22.195 17.000 22.336 17.000 32.514 17.000 32.519	CTG2 22,195 70,000 22,736 70,000 22,514 70,000 22,514 70,000 22,919	Exy 28,784 24,084 18,084 13,201 24,084 13,201 24,084 13,220	Ann. PCB Ez 28,784 2,490 18,680 13,201 3,460 13,201 3,460 13,230
to edd thickne Layer 1 2 3 4 5 6 7	properties to competies to Type SIGNAL Laminate PCWER Distance Distance SIGNAL Laminate SIGNAL	a battle of layer. Pro theyer propodes. Material COPPER of 4 950 Densels (FIS-8 COPPER of 954) Densels (FIS-8 COPPER of 954) Densels (FIS-4 COPPER of 954)	Thickness Thickness 15.4 mil 18.0 c 16.4 mil 8.5 cc 15.4 mil 8.5 cc	Density 2,8979 1,9900 2,1479 1,9000 1,9126 1,9000 1,9005 1,9000	27.195 27.195 17.000 22.736 17.000 22.514 17.000 22.519 17.000	CTG2 22.195 70.000 22.736 70.000 22.514 70.000 22.519 70.000	Exy 28,784 24,088 18,088 29,088 13,201 24,084 13,220 24,084	Ann. PCB Ez 28,784 2,490 18,682 13,201 3,450 13,201 3,450 13,230 3,450 3,450
to edd thiolow Laget 1 2 3 4 5 6 7 8 0 10	properties to the and defer Type Schall Laminate Schall Laminate Schall Laminate Schall Laminate Schall Laminate Schall Laminate	ra baset octayers. Pro ult layert pooperies. Material COPPERIO 4 890 Densels PP-8 COPPERIO 506 Densels PP-8 COPPERIO 506 Densels PP-4 COPPERIO 506 Densels PP-4 COPPERIO 506 Densels PP-8	Thickness ESec 154 will 164 will 164 will 85 cc 154 will 85 cc 154 will 100 cc 164 will	5 Starkap La Cencity 2.8579 1.9500 3.1479 1.9500 1.9106 1.9005 1.9005 1.9005 1.9005 1.9005	27.195 27.195 17.000 22.736 17.000 22.514 17.000 22.519 17.000	egiste al 12 22.195 79.000 22.736 79.000 22.914 79.000 22.919 70.000 22.735	Env 28,194 28,194 28,084 18,084 13,201 24,084 13,220 24,084 13,220 24,084	5440 PCB Ez 28,784 3,490 18,662 3,450 13,201 3,450 13,200 13,200 18,084 3,490
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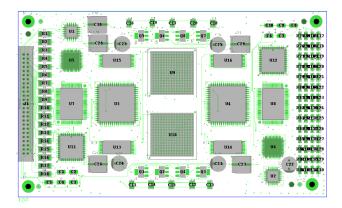


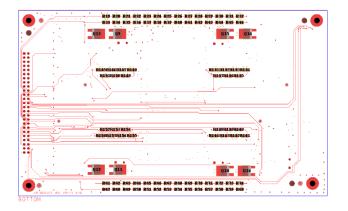
Methodology - Input Review

Top Components

9

Bottom Components







Virtual Shock Testing - Maximum Stress

Parameters

Shock Profile



There's no doubt that taxes and pot-holes are the primary concern of all local governments.

of Cycles: 400
Duration: 10 ms
Peak Load: 25 5





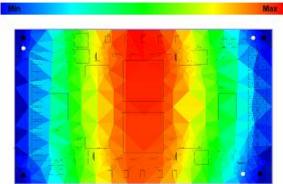
Virtual Shock Testing - FEA Results

PCB Displacement 25G, 4.9ms, half sine pulse

PCB Strain 25G, 4.9ms, half sine pulse

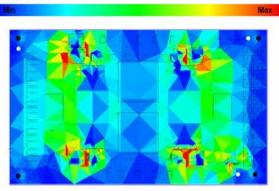
Shock Displacement @ 4.9ms

The following image depicts the displacement of the PCB at the designated time based on the specified shock profile. Coloring is based on the relative displacement, ranging from blue at minimum displacement to red at maximum displacement. Dark colors indicate a negative displacement, while light colors indicate a positive displacement.



Shock Strain @ 4.9ms

The following image depicts the combined strain of the PCB at the designated time based on the specified shock profile. Coloring is based on the relative strain, ranging from blue at minimum strain to red at maximum strain.





Virtual Shock Testing - Component Assessments

Components with Highest Strain

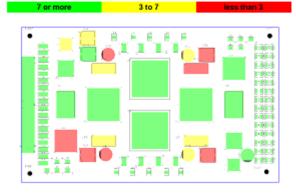
Shock Fatigue Scores

RefDes	Side	Package	Max Disp	Max Strain
C29	702	ADS_SM_CT_BULKCAP-G	1.62-2	1.62-3
011	202	Q72-44 (NO-089AB)	1.02-2	7.42-4
C26	202	ADS_SH_CT_BULKCAP-S	1.42-2	7.32-4
Q16	207	DPAK	1.32-2	6.52-4
016	202	TSOP-32 (NO-14280)	1.82-2	5.82-4
C27	202	ADS_SH_CT_BULKCAP-S	1.52-2	5.62-4
C23	202	ADS_CPCYL1_0400_15200_034	1.82-2	5.62-4
C24	202	ADS_CPCYL1_0400_15200_034	1.72-2	5.32-4
015	202	790P-32 (MO-14280)	1.82-2	5.02-4
014	202	7907-32 (MO-14290)	1.82-2	4.22-4

Top 10 Components with Highest Strain (Mechanical Shock)

Shock Fatigue Top

The colors in this image represent the predicted reliability of the component based on the strains predicted for the given Mechanical Shock environment.





Virtual Vibration Testing - Stress

Parameters

Random Vibration Profile (Harmonic Vibration also available)

1 - Vibration

Back country roads shake and rattle electronic components.

of Cycles: 5.00s-1 PER MIN





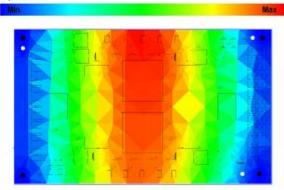
Virtual Vibration Testing - FEA Results

PCB Displacement

PCB Strain

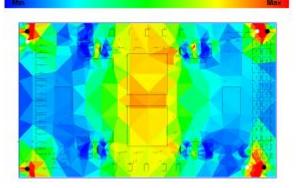
Random Vibration RMS Displacement

The following image depicts the RMS displacement of the PCB based on the specified PSD profile. Coloring is based on the relative displacement, ranging from blue at minimum displacement to red at maximum displacement.



Random Vibration RMS Strain

The following image depicts the combined RMS strain of the PCB based on the specified PSD profile. Coloring is based on the relative strain, ranging from blue at minimum strain to red at maximum strain.





Virtual Vibration Testing - Component Assessments

Components with Highest Strain

Shock Fatigue Scores

RefDes	Side	Package	Max Strain	TTF (yrs)
010	702	BGA676	2.02-4	5.9
09	702	BGA676	1.92-4	7.6
015	102	7907-32 (MO-14290)	1.72-4	>50
013	702	TSOP-32 (NO-1428D)	1.62-4	>50
C29	702	ADS_SM_CT_BULKCAP-G	2.12-4	>50
C27	202	ADS_SM_CT_BULKCAP-S	2.02-4	>50
016	702	7907-32 (NO-14280)	1.42-4	>50
014	702	790P-32 (NO-14280)	1.32-4	350
910	207	DPAX.	2.42-4	>50

ADS_CPCYL1_0400_15200_034

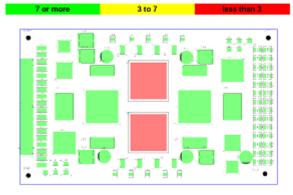
Top 10 Components with Shortest Lifetime (Random Vibration)

702

C23

Random Fatigue Top

The colors in this image represent the predicted reliability of the component based on the strains predicted for the given Random Vibration environment.





2.42-4

>50

Virtual Thermal Cycle Testing - Stress

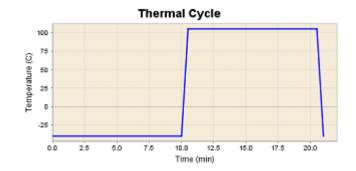
Parameters

Temperature Cycle Profile



The engine compartment always seems to be super cold before we start the engine.

of Cycles: 3
Duration: 21 min





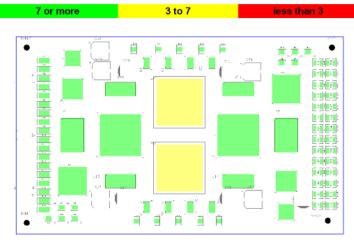
Virtual Thermal Cycle Testing - Component Assessments

Components with Shortest Lifetime

Solder Fatigue Scores

Solder Joint Fatigue Scores (Top Components)

The following image shows the results for all leadless chip components and Ball Grid Array (BGA) components analyzed. The colored symbols represent the predicted reliability of the component relative to the expected service life of the circuit card.



Top 10 Components with Shortest Lifetime (Thermal Cycling)

17

RefDes	Side	Package	Solder	Max dT (C)	TTF (yrs)
09	202	BGA676	\$80305	145.0	16.25
010	702	BGA676	\$80305	145.0	16.25
01	202	1000-20	\$80305	145.0	25.40
02	702	1000-20	\$80305	145.0	25.40
013	702	TSOP-32 (NO-14280)	\$80305	145.0	34.73
014	702	TSOP-32 (NO-14280)	\$80305	145.0	36.73
015	702	7509-32 (NO-14280)	\$80305	145.0	36.73
016	702	TSOP-32 (NO-14280)	\$80305	145.0	34.73
03	702	Q73-68 (MD-387AD)	\$AC305	145.0	>50
24	702	Q72-68 (ND-087AD)	\$80305	145.0	>50



Virtual Thermal Cycle Testing - PTH Assessments

PTH with Shortest Lifetime

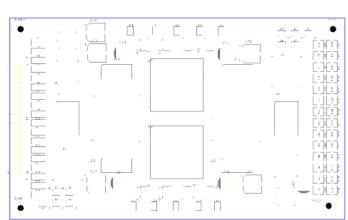
PTH Fatigue Scores

PTH Fatigue Scores

7 or more

The following image shows the results for all plated through holes that were analyzed. The colored symbols represent the predicted reliability of the hole relative to the expected service life of the circuit card.

3 to 7



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less than 3

Diameter (in) Max dT (C) Y (in) TTF (yrs) X (in) -1.0210 -1.3180 0.0080 145.0 26.0 -1.1860 1.8370 0.0080 145.0 26.0 -1.3510 1.8270 0.0080 145.0 26.0 -0.1380 0.1850 0.0080 145.0 26.0 -0.1480 0.1280 0.0080 145.0 26.0 -1.4990 1.6670 0.0080 145.0 26.0 -0.1680 0.1360 0.0080 145.0 26.0 -0.1700 -0.0850 0.0080 145.0 26.0 -0.1740 0.1820 0.0080 145.0 26.0 -1.8190 0.9290 0.0080 145.0 26.0

Top 10 Plated Holes with Shortest Lifetime

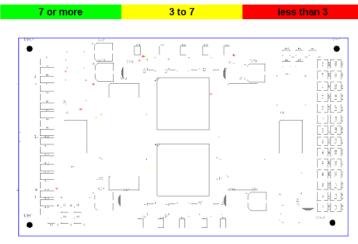
Virtual Conductive Anodic Filament (CAF) Assessments

Hole Pairs with Closest Spacing

CAF Scores

CAF Formation Scores

The following image shows the results for all hole pairings that were analyzed. The colored symbols represent the predicted reliability of the hole pairings based on the distance between hole centers and the percentage of overlap.



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Top 10 Plated Hole Pairs with Closest Spacing

X1 (in)	Yl (in)	X2 (in)	¥2 (in)	Distance (mil)
-0.9930	1.7230	-0.9930	1.7390	8.0
0.6340	0.9670	0.6500	0.9670	8.0
-2.0330	1.1930	-2.0490	1,1960	1.3
-2.6730	1.4860	-2.6890	1.4900	1.5
-0.9070	1.8260	-0.9240	1.8260	9.0
1.1510	1.8510	1.1720	1.8510	11.0
-0.8880	1.8250	-0.9070	1.8260	11.0
-2.3220	0.6280	-2.3610	0.6260	11.1
1.1520	1.8580	1.1720	1.8510	11.2
-2.8610	-1.1740	-2.8800	-1.1780	11.4

Scorecard

20

Tutorial Board Scores

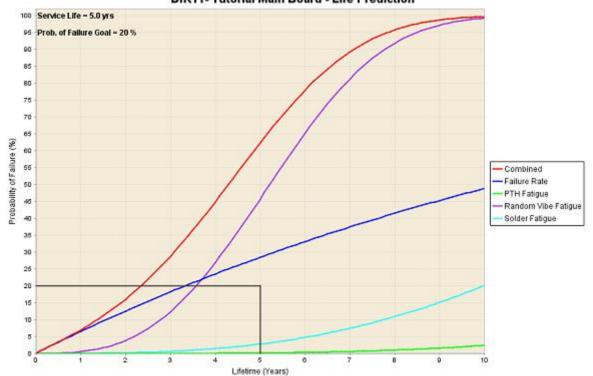
Score Classifications

Analysis Module	Module Score
CAF Failure	0.0
Failure Rate	0.0
Mechanical Shock	0.0
PTH Fatigue	6.0
Random Vibe Fatigue	0.0
Solder Fatigue	8.6
OVERALL SCORE	0.0

A score of 10 is in accordance with industry best practices. A score of 7 to 10 is designated green and indicates a preferred design. A score of 5 is in accordance with minimum acceptable practice within the electronics industry. A score of 4 to 6 is designated yellow and indicates a marginal design. A score of 0 strongly suggests a high likelihood of failure (> 90%) during the desired lifetime. A score of 0 to 3 is designated red and indicates a high risk design.

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Life Prediction



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DfR11- Tutorial Main Board - Life Prediction

Outdoor Deployment Thermal Stresses

- Daily thermal cycle
 - $_{\circ}$ Modeled daily dT = 40°C
 - Ambient dT + solar load + internal dT
 - Compared 3 temperature ramp durations: 1, 2, 3 hours
- Daily thermal cycle with mini-cycles
 - Modeled daily $dT = 20^{\circ}C$, temperature ramp 1 hour
 - Superimposed 25 daily cycles $dT = 20^{\circ}C$ at low temp
 - Superimposed 25 daily cycles $dT = 20^{\circ}C$ at high temp

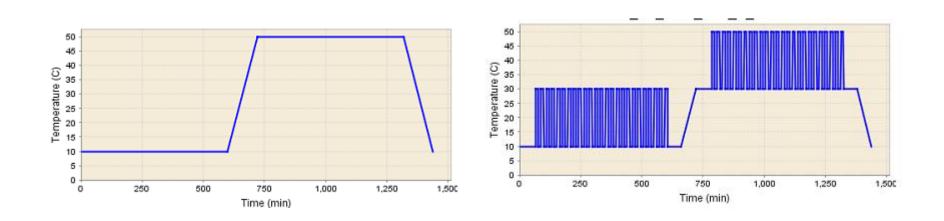
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Outdoor Deployment Thermal Stresses (cont.)

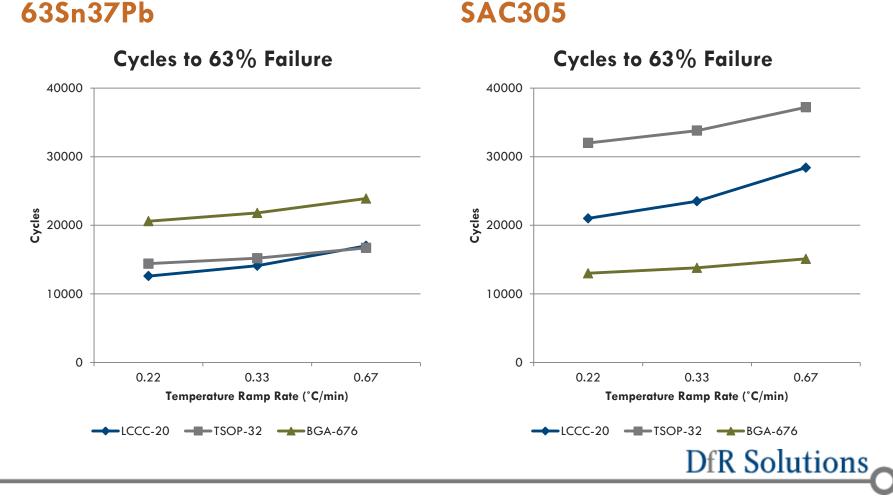
Daily $dT = 40^{\circ}C$

Daily dT = 20°C + mini-cycles

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Daily 40°C dT Solder Fatigue by Solder and Component



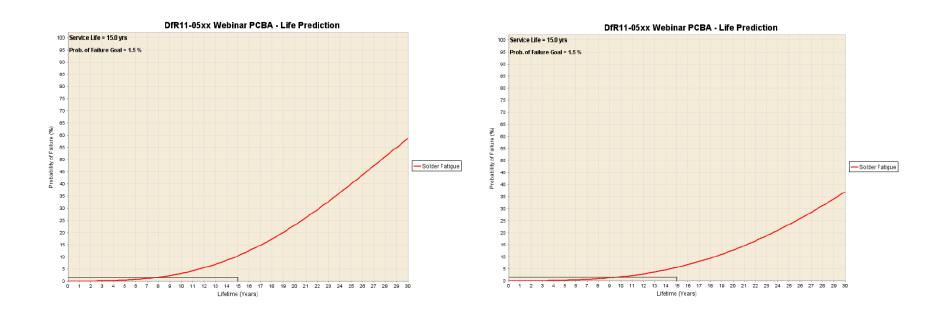
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Daily 40°C dT Assembly Solder Fatigue Life Prediction

63Sn37Pb

SAC305

DfR Solutions

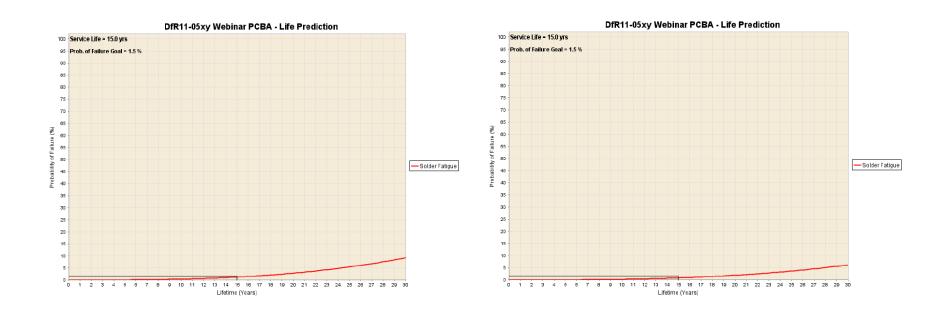


Daily 20°C dT + 20°C Mini-cycles Assembly Solder Fatigue Life Prediction

63Sn37Pb

SAC305

DfR Solutions



Observations

- Solder fatigue predictions at $dT = 40^{\circ}C$
 - $_{\circ}$ ~10% failures at 15 years for this SnPb assembly
 - $_{\circ}$ ~ 6% failures at 15 years for this SAC305 assembly
- Predictions at $dT = 20^{\circ}C + 20^{\circ}C$ mini-cycles
 - $_{\circ}$ ~1% failures at 15 years for this SnPb assembly
 - <1 % failures at 15 years for this SAC305 assembly

Observations (cont.)

- All components included in this analysis except BGA components are predicted to have longer solder joint lifetimes with SAC305 compared to SnPb eutectic.
- Solder fatigue is predicted to increase at slower temperature ramp rates



Further Information

- Recommend stress dependent lifetime modeling for assemblies with sizable BGA and QFN components
- Model validation reports are available from DfR Solutions