NEPP Electronic Technology Workshop
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National Aeronautics
and Space Administration

NASA/DoD Lead-Free Project

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NASA/DoD Lead-Free Project

Description:

- Support the responsible NASA official for Pb-free solder evaluation
- Serve as the NASA technical liaison to the NASA/DoD Pb-free Project
- Assure NASA areas of interest are included in JG-PP follow-on work
- Support NASA/DoD telcons and face-to-face meetings
- Update MSFC Pb-free solder lessons learned report

FY11 Plans:

- Generate reliability data from the NASA/DoD Pb-free Project on Pb-free solder applications for various part lead finishes and board finishes under space environments
- Update Pb-free solder risks and risk mitigation strategies for NASA
- Evaluate Pb-free alloy/Pb-free finish reliability in design application
- Status CAVE projects on Pb-free solder
- Compile the LTESE flight and bench data

Schedule:

(task)	2010			2011								
	O	N	D	J	F	M	A	M	J	J	A	S
Update Pb-free Lessons Learned	█	█	█	█	█	█ Ongoing	█	█	█	█	█	█
CAVE^3 Status 1						◆						◆
NASA/DoD Pb-Free Status			◆			◆		◆				◆
LTESE Report										█	█	█

Deliverables:

- Updated MSFC Pb-free lessons learned report
- Report on Pb-free alloy/Pb-free finish reliability
- Reliability data from Space Station Pb-free experiment
- Provide NASA/DoD Pb-free solder test results
- Provide CAVE^3 Pb-free solder projects status

NASA/DoD Lead-Free Project

NASA/DoD Lead-Free Electronics Project:

- Overview
- Vibration Test
- Mechanical Shock Test
- Thermal Cycle Test -55°C to +125°C
- Thermal Cycle Test -20^{o}C to +80^{o}C
- Combined Environments Test
- Drop Test

NASA/DoD Lead-Free Project

- This project is a follow-on to the Joint Council on Aging Aircraft/Joint Group on Pollution Prevention (JCAA/JG-PP) Pb-free Solder Project which was the first effort to test the reliability of Pb-free solder joints against the requirements of the aerospace and military community.
- The intended goal of the NASA/DoD project is to:

  - Determine the reliability of reworked solder joints in high-reliability military and aerospace electronics assemblies.

  - Assess the process parameters for reworking high-reliability Pb-free military and aerospace electronics assemblies.

  - Develop baseline recommendations for process guideline and risk assessment for assembling high-reliability Pb-free military and aerospace electronics assemblies

NASA/DoD Lead-Free Project

Invaluable technical, business, and programmatic contributions were provided by the organizations listed below.

- BAE Systems
- Boeing
- CALCE
- Celestica
- COM DEV
- DMEA
- F-15 Program Office
- Harris
- Honeywell
- Lockheed Martin
- NASA Jet Propulsion Lab
- NASA Marshall Space Flight Center
- NAVSEACrane
- Nihon Superior
- Raytheon
- Rockwell Collins
- Texas Instruments
- TT Apsco
- Warner Robins Air Logistics Center, Robins Air Force Base

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Test Vehicle

NASA/DoD Lead-Free Project

Test Vehicle

- Board Material: FR4 with a minimum T_g of $170^{o}C$
- Bare Boards: comply with IPC-6012 Class 3, Type 3
- Surface Finishes:
  - Immersion Silver
  - Electroless Nickel/Immersion Gold (ENIG)
- Solder: Eutectic SnPb (63Sn37Pb) – Control

  SAC 305 (Sn3.0Ag0.5Cu)

  SN100C (Sn-0.7Cu-0.05Ni + Ge)

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- The test vehicle PWA size is 14.5 X 9 X 0.09 inches with six 0.5-ounce copper layers. The design incorporates components representative of the parts used for military and aerospace systems and was designed to reveal relative differences in solder alloy performance.

- One hundred and ninety three (193) test vehicles were assembled by BAE Systems in Irving, Texas to J-STD-001D, Class 3. One hundred and twenty (120) of these test vehicles were "Manufactured" PWA's and seventy three (73) were "Rework" PWA's.

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- “Manufactured” (Mfg.) test vehicles represent printed wiring assemblies newly manufactured for use in new product.
- The “Rework” (Rwk.) test vehicles represent printed wiring assemblies manufactured and reworked prior to being tested. Solder mixing (SnPb/Pb-free & Pb-free/SnPb) will be evaluated on all “Rework” test vehicles.

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- **FLUX: The flux systems used during soldering were "low residue" or no-clean fluxes and the group chose to clean the test vehicles after processing**

SOLDER ALLOY	REFLOW SOLDERING	WAVE SOLDERING	MANUAL SOLDERING
SAC 305	R0L1	N/A	R0L0 Tacky Flux
SN100C	R0L0	ORL0	R0L0 Tacky Flux
Sn Pb Control	R0L0	ORM0	R0L0 Tacky Flux

ROL0 = Rosin, Low flux/flux residue activity, < 0.05% halide
ROL1 = Rosin, Low flux/flux residue activity, < 0.5% halide
ORL0 = Organic, Low flux/flux residue activity, < 0.05% halide
ORM0 = Organic, Moderate flux/flux residue activity, < 0.05% halide

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Test Parts

Component Type	Component Finish	Part Number
CLCC-20	SAC305	20LCC-1.27mm-8.9mm-DC
	SnPb	
QFN-20	Sn	A-MLF20-.5mm-.65mm-DC
	SnPb	
QFP-144	Sn	A-TQFP144-20mm-.5mm-DC
	SnPb	
	NiPdAu	
	SAC305	
PBGA-225	SnPb	PBGA225-1.5mm-27mm-DC
	SAC405	
CSP-100	SnPb	A-CABGA100-.8mm-1.0mm-DC
	SAC105	
	SN100C	
PDIP-20	Sn	A-PDIP20T-7.6mm-DC
	NiPdAu	
	SnPb	
TSOP-50	Sn	A-TII-TSOP50-10.16x20.95mm-.8mm-DC
	SnBi	
	SnPb	

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TEST	LOCATION	REFERENCE	ELECTRICAL TEST	ACCEPTANCE CRITERIA
Vibration	Boeing Seattle, WA	MIL-STD-810F, Method 514.5, Procedure I	Electrical continuity failure	Better than or equal to SnPb controls
Mechanical Shock	Boeing Seattle, WA	MIL-STD-810F, Method 516.5	Electrical continuity failure	Better than or equal to SnPb controls
Thermal Cycling	Boeing Seattle, WA Rockwell Collins Cedar Rapids, IA	IPC-SM-785	Electrical continuity failure	Better than or equal to SnPb controls at 10% Weibull cumulative failures
Combined Environments Test	Raytheon McKinney, TX	MIL-STD-810F Method 520.2 Procedure I	Electrical continuity failure	Better than or equal to SnPb controls at 10% Weibull cumulative failures
Drop Testing	Celestica Toronto, Ontario	JEDEC Standard JESD22-B110A	Electrical continuity failure	Better than or equal to SnPb controls
Interconnect Stress Test (IST)	PWB Interconnect Solutions Inc. Toronto, Ontario	IPC-TM-650-2.6.26	Electrical continuity testing	3 thermal cycles simulate assembly and 6 thermal cycles simulate assembly and rework
Copper Dissolution	Celestica Toronto, Ontario Rockwell Collins Cedar Rapids, IA	IPC-TM-650-2.1.1 ASTM-E-3	Cross section/ metallographic analysis	N/A

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Vibration Test

- **27 test vehicles were delivered to Boeing for vibration testing:**

  -5 SnPb “Manufactured” test vehicles (ImAg)

  -6 Pb-free “Manufactured” test vehicles assembled with SAC305 paste (5 ImAg, 1 ENIG)

  - 5 Pb-free “Manufactured” test vehicles assembled with SN100C paste (ImAg)

  -6 SnPb “Rework” test vehicles (5 ImAg, 1 ENIG)

  -5 Pb-free “Rework” test vehicles (ImAg)

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Vibration Test

- **Conducted a step stress test in the Z-axis only (i.e., perpendicular to the plane of the circuit board).**
- **Subjected the test vehicles to 8.0 g_{rms} for one hour. Then increased the Z-axis vibration level in 2.0 g_{rms} increments, shaking for one hour per step until the 20.0 g_{rms} level was completed.**
- **Then subjected the test vehicles to a final one hour of vibration at 28.0 g_{rms}.**

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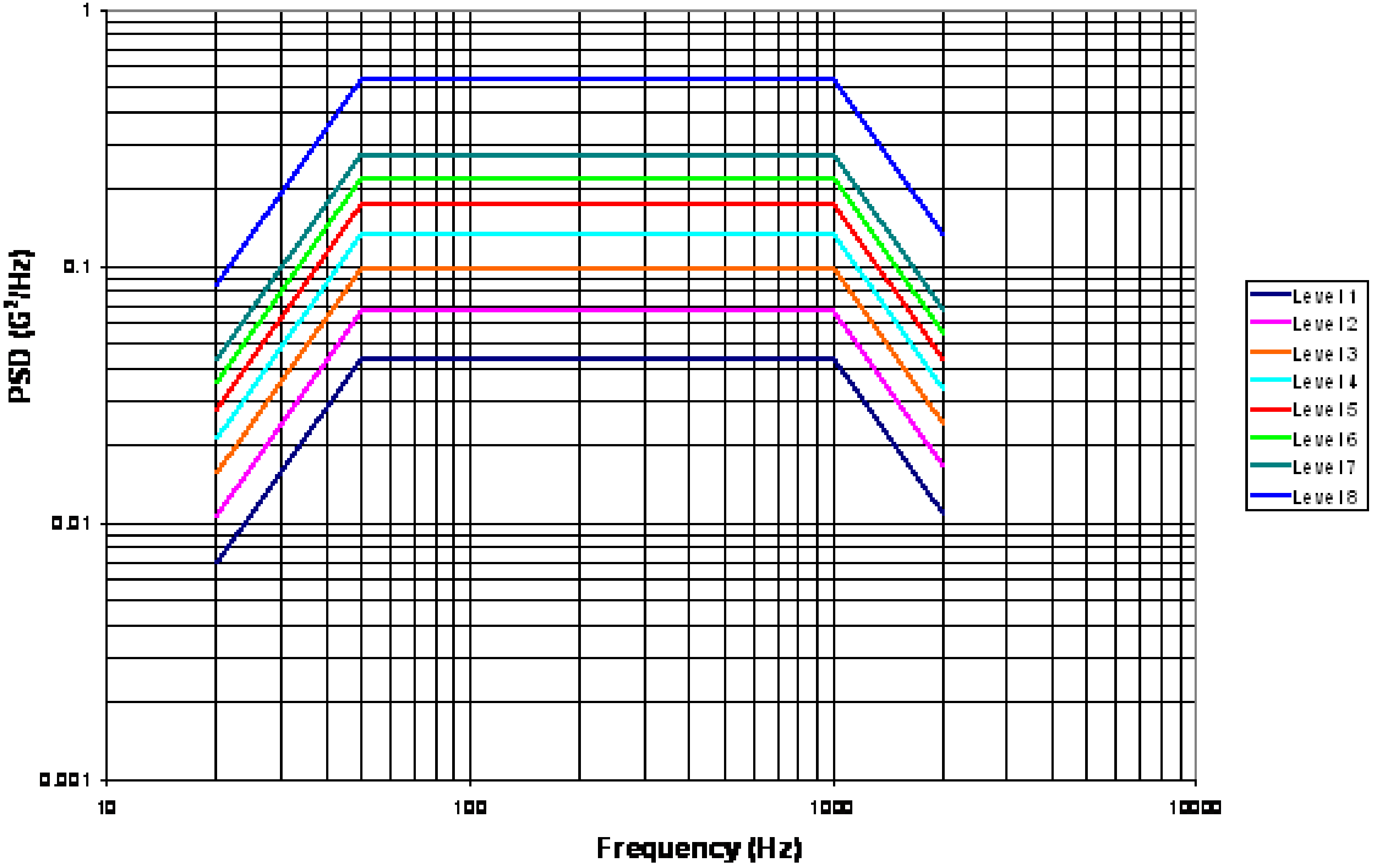
Vibration Test



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Vibration Test Results

Includes Mixed Solders

	% of Components Failed During Vibration Testing				
	"Manufactured" Test Vehicles			"Rework" Test Vehicles	
	SnPb Paste	SAC305 Paste	SN100C Paste	SnPb Paste	Pb-Free Paste
Component					
BGA-225	84	98	100	100	100
CLCC-20	32	43	90	35	68
CSP-100	62	73	70	62	80
PDIP-20	98	92	100	88	96
QFN-20	0	21	20	8	10
TQFP-144	60	63	64	70	70
TSOP-50	62	73	86	77	80

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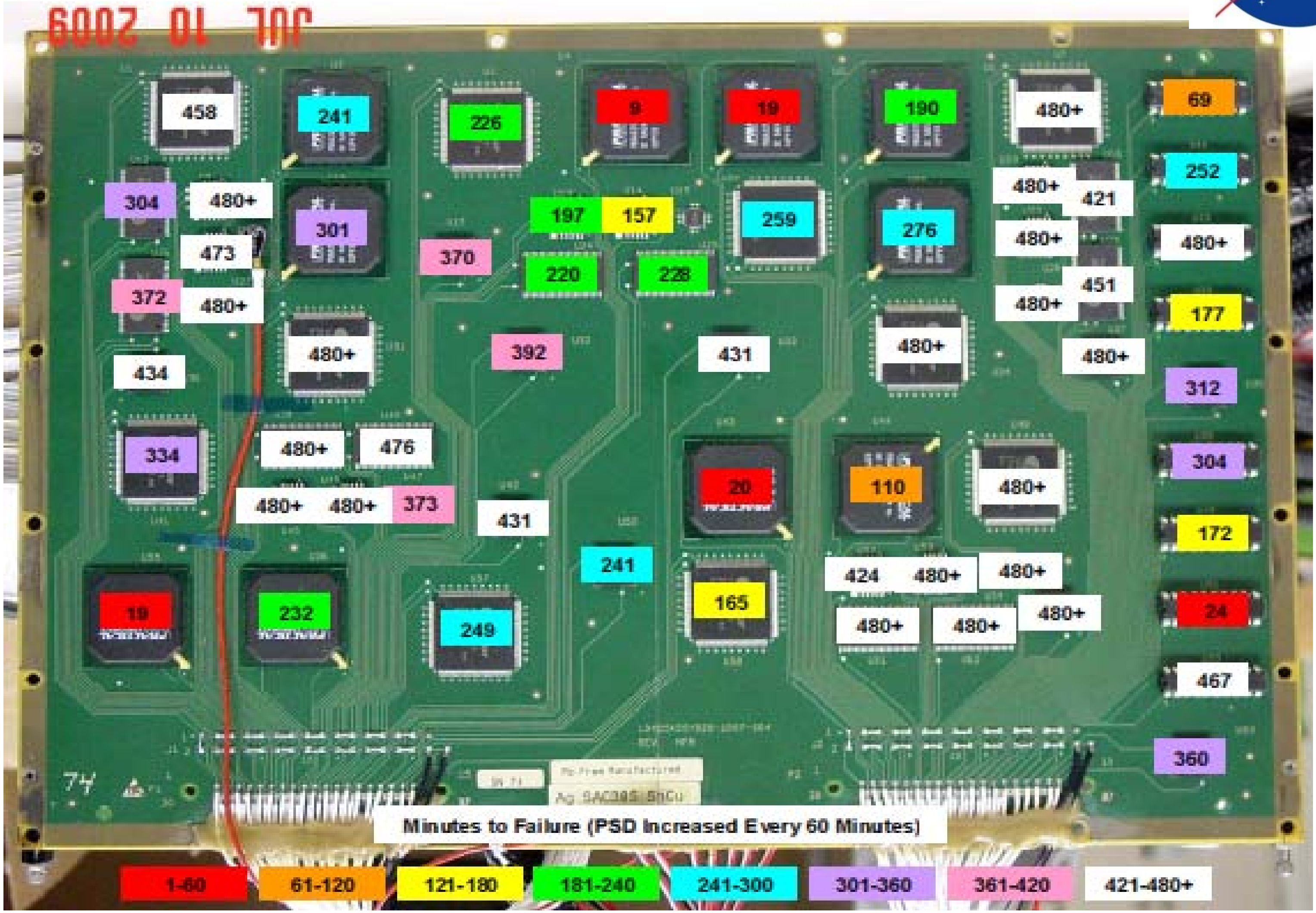
Vibration Test Results



MINUTES TO FAILURE

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Vibration Test Results

Ranking of Solder Alloy/Component Finish Combinations

Relative Ranking (Solder Alloy / Component Finish)

BGA-225	Sn37Pb/ Sn37Pb	SAC305/ SAC405	Sn37Pb/ SAC405	SAC305/ Sn37Pb	Rwk Flux Only/ Sn37Pb	Rwk Flux Only/ SAC405	Rwk Sn37Pb/SAC405 (SnPb Profile)	Rwk Sn37Pb/SAC405 (Pb-Free Profile)	SN100C/ SAC405
	1	3	3	3	3	3	3	3	3

CLCC-20	Sn37Pb/ Sn37Pb	SAC305/ SAC305	Sn37Pb/ SAC305	SAC305/ Sn37Pb	SN100C/ SAC305
	1	3	2	3	3

CSP-100	Sn37Pb/ Sn37Pb	SAC305/ SAC105	Sn37Pb/ SAC105	SAC305/ Sn37Pb	Rwk Flux Only/ Sn37Pb	Rwk Flux Only/ SAC105	Rwk Sn37Pb/SAC105 (SnPb Profile)	Rwk Sn37Pb/SAC105 (Pb-Free Profile)	SN100C/ SAC105
	1	1	1	2	1	2	1	3	1

PDIP-20	Sn37Pb/ SnPb	SN100C/ Sn	Sn37Pb/ NiPdAu	Rwk Sn37Pb/ Sn	Rwk Sn100C/ Sn	SN100C/ NiPdAu
	1	3	2	3	3	3

QFN-20	Sn37Pb/ Sn37Pb	SAC305/ Sn	Sn37Pb/ Sn	SAC305/ Sn37Pb	SN100C/ Sn
	1	2	1	1	2

TQFP-144	Sn37Pb/ Sn	SAC305/ Sn	Sn37Pb/ NiPdAu	SAC305/ NiPdAu	Sn37Pb/ Sn37Pb Dip	SAC305/ SAC305 Dip	SN100C/ Sn
	1	1	1	2	1	2	1

TSOP-50	Sn37Pb/ SnPb	Sn37Pb/ Sn	Sn37Pb/ SnBi	SAC305/ Sn	SAC305/ SnBi	SAC305/ SnPb	Rwk Sn37Pb/ SnPb	Rwk Sn37Pb/Sn (SnPb Profile)	Rwk Sn37Pb/Sn (Pb-free Profile)	Rwk SAC305/ SnBi	SN100C/ Sn	SN100C/ SnBi
	1	2*	2*	2*	2*	2	2	2*	2*	2	2	2

*Performance relative to Sn37Pb control may depend on orientation of the TSOP

1 = as good as or better than Sn37Pb control

2 = worse than Sn37Pb control

3 = much worse than Sn37Pb control

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Vibration Test Results

Ranking of Solder Alloy/Component Finish Combinations

	Sn37Pb/ Sn37Pb	SAC305/ SAC305	Sn37Pb/ SAC305	SAC305/ Sn37Pb	Sn100C/ SAC305
CLCC-20	1	**3**	**2**	**3**	**3**

1=as good as or better than Sn37Pb control

2=worse than Sn37Pb control

3= much worse than Sn37Pb control

NASA/DoD Lead-Free Project
Vibration Test Results

SUMMARY

- **The results of this study suggest that for some component types, the Pb-free solders tested are not as reliable as eutectic SnPb solder with respect to vibration.**
- **Rework also had a negative effect on both SnPb and Pb-free solders with respect to vibration.**

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Mechanical Shock Test

- **A step stress shock test was performed to maximize the number of failures generated which allowed comparisons of solder reliability**
- **All of the shocks applied in the Z-axis**
- **100 shocks applied per test level**
- **For Level 6 (300 G’s), 400 shocks were applied instead of 100**
- **Testing continued until a majority (approximately 63 percent) of components failed**

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Mechanical Shock Test

- **Number of Test Vehicles Required - 21**
- Mfg. SnPb = 5
- Mfg. Pb-free = 5
- Rwk. SnPb = 5
- Rwk. SnPb = 1 {ENIG}
- Rwk. Pb-free = 5

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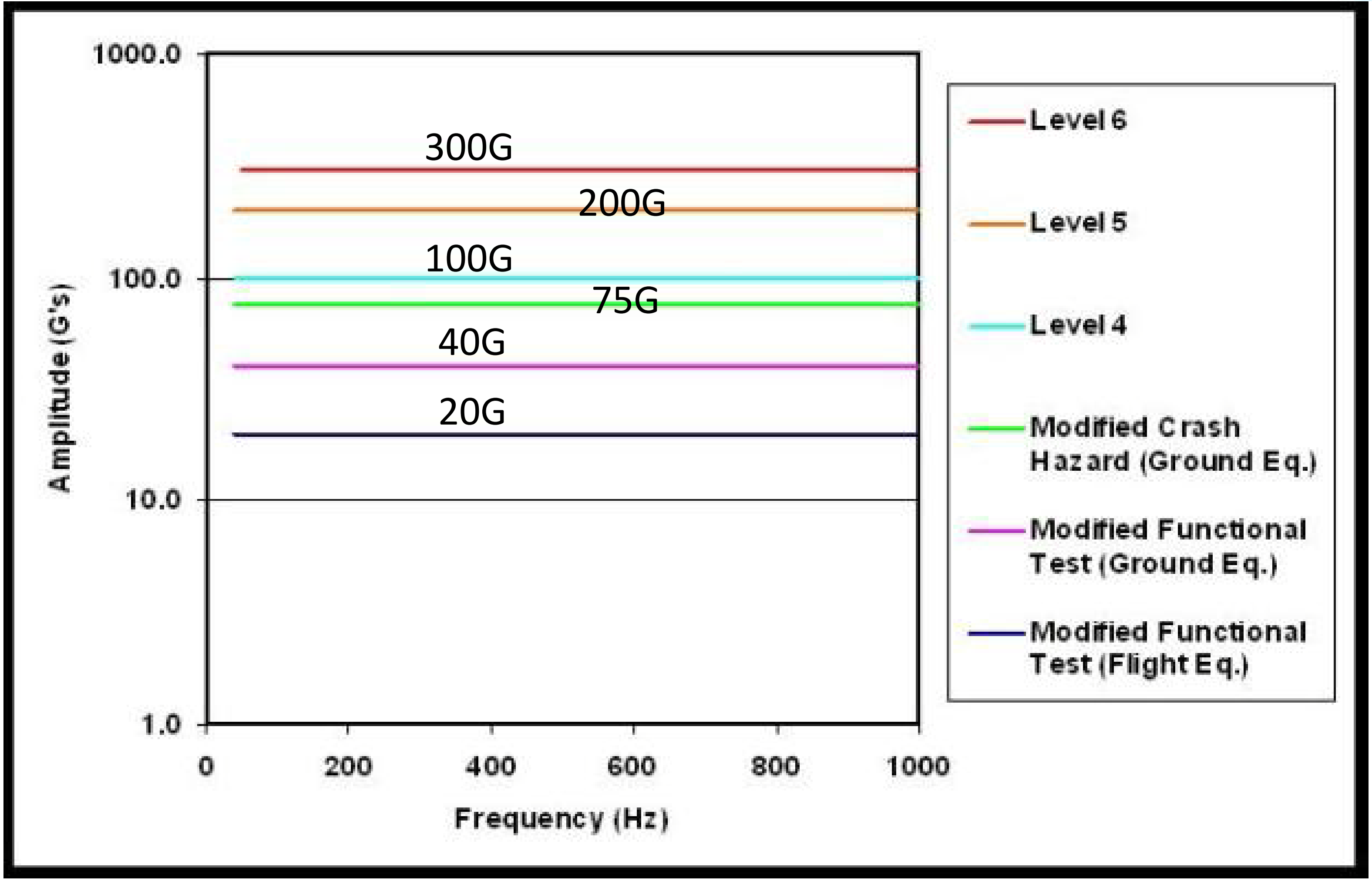
Mechanical Shock Test



Mechanical Shock Response Spectrum Test Levels

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Mechanical Shock Test

Relative Ranking (Solder/Component Finish)

Component	Sn37Pb/Sn37Pb	SAC305/SAC405	Sn37Pb/SAC405	SAC305/Sn37Pb	Rwk Flux Only /Sn37Pb	Rwk Flux Only /SAC405	Rwk Sn37Pb/SAC405 (SnPb Profile)	Rwk Sn37Pb/SAC405 (Pb-Free Profile)
BGA-225	1	1	2	1	1	1	2	1

Component	Sn37Pb/Sn37Pb	SAC305/SAC305	Sn37Pb/SAC305	SAC305/Sn37Pb
CLCC-20	1	2	2	2

Component	Sn37Pb/Sn37Pb	SAC305/SAC105	Sn37Pb/SAC105	SAC305/Sn37Pb	Rwk Flux Only /Sn37Pb	Rwk Flux Only /SAC105	Rwk Sn37Pb/SAC105 (SnPb Profile)	Rwk Sn37Pb/SAC105 (Pb-Free Profile)
CSP-100	1	1	2	1	2	1	2	2

Component	Sn37Pb/SnPb	SN100C/Sn	Sn37Pb/NiPdAu	Rwk Sn37Pb/Sn	Rwk SN100C/Sn
PDIP-20	1	1	1	2	2

Component	Sn37Pb/Sn37Pb	SAC305/Sn	Sn37Pb/Sn	SAC305/Sn37Pb
QFN-20	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank

Component	Sn37Pb/Sn	SAC305/Sn	Sn37Pb/NiPdAu	SAC305/NiPdAu	Sn37Pb /Sn37Pb Dip	SAC305 /SAC305 Dip
TQFP-144	1	1	1	1	1	2

Component	Sn37Pb/SnPb	Sn37Pb/Sn	Sn37Pb/SnBi	SAC305/Sn	SAC305/SnBi	SAC305/SnPb	Rwk Sn37Pb/SnPb	Rwk Sn37Pb/Sn (SnPb Profile)	Rwk Sn37Pb/Sn (Pb-Free Profile)	Rwk SAC305/SnBi
TSOP-50	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	2	2	2	2

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Mechanical Shock Test

SUMMARY

- **Pure Pb-free systems (SAC305/SAC405 balls, SAC305/SAC105 balls, SAC305/Sn, and SN100C/Sn) performed as well or better than the SnPb controls (SnPb/SnPb or SnPb/Sn).**
- **For mixed technologies, SnPb solder balls combined with SAC305 paste reflowed with a Pb-free profile performed as well as the SnPb controls on both the BGA's and the CSP's.**
- **SnPb solder paste combined with either SAC405 or SAC105 balls reflowed with a SnPb thermal profile underperformed the SnPb/SnPb controls.**
- **Rework operations on the PDIP's and TSOP's reduced the reliability of both the SnPb and the Pb-free solders when compared to the unreworked SnPb/SnPb controls**

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Mechanical Shock Test

SUMMARY (cont'd)

- **Rework of SnPb and SAC405 BGA's and SAC105 CSP's using flux-only gave equivalent performance to the unreworked SnPb/SnPb controls.**
- **Pb-free BGA's with SAC405 balls reworked with SnPb paste and (and a Pb-free thermal profile) were also equivalent to the SnPb controls.**
- **The combination of SAC305 solder/SAC105 balls generally performed as well as the SnPb/SnPb for chip scale packages.**

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Thermal Cycle -55°C to +125°C Test

Parameters:

- **-55°C to +125°C**
- **5 to 10°C/minute ramp**
- **30 minute high temperature dwell**
- **10 minute low temperature dwell**
- **Cycles: Test terminated at 4068 cycles**

NASA/DoD Lead-Free Project

Thermal Cycle -55°C to +125°C Test

- **Number of Test Vehicles Required - 27**
- Mfg. SnPb = 5
- Mfg. Pb-free = 5
- Mfg. Pb-free {SN100C} = 5
- Mfg. Pb-free = 1 {ENIG}
- Rwk. SnPb = 5
- Rwk. SnPb = 1 {ENIG}
- Rwk. Pb-free = 5

NASA/DoD Lead-Free Project

Thermal Cycle -55°C to +125°C Test

- **Manufactured Test Vehicle after 3600 Thermal Cycles**

Component Type	Total Failures	Population	Percent Failed
CLCC-20	232	311	74.6%
QFN-20	70	134	52.2%
QFP-144	228	309	73.8%
PBGA-225	156	279	56.0%
PDIP-20	160	220	72.7%
CSP-100	175	281	62.3%
TSOP-50	178	249	71.5%

- **Reworked Test Vehicle after 3600 Thermal Cycles**

Component Type	Total Failures	Population	Percent Failed
PBGA-225	27	66	40.9%
PDIP-20	41	60	68.3%
CSP-100	31	67	46.3%
TSOP-50	62	99	62.6%

NASA/DoD Lead-Free Project

Thermal Cycle -55°C to +125°C Test

SUMMARY

- CLCC: The completely Pb-free combinations (SAC/SAC and SNIC/SAC) were outperformed by solder/finish combinations that contained SnPb
- QFN: The QFN-20 components were the most robust component type in the investigation. The SnPb/Sn combination has the best thermal cycle performance
- QFP: N63 for all components ~2000-3000 cycles
- BGA: Significant range in N63 (~1500 –3900) without clear trends as to cause. Parts on reworked boards had larger N63s
- CSP: SnPb parts had somewhat better reliability; reworked parts generally more reliable
- TSOP: significant differences among parts –analysis needed to understand
- PDIP: SnPb/Sn had best reliability

NASA/DoD Lead-Free Project

Thermal Cycle -20°C to +80°C Test

- Approximately 11,000 cycles have been completed as of May 17, 2011
- No lead-free BGAs or CSPs have failed
- Hope to complete 17,000 thermal cycles

NASA/DoD Lead-Free Project

Combined Environments Test

- **The Combined Environments Test (CET) for the NASA-DoD Lead-Free Electronics Project was based on a modified Highly Accelerated Life Test (HALT), a process in which products are subjected to accelerated environments to find weak links in the design and/or manufacturing process.**

NASA/DoD Lead-Free Project

Combined Environments Test

- **Number of Test Vehicles Required - 27**
- Mfg. SnPb = 5
- Mfg. Pb-free {SAC 305}= 5
- Mfg. Pb-free {SN100C} = 5
- Mfg. Pb-free = 1 {ENIG}
- Rwk. SnPb = 5
- Rwk. SnPb = 1 {ENIG}
- Rwk. Pb-free = 5

NASA/DoD Lead-Free Project

Combined Environments Test

Parameters

- **-55°C to +125°C**
- **20°C/minute ramp**
- **15 minute soak**
- **Number of cycles ≥ 500**
- **Vibration for duration of thermal cycle**
- **10 G_{rms}, initial**
- **Increase 5 G_{rms} after every 50 thermal cycles**
- **55 G_{rms}, maximum**

NASA/DoD Lead-Free Project

Combined Environments Test

SUMMARY

- The part type had the greatest effect on solder joint reliability; solder alloy had a secondary effect
- The plated-through hole parts {PDIP-20} were more reliable than the SMT parts
- The TQFP-144 and QFN-20 parts performed the best of the SMT parts
- The BGA-225 parts performed the worst

SUMMARY (cont'd)

- **SnPb finished parts soldered with SnPb solder paste were the most reliable**
- **SAC soldered parts were less reliable than the SnPb soldered controls**
- **SnPb contamination on BGA-225 parts degrades early life performance of Sn100C and SAC 305 solder paste**

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Drop Test

- **Number of Test Vehicles Required - 21**

  Mfg. SnPb = 5

  Mfg. Pb-free = 5

  Rwk. SnPb = 5

  Rwk. SnPb = 1 {ENIG}

  Rwk. Pb-free = 5

- **Shock testing conducted in the -Z direction**
- **500G peak input, 2ms pulse duration**
- **Test vehicles were dropped until all monitored components failed or 20 drops had been completed**

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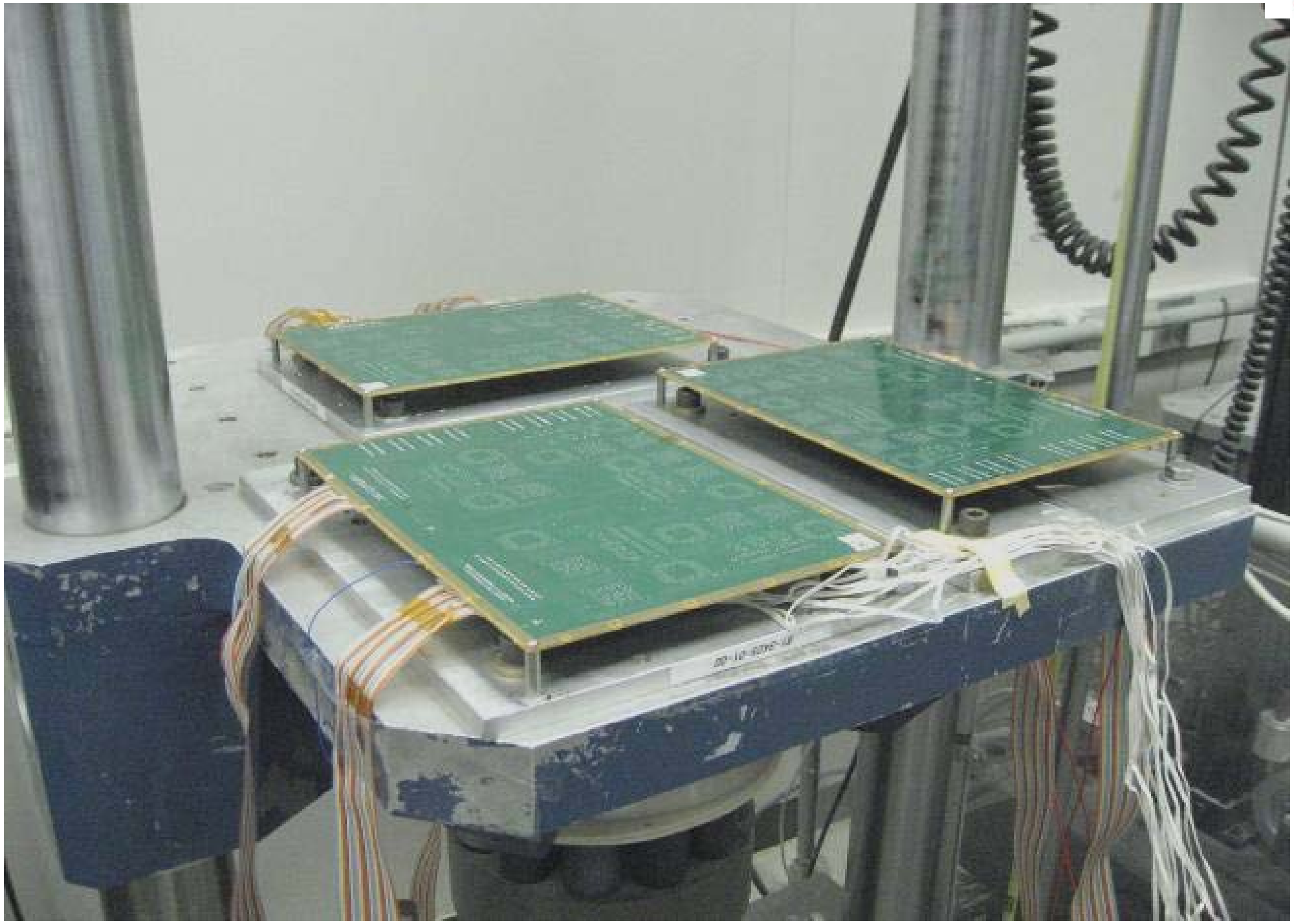
Drop Test



Drop Table with Fixtured/Wired Test Vehicles

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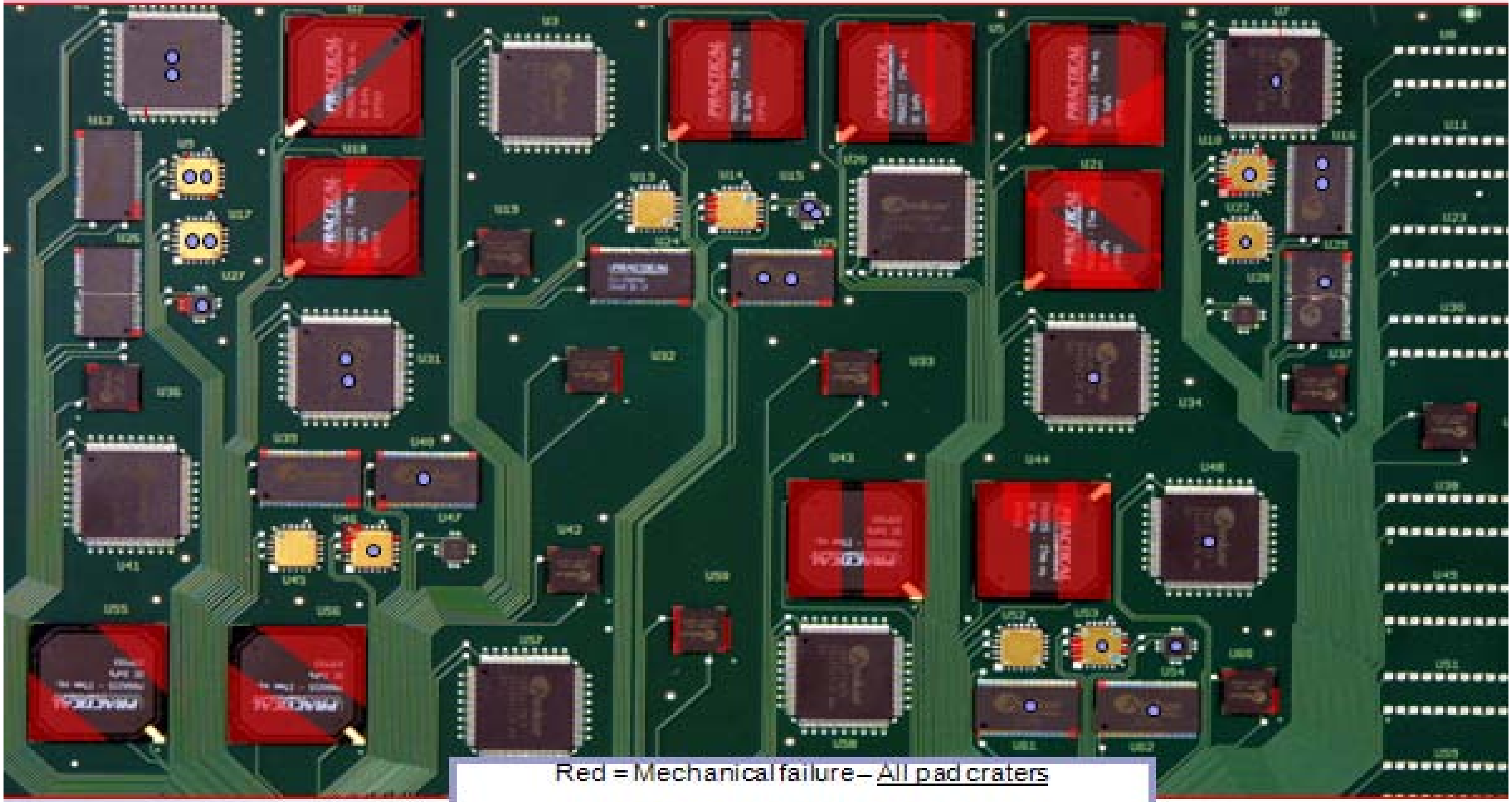
Drop Test

Mechanical Failures



Red = Mechanical failure – <u>All pad craters</u>

All BGAs are Electrically Failed

No leaded parts on this board failed electrically

Blue Dots on Some Parts = # of SnPb Hand Reworks

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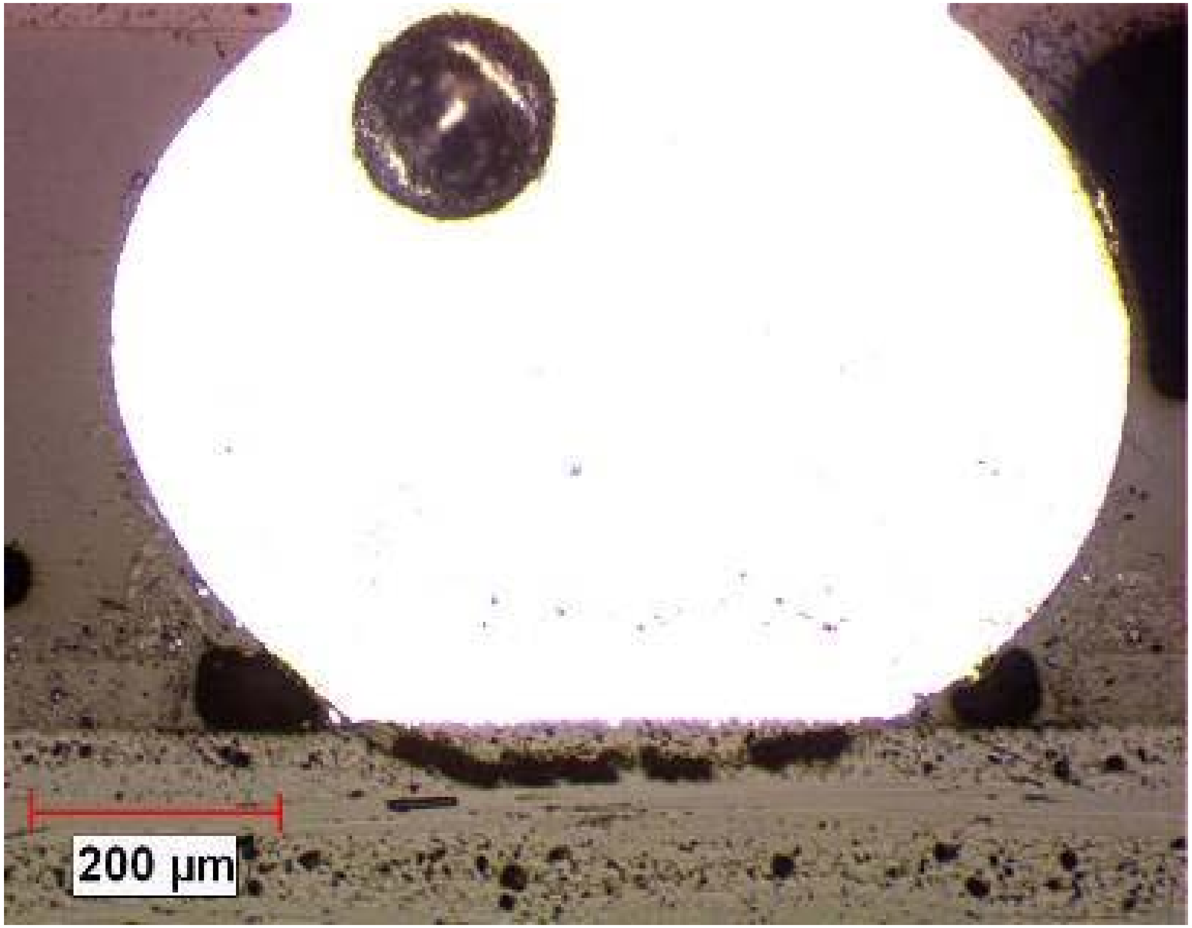
Drop Test

PAD CRATERING



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Drop Test

Electrical Results

- **Vast majority of electrical failures were PBGAs**
- **Wide range in # of drops until failure**
- **40% failed electrically within less than 6 drops**
- **99% failed electrically by 20 drops**
- **All CSPs electrically passed drop testing**
- **Less than 1% of non-BGA components electrically failed after 20 drops**

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Drop Test

SUMMARY

- **Component *location* on the board plays a large role**
- **Component *type* plays a large role in drop test results**
- **Significant mechanical damage occurs well before electrical failure**
- **Mixed solder joints fail sooner than pure SnPb BGAs**
- **Reworking reduces the mechanical robustness of BGAs**

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Drop Test

SUMMARY (cont'd)

- SnPb reworked parts are no less reliable than their Pb-free as manufactured counterparts
- Both electrical and mechanical damage was at a minimum for non-BGA parts
- Predominant failure mechanism was pwb-side pad cratering
- Of parts subjected to failure analysis ~1/3 that passed electrical test had mechanical damage

NASA/DoD Lead-Free Project

The website for the NASA/DoD Lead-free Project is:

http://teerm.nasa.gov/NASA_DODLeadFreeElectronics_Proj2.html

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QUESTIONS?