HALT to Qualify Electronic Packages – *A Proof of Concept*[*]

Rajeshuni Ramesham Ph.D.

Jet Propulsion Laboratory
Reliability Engineering, Office of Safety and Mission Success
California Institute of Technology
Pasadena, CA 91109

Tel.: 818 354 7190
E-mail: Rajeshuni.ramesham@jpl.nasa.gov

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Outline

- **Life Testing Requirements**
- **Introduction**
- **Objectives**
- **Experimental Approach and Details**
- **Test Results**
- **Summary**
- **Acknowledgements**

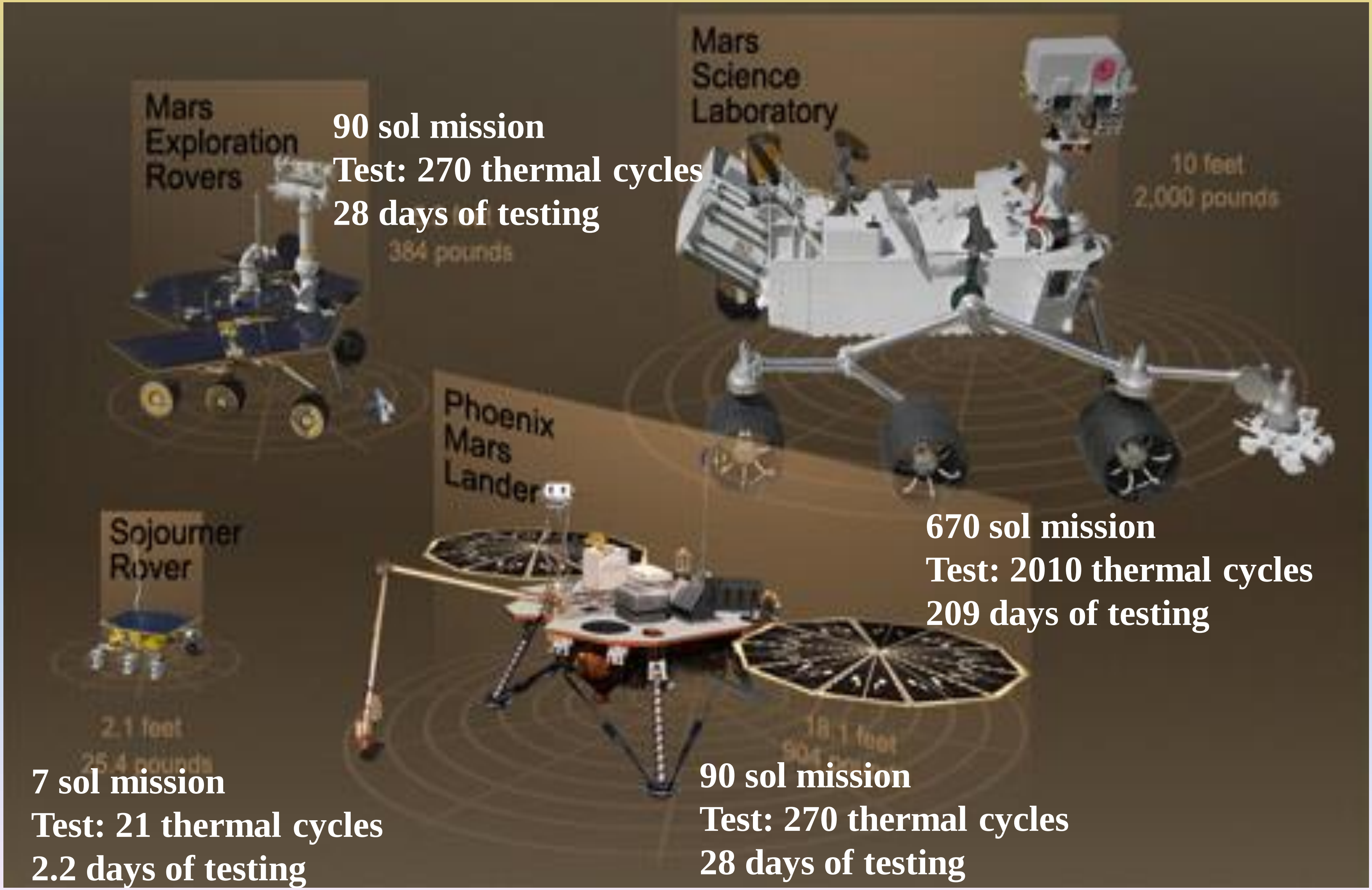
Life Testing Requirement

The following requirement is from the JPL Design Principles.

***Thermal cycling* -**

- Electronic hardware design shall be capable of surviving power **ON-OFF** temperature cycling and/or solar exposure cycling of **three times** the number of worst-case expected mission cycles with worst-case flight temperature excursions.

Mars Family of Rovers and Lander: Pathfinder, Spirit/Opportunity, Curiosity, & Phoenix



90 sol mission
Test: 270 thermal cycles
28 days of testing

670 sol mission
Test: 2010 thermal cycles
209 days of testing

7 sol mission
Test: 21 thermal cycles
2.2 days of testing

90 sol mission
Test: 270 thermal cycles
28 days of testing

Introduction

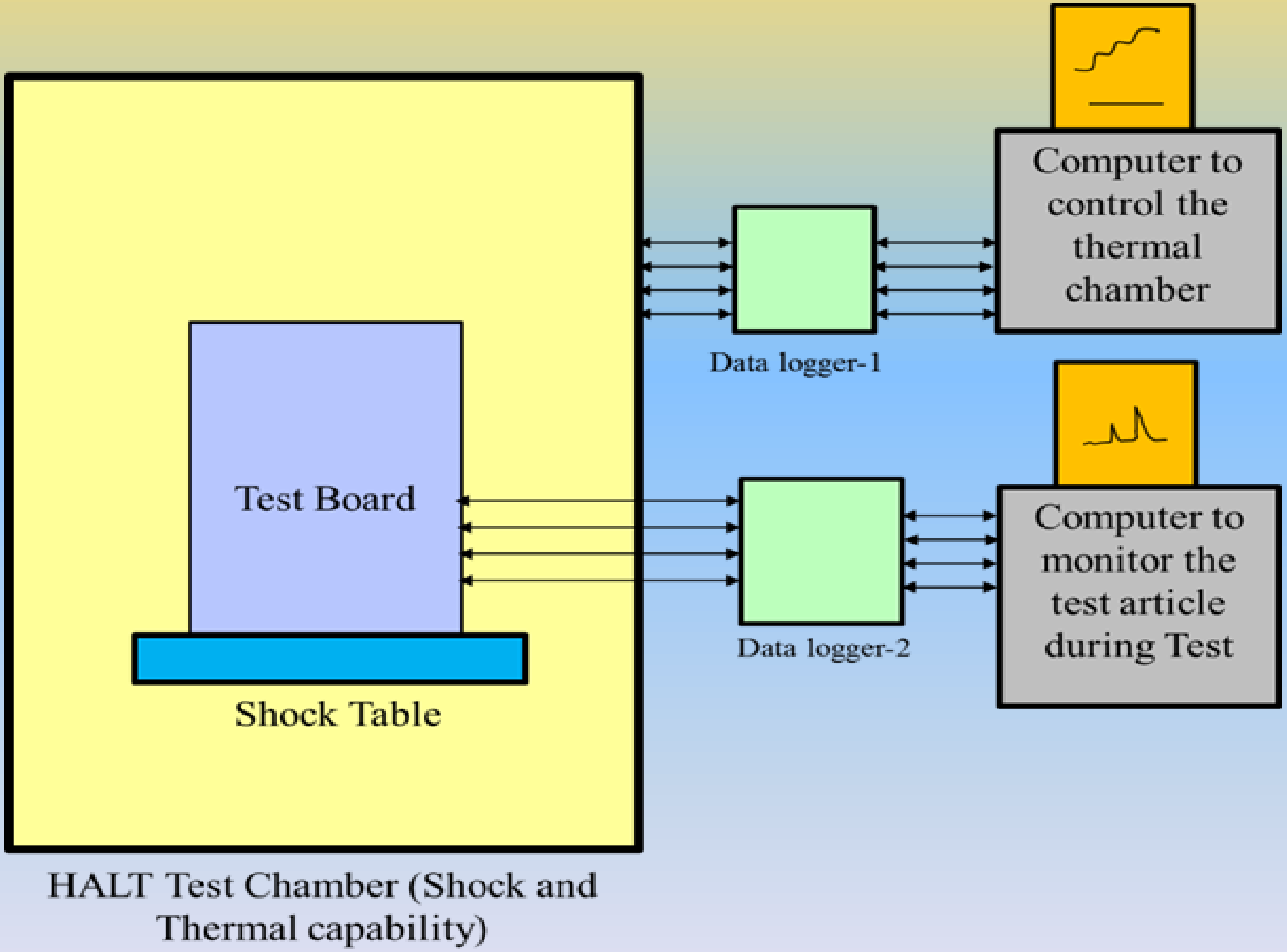
- Explore *a proof of concept* of Highly Accelerated Life Testing (HALT) technique to assess packaging designs for long duration deep space missions in a wide temperature range (–150°C to +125°C).
- HALT is a custom hybrid package suite of testing technique, such as extreme temperature down to -150°C to +125°C and vibration step processing up to 50g acceleration.
- HALT testing implements repetitive multiple-axis vibration combined with thermal cycles testing of the test article to precipitate defects.

Objective

- Predict reliability, failure mechanism and survivability of selected advanced electronic interconnect packages (Ball Grid Arrays, Flip-chips, surface mount packages, etc.) for long duration deep space missions in a shorter duration.
- Reduce the development cycle time for improvements to the packaging design.

Experimental Approach and Details

- Design and build advanced test boards that are considered useful for a variety of NASA projects.
- Select stress stimuli thermal cycling and/or all-axis vibration or both simultaneously
- Perform stress testing
- Analyze the test results and compare with the thermal cycling test data.
- Estimate the acceleration factor for package failures observed.



Schematic diagram for the solder joint continuity monitoring HALT test system

Two Test Boards Were Tested

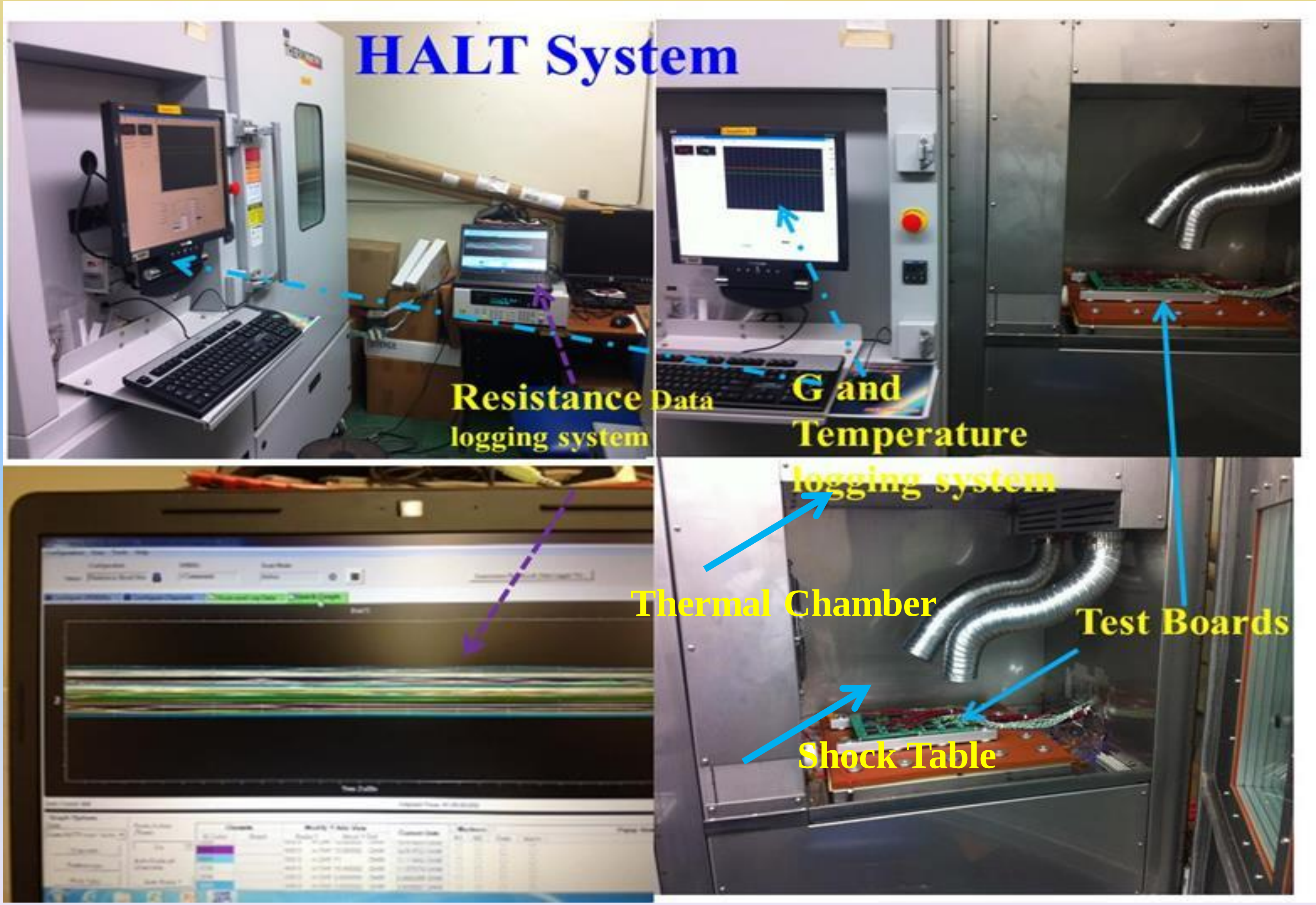
Board #	Board Label : Test Point	Channel #
1	BGA256 Left Top ± T1	1001
1	BGA256 Left Top ± T2	1002
1	BGA256 Left Bottom ± T1	1003
1	BGA256 Left Bottom ± T2	1004
1	PBGA388 Top ± A	1005
1	PBGA388 Top ± B	1006
1	PBGA388 Top ± C	1007
1	PBGA388 Bottom ± A	1008
1	PBGA388 Bottom ± B	1009
1	PBGA388 Bottom ± C	1010
1	CVBGA97 Top ± T	1011
1	CVBGA97 Bottom ± T	1012
1	QFP100 Left ± T	1013
1	QFP100 Right ± T	1014
1	QFP256 Left ± T	1015
1	QFP256 Right ± T	1016
1	QFP208 Left ± T	1017
1	QFP208 Right ± T	1018
1	MLF68 Top ± T	1019
1	MLF68 Bottom ± T	1020
2	BGA256 Left Top ± T1	1021
2	BGA256 Left Top ± T2	1022
2	BGA256 Left Bottom ± T1	1023
2	BGA256 Left Bottom ± T2	1024
2	PBGA388 Top ± A	1025
2	PBGA388 Top ± B	1026
2	PBGA388 Top ± C	1027
2	PBGA388 Bottom ± A	1028
2	PBGA388 Bottom ± B	1029
2	PBGA388 Bottom ± C	1030
2	CVBGA97 Top ± T	1031
2	CVBGA97 Bottom ± T	1032
2	QFP100 Left ± T	1033
2	QFP100 Right ± T	1034
2	QFP256 Left ± T	1035
2	QFP256 Right ± T	1036
2	QFP208 Left ± T	1037
2	QFP208 Right ± T	1038
2	MLF68 Top ± T	1039
2	MLF68 Bottom ± T	1040

Each test board has similar components. Some of the components were independently daisy chained.

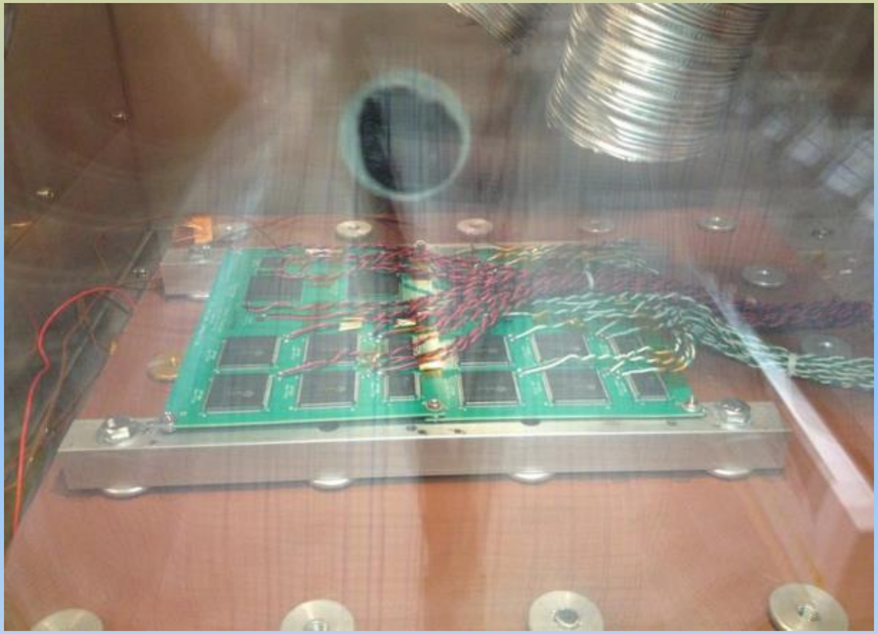
BGA: Ball grid array
PBGA: Plastic ball grid array
CVBGA: Very thin chip array ball grid array
QFP: Quad flat pack
MLF: Micro Lead Frame

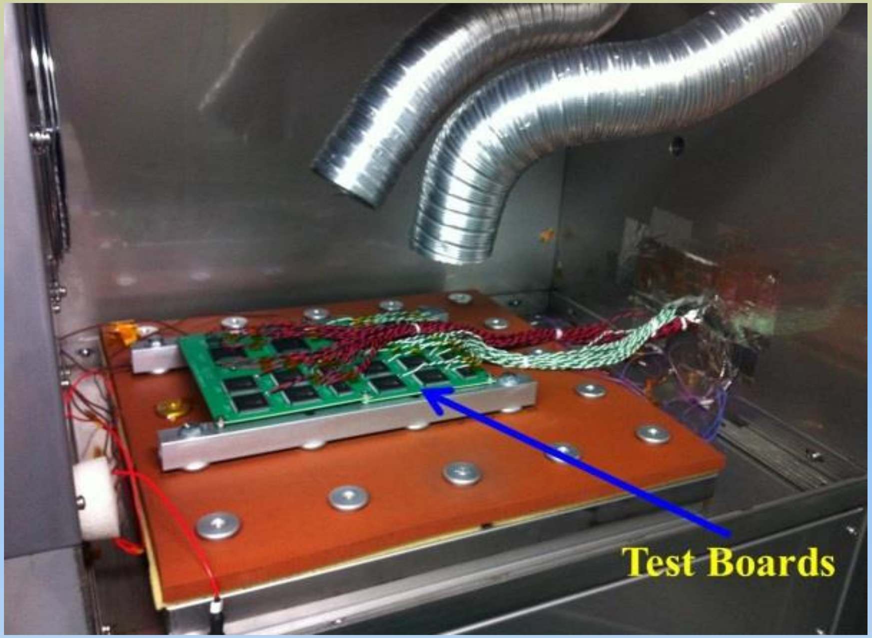
Source: Practical components data sheet

Test Boards in the HALT System

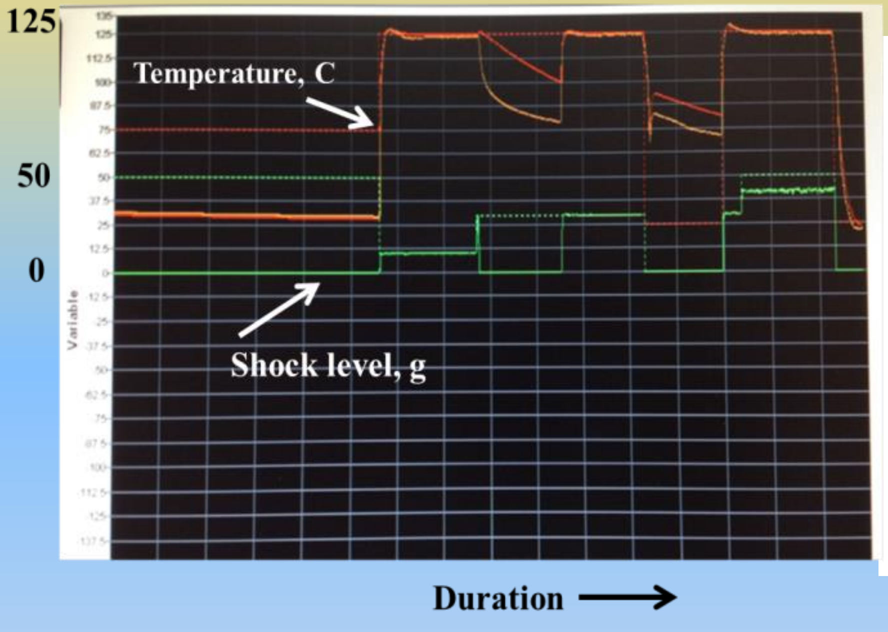


Two Test boards in the HALT chamber

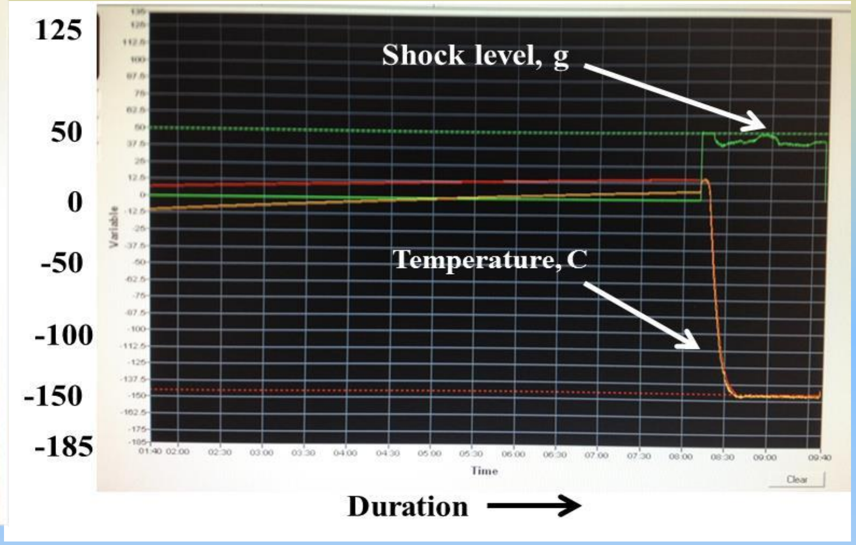




Experimental Details



Temperature (125°C), g level (~10g, 30, 40g) vs. test duration of 1 hour

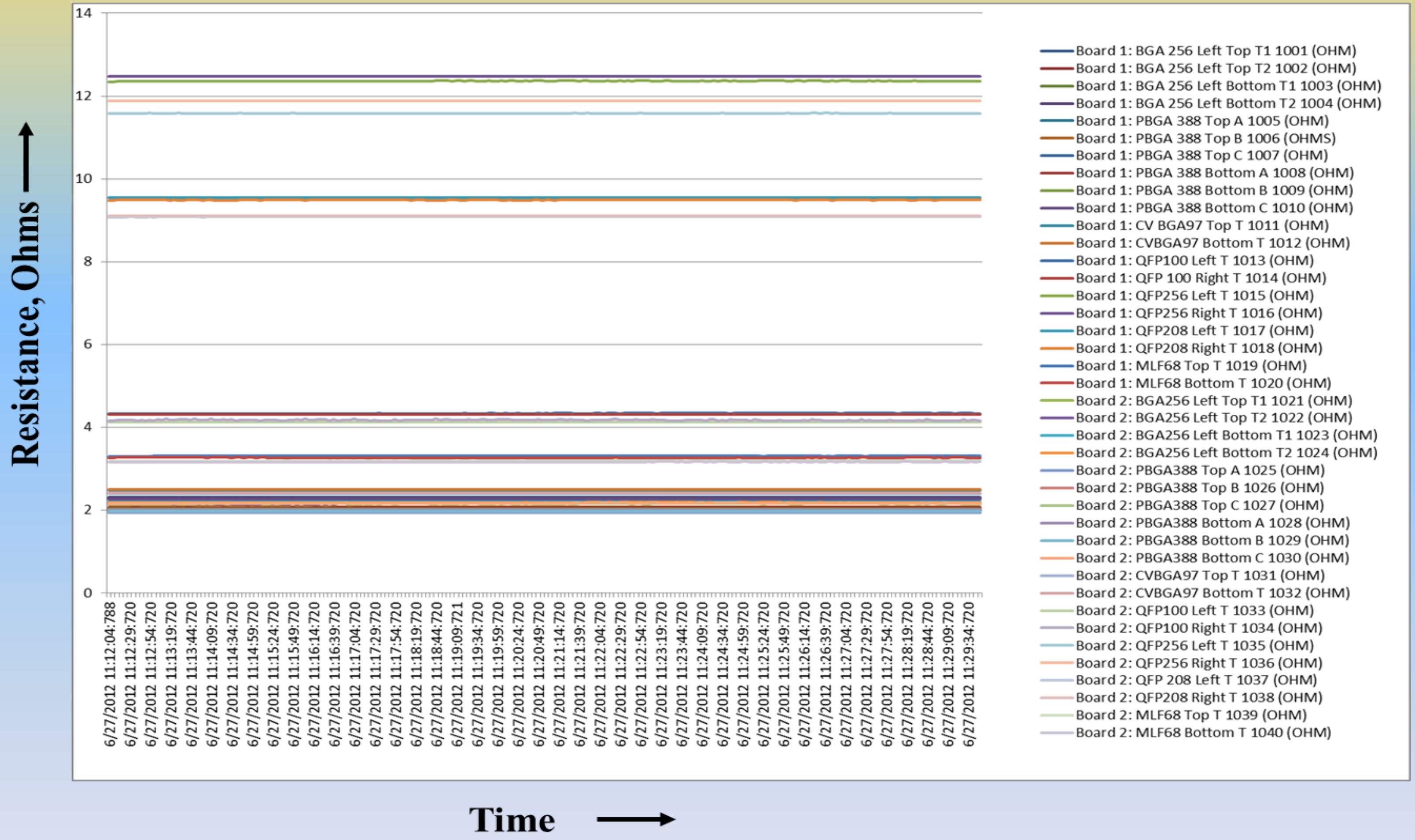


Temperature (-150°C), g level (~40g) vs. test duration of 1 hour

Test Results summary: Various test runs with variations of temperature, acceleration, and test duration

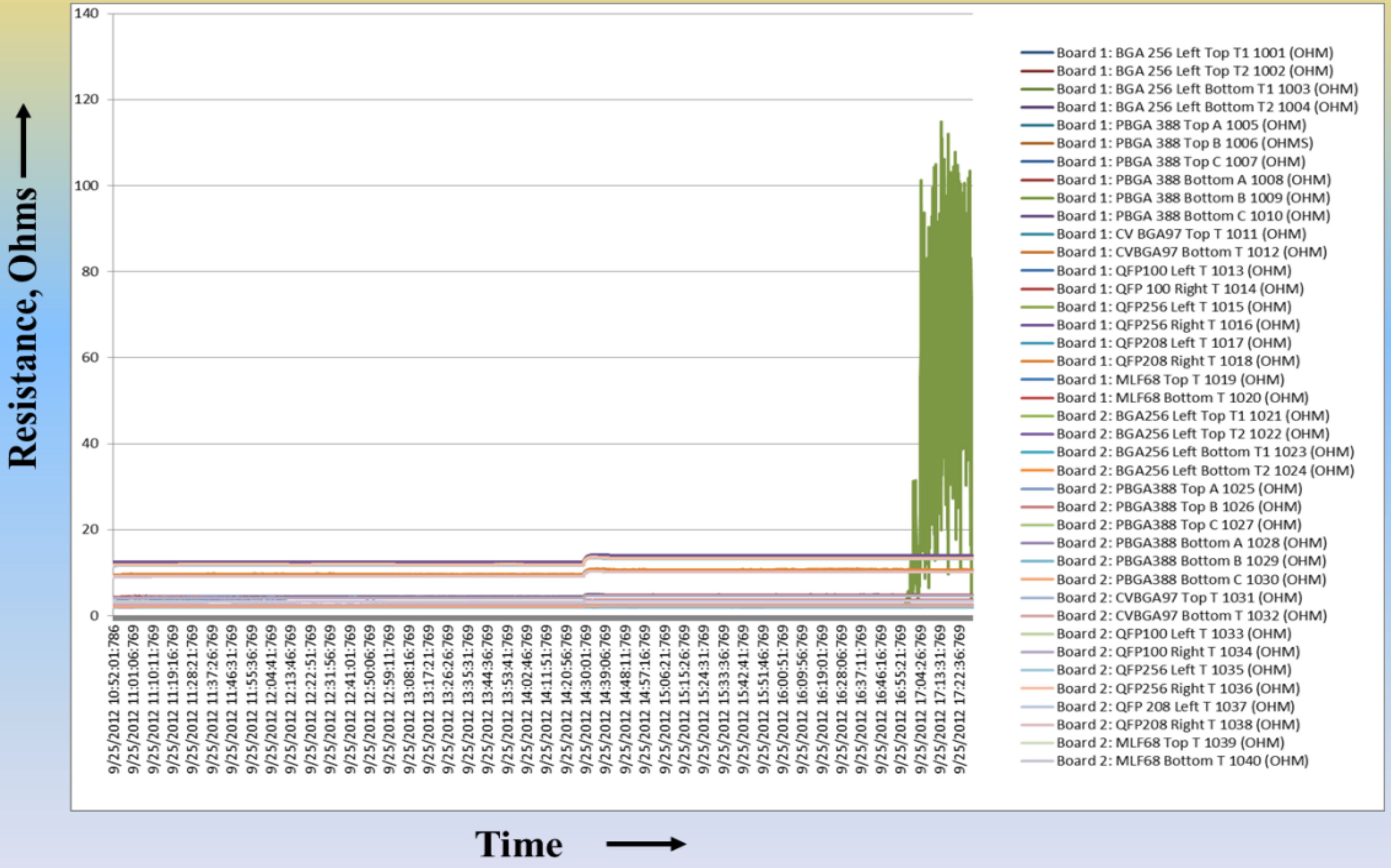
S/N	Temperature, C	Acceleration, g	Test Duration	Observation
1	+25oC to -125oC	5g		No anomalous behavior observed during this test.
2	@50C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
3	@75C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
4	@100C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
5	@125C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
6	@0C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
7	@-25C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
8	@-50C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
9	@-75C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
10	@-100C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
11	@125C	10, 15, 20, 30, 40, and 50g	10 minutes at each g level	No anomalous behavior observed during this test.
12	@25C	10, 15, 20, 30, 40, and 50g	60 minutes at each g level	No anomalous behavior observed during this test.
13	@75C	10, 15, 20, 30, 40, and 50g	60 minutes at each g level	No anomalous behavior observed during this test.
14	@100C	10, 15, 20, 30, 40, and 50g	60 minutes at each g level	No anomalous behavior observed during this test.
15	@125C	10, 15, 20, 30, 40, and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
16	@25C	10, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
17	@75C	10, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
18	@125C	10, 15, 20, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
19	@20C	10, 20, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
20	@-50C	10, 20, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
21	@-100C	10, 20, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance
22	@-150C	10, 20, 30 and 50g	60 minutes at each g level	Failures were observed during this test run. Observed change in the daisy-chain resistance

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature



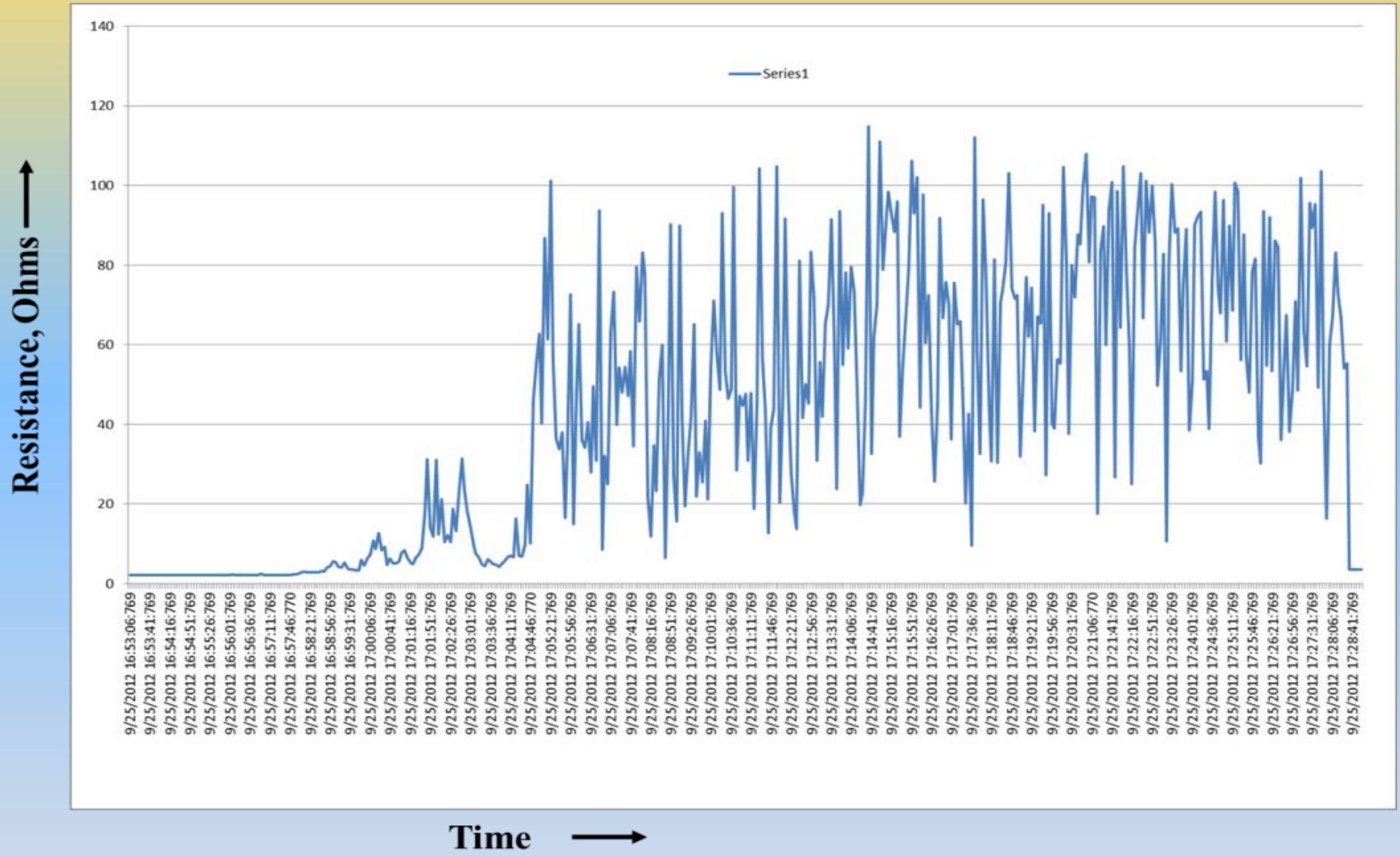
No anomalies were observed in all the daisy-chains of advanced electronic packages since the resistance is constant vs test time

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature



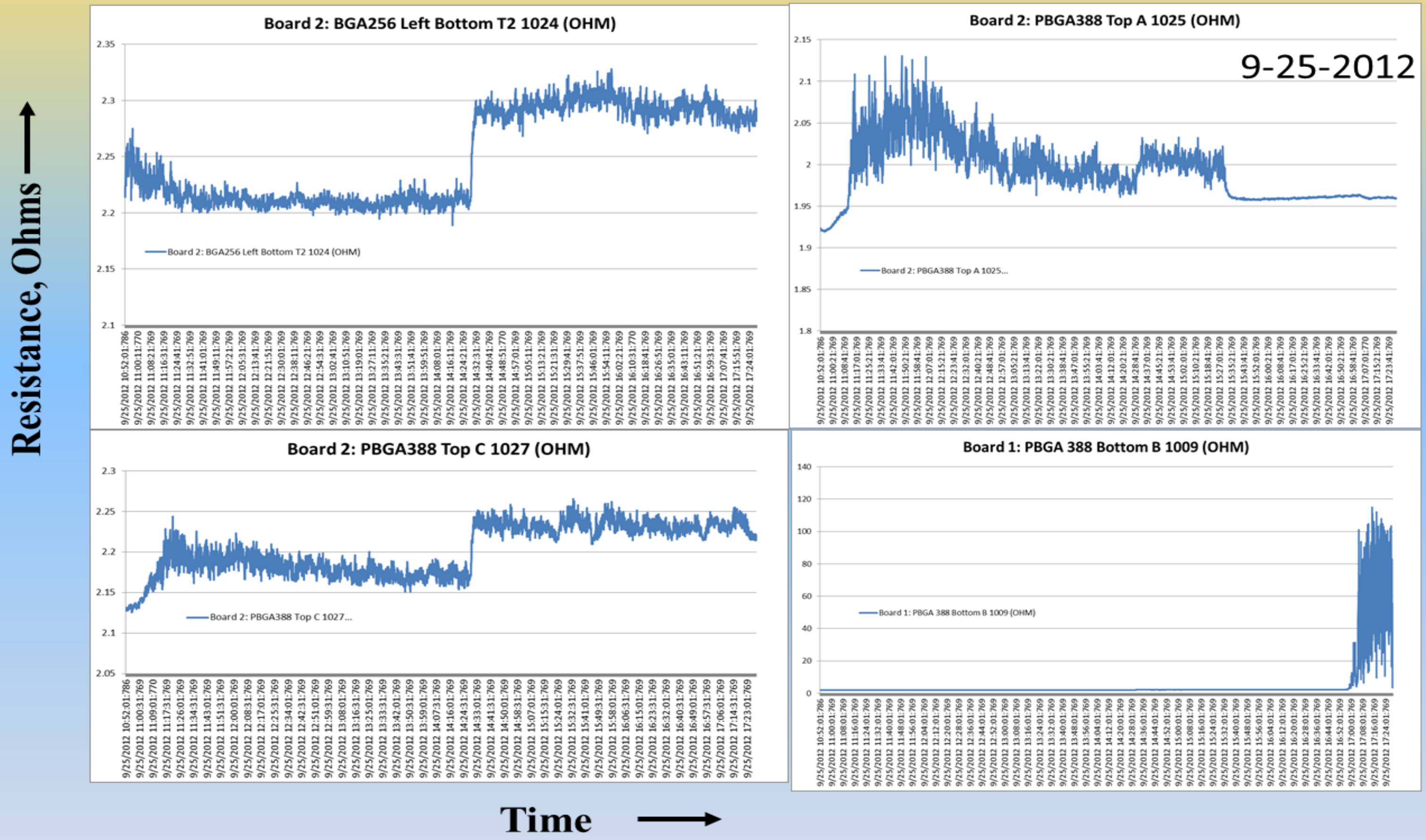
Resistance of various daisy chains vs., time at a given dynamic load of g particularly the daisy-chain resistance anomalous behavior of PBGA Package

Test Results: Resistance of PBGA daisy chain vs. time at a given dynamic load of g and temperature



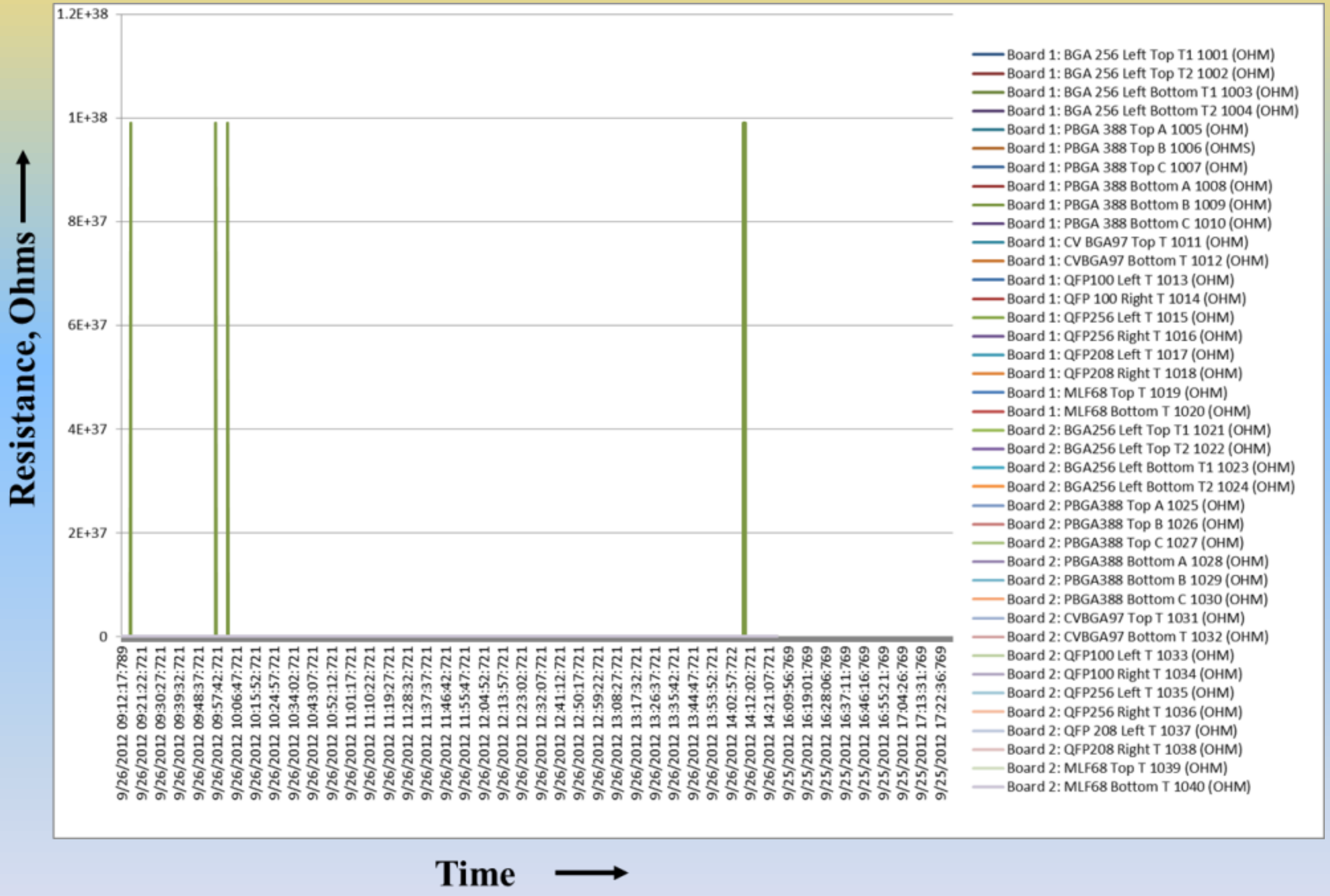
Resistance of PBGA daisy chain vs., time at a given dynamic load of g particularly (corresponding to channel #1009). Daisy chain resistance change was highly intermittent due to the failure of a PBGA388 package (on board#1).

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature



Resistance of PBGA daisy chains vs., time at a given dynamic load of g particularly (corresponding to channel #1009 (board 1), 1025, 1024, 1027 (board#2)). Daisy chain resistance change was highly intermittent due to the failure of a PBGA388 package on board#1 and small variations in daisy chain resistance of BGA256, PBGA388 of board#2.

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

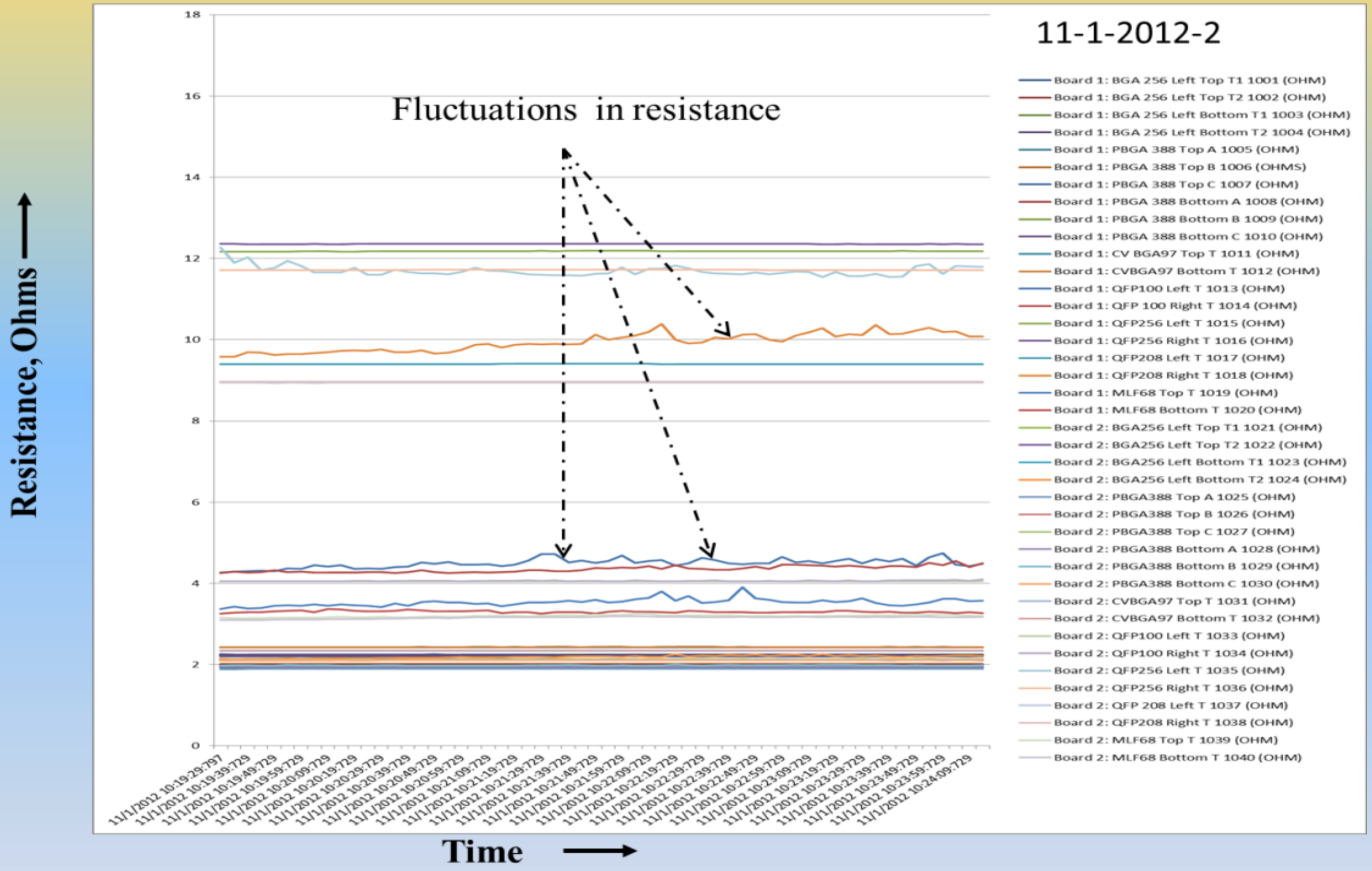


PBGA388 (channel 1009) has failed completely and daisy chain resistance is infinity or open circuit.

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

PBGA388 (channel 1009) has failed completely and daisy chain resistance is very high. Resistance is normal when no stress is applied on test board.

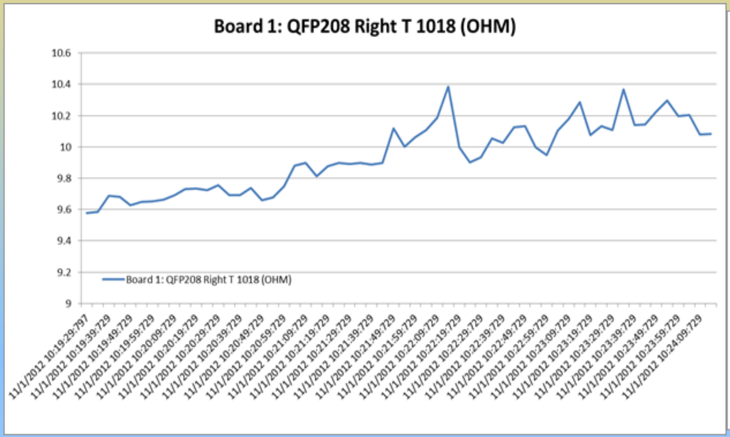
Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

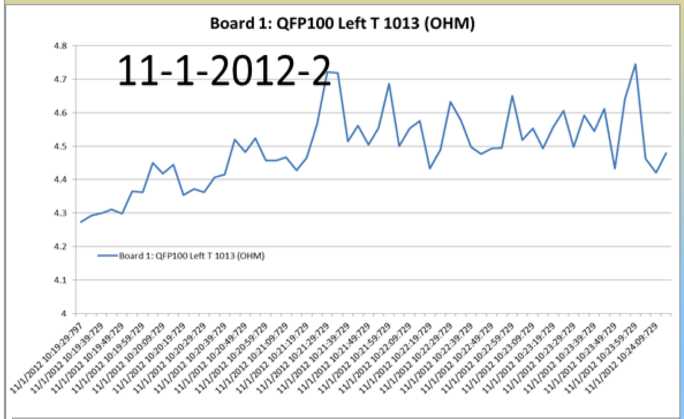


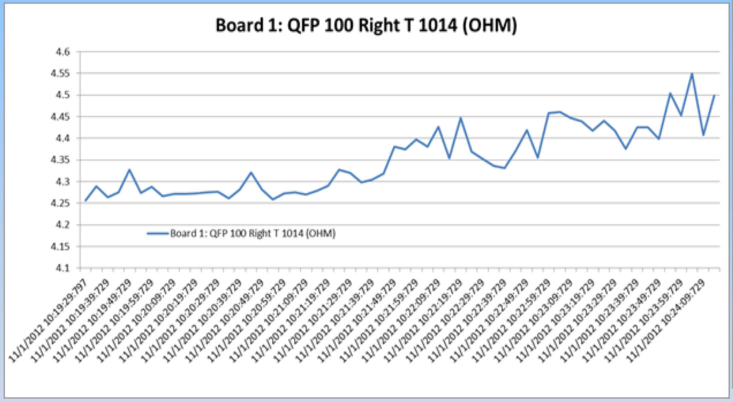
Resistance of some of the daisy chains were responding

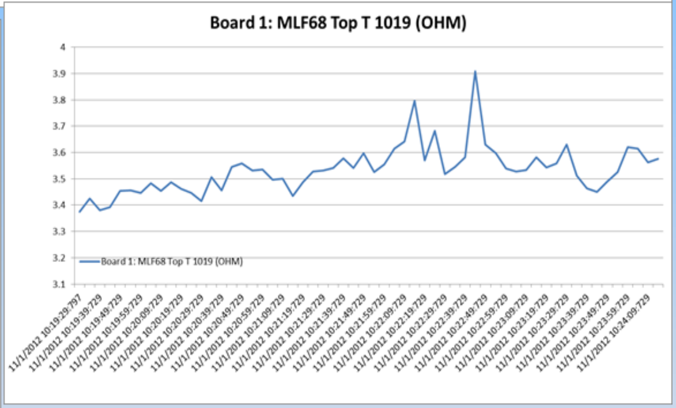
Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

Resistance, Ohms







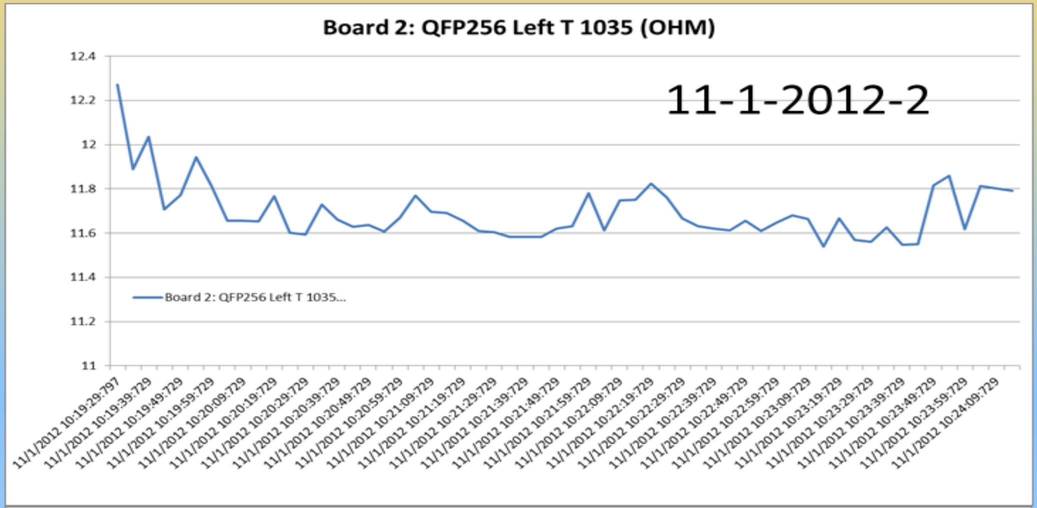


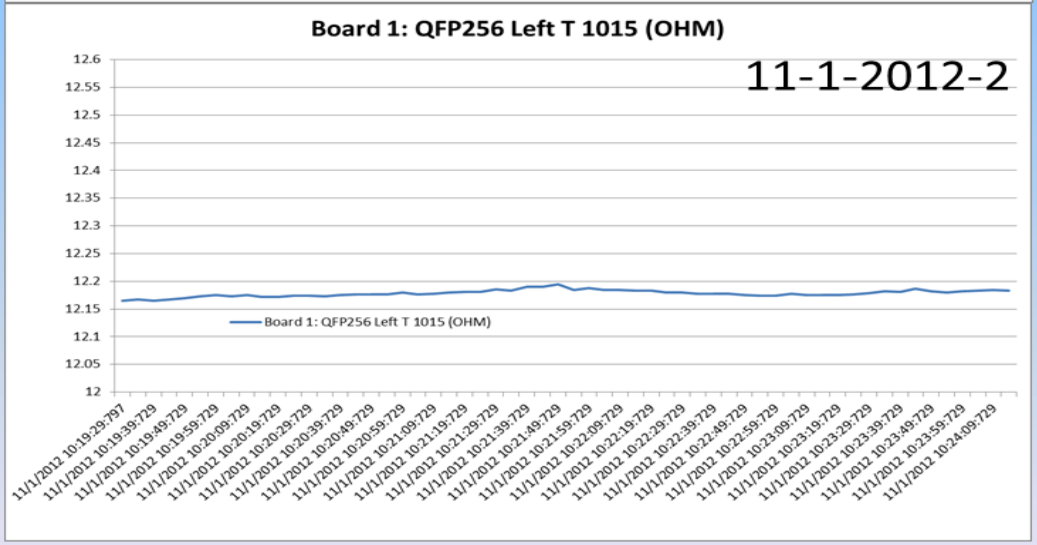
Time

Change is daisy chain resistance of QFP208, QFP100, QFP100, MLF68 as a result of combined stresses of thermal and dynamic loads on board #1.

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

Resistance, Ohms →



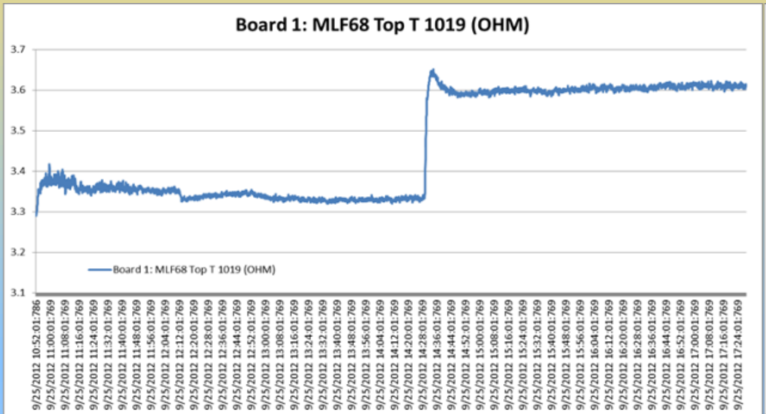


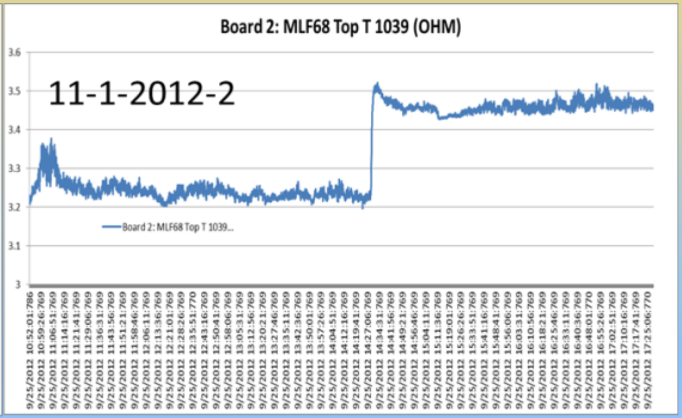
Time →

Daisy chain resistance of QFP256 on board#2 and QFP256 on board#1. Resistance fluctuations of QFP on board #2 are more over the similar QFP256 on board#1.

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

Resistance, Ohms


Board 1: MLF68 Top T 1019 (OHM)


Board 2: MLF68 Top T 1039 (OHM)

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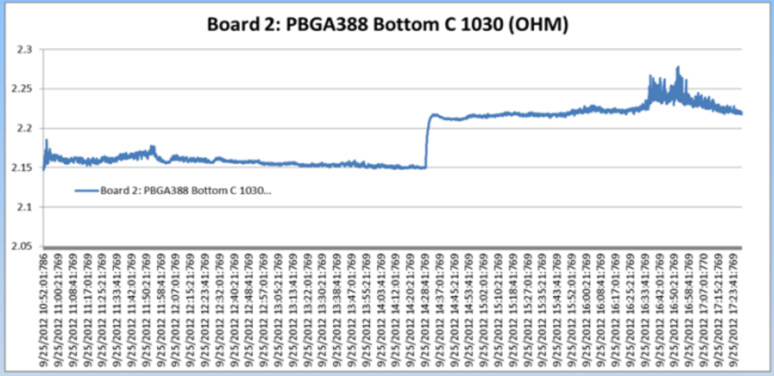
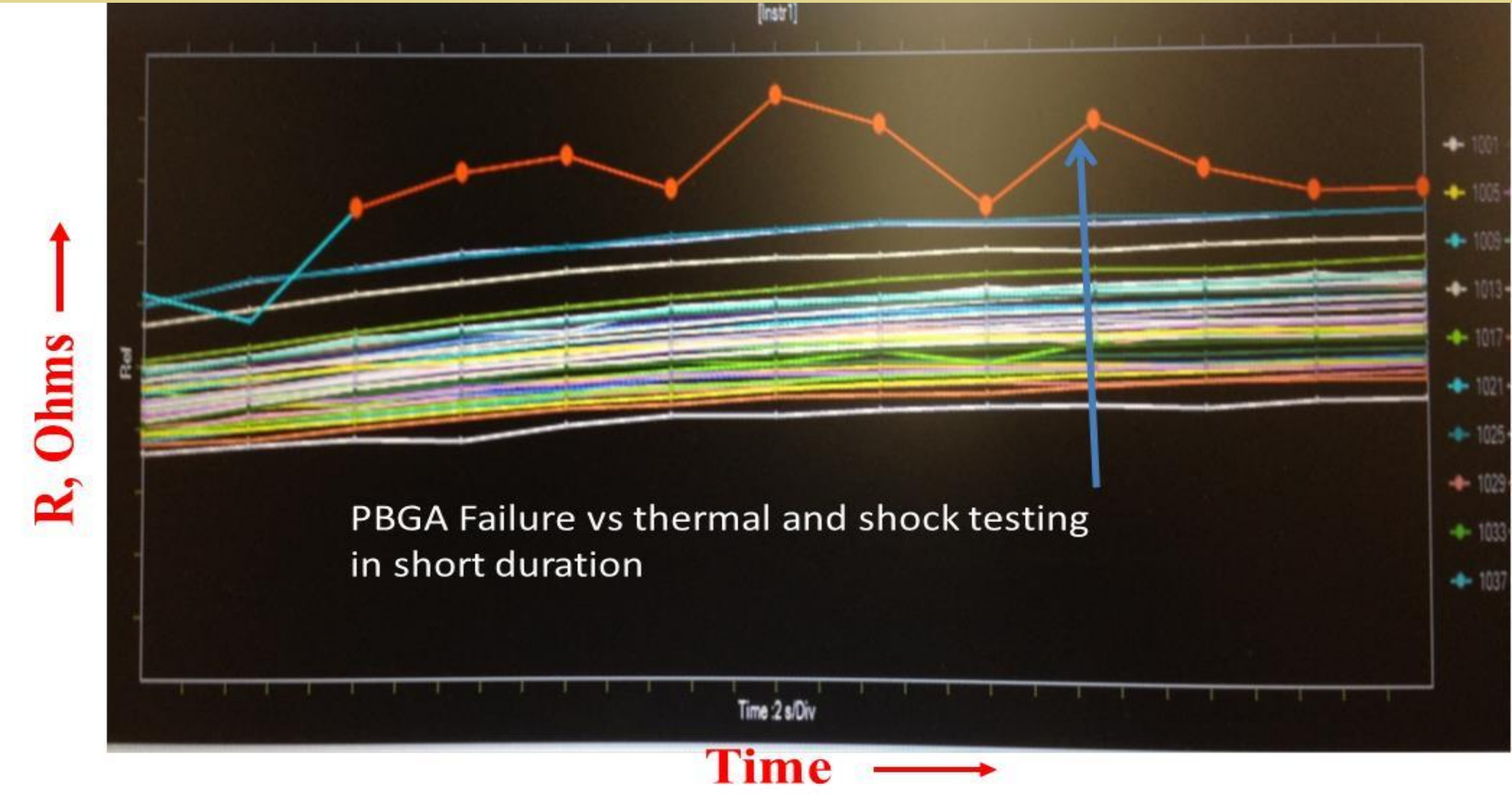

Board 2: PBGA388 Bottom C 1030 (OHM)

Time

Daisy chain resistance of MLF68 on board 1 and board 2.
Slight fluctuations or intermittent changes in a daisy chain resistance of MLF68 on board #2. Similarly PBGA388 on board#2.

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature



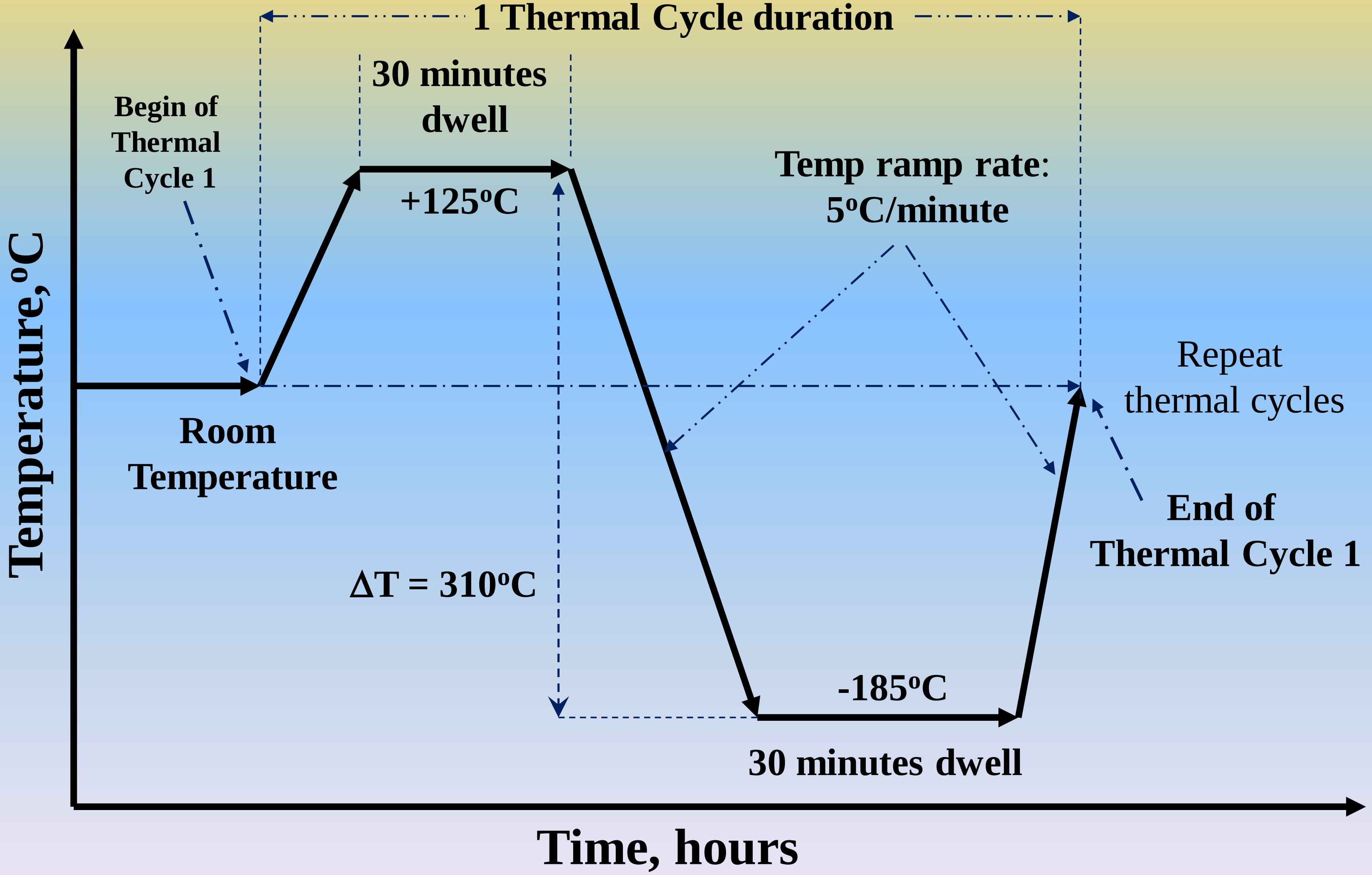
PBGA Failure vs thermal and shock testing in short duration

Captured a screen shot of daisy chain resistance of PBGA on board #1 channel 1009 during the test. The curve indicates the intermittent failure of daisy chain resistance of PBGA388

Test Results:
All the test data was normalized to worst case Delta T temperature and shock level.

Temperature, C	T2, min	T2, hours	G1, g	G2, g	T2, hours
50	10	0.16667	10	50	5.60326E-06
50	10	0.16667	15	50	7.50628E-05
50	10	0.16667	20	50	0.000473187
50	10	0.16667	30	50	0.006338942
50	10	0.16667	40	50	0.039959925
50	10	0.16667	50	50	0.166666667
75	10	0.16667	10	50	5.60326E-06
75	10	0.16667	15	50	7.50628E-05
75	10	0.16667	20	50	0.000473187
75	10	0.16667	30	50	0.006338942
75	10	0.16667	40	50	0.039959925
75	10	0.16667	50	50	0.166666667
100	10	0.16667	10	50	5.60326E-06
100	10	0.16667	15	50	7.50628E-05
100	10	0.16667	20	50	0.000473187
100	10	0.16667	30	50	0.006338942
100	10	0.16667	40	50	0.039959925
100	10	0.16667	50	50	0.166666667
125	10	0.16667	10	50	5.60326E-06
125	10	0.16667	15	50	7.50628E-05
125	10	0.16667	20	50	0.000473187
125	10	0.16667	30	50	0.006338942
125	10	0.16667	40	50	0.039959925
125	10	0.16667	50	50	0.166666667
0	10	0.16667	10	50	5.60326E-06
0	10	0.16667	15	50	7.50628E-05
0	10	0.16667	20	50	0.000473187
0	10	0.16667	30	50	0.006338942
0	10	0.16667	40	50	0.039959925
0	10	0.16667	50	50	0.166666667
-25	10	0.16667	10	50	5.60326E-06
-25	10	0.16667	15	50	7.50628E-05
-25	10	0.16667	20	50	0.000473187
-25	10	0.16667	30	50	0.006338942
-25	10	0.16667	40	50	0.039959925
-25	10	0.16667	50	50	0.166666667
-50	10	0.16667	10	50	5.60326E-06
-50	10	0.16667	15	50	7.50628E-05
-50	10	0.16667	20	50	0.000473187
-50	10	0.16667	30	50	0.006338942
-50	10	0.16667	40	50	0.039959925
-50	10	0.16667	50	50	0.166666667
-75	10	0.16667	10	50	5.60326E-06
-75	10	0.16667	15	50	7.50628E-05
-75	10	0.16667	20	50	0.000473187
-75	10	0.16667	30	50	0.006338942
-75	10	0.16667	40	50	0.039959925
-75	10	0.16667	50	50	0.166666667
-100	10	0.16667	10	50	5.60326E-06
-100	10	0.16667	15	50	7.50628E-05
-100	10	0.16667	20	50	0.000473187
-100	10	0.16667	30	50	0.006338942
-100	10	0.16667	40	50	0.039959925
-100	10	0.16667	50	50	0.166666667
-125	10	0.16667	10	50	5.60326E-06
-125	10	0.16667	15	50	7.50628E-05
-125	10	0.16667	20	50	0.000473187
-125	10	0.16667	30	50	0.006338942
-125	10	0.16667	40	50	0.039959925
-125	10	0.16667	50	50	0.166666667
25	60	1	50	50	1
75	60	1	10	50	3.36196E-05
75	60	1	30	50	0.03803365
75	60	1	50	50	1
125	60	1	10	50	3.36196E-05
125	60	1	30	50	0.03803365
125	60	1	50	50	1
25	60	1	10	50	3.36196E-05
25	60	1	30	50	0.03803365
25	60	1	50	50	1
75	60	1	10	50	3.36196E-05
75	60	1	30	50	0.03803365
75	60	1	50	50	1
125	60	1	10	50	3.36196E-05
125	60	1	30	50	0.03803365
125	60	1	50	50	1
20	60	1	10	50	3.36196E-05
20	60	1	30	50	0.03803365
20	60	1	50	50	1
-50	60	1	10	50	3.36196E-05
-50	60	1	30	50	0.03803365
-50	60	1	50	50	1
-100	60	1	10	50	3.36196E-05
-100	60	1	30	50	0.03803365
-100	60	1	50	50	1
-150	60	1	10	50	3.36196E-05
-150	60	1	30	50	0.03803365
-150	60	1	50	50	1
					12.47779929

Extreme Temperature Thermal Cycling Profile



1 Thermal Cycle duration

30 minutes dwell

Begin of Thermal Cycle 1

+125°C

Temp ramp rate: 5°C/minute

Repeat thermal cycles

Room Temperature

End of Thermal Cycle 1

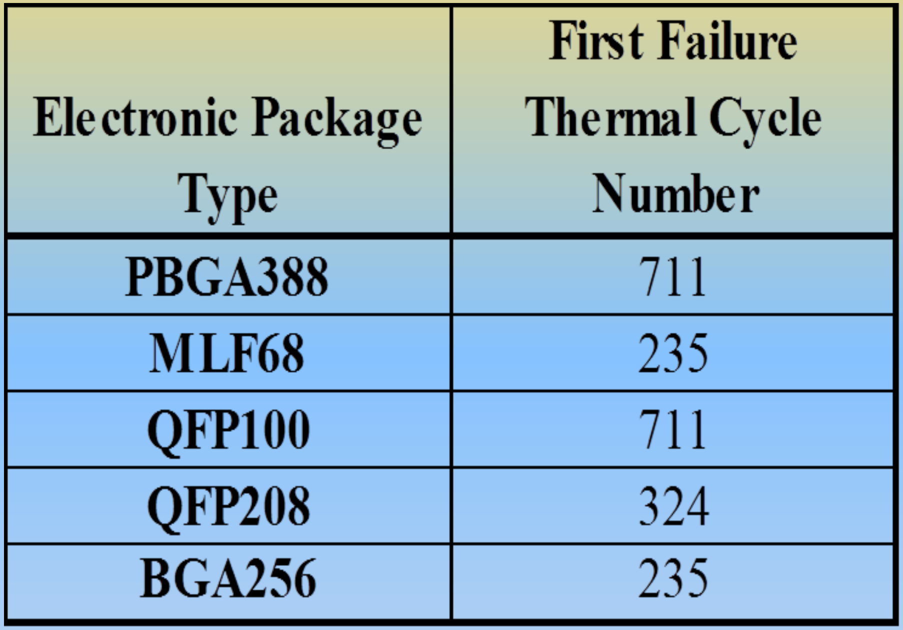
ΔT = 310°C

-185°C

30 minutes dwell

Temperature, °C

Time, hours



Electronic Package Type	First Failure Thermal Cycle Number
PBGA388	711
MLF68	235
QFP100	711
QFP208	324
BGA256	235

Failure of advanced electronic packages vs. number of thermal cycles from -185°C to +125°C

Summary-1

- Studied a *proof of concept* of HALT technique to assess fatigue reliability of electronic packaging designs:
  - ✓ temperature range: –150°C to +125°C
  - ✓ acceleration range of up to 50g.
- The test boards were subjected to various g levels, dwell durations, and the hot and cold temperature levels. Advanced electronic packages have shown signs of continuity problems.
  - ✓ plastic ball grid array (PBGA)
  - ✓ ball grid array (BGA)
  - ✓ micro-lead-frame (MLF)
  - ✓ quad flat-pack (QFP)
- In this very preliminary study, PBGA package was completely open where as other package designs have shown signs of continuity variations.

Summary-2

- The failure of the PBGA occurred within 12 hours of the start of accelerated testing using dynamic and thermal loads.
- The PBGA package failed during the independent thermal cycling test:
  - ✓ -185°C to +125°C after 711 thermal cycles (test data)
    - 959 cycles of -150°C to +125°C, extrapolated from the test data where m=2.5)
  - ✓ Each thermal cycle requires 2.33 hours and a total test time to fail PBGA was 2,237 hours (or ~3.1 months) due to thermal cycling fatigue alone.
- HALT technique required only 12 hours to fail
  - ✓ indicates that there is an acceleration factor of ~186 times (more than 2 orders of magnitude) to fail the same PBGA component.
- ✓ We do not know the failure mechanism of PBGA failures yet in HALT technique and is yet to be determined. Relationship between failure mechanism and HALT test parameters will be addressed in the future efforts. DPA and X-ray imaging techniques and others will be employed to understand the failure mechanisms.
- ✓ One can determine in this preliminary study that the life of the PBGA component in less than 12 hours of testing using HALT instead of testing for 3.1 months in thermal cycling alone.

Acknowledgements

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- NEPP program is highly appreciated for supporting me to work on HALT task. MSL Project has generated the interest in me in obtaining the experimental data for SMT packages in a short duration for present and future JPL/NASA projects.
- This paper was presented at the SPIE Reliability conference in Feb 2014.
- Thanks are due to
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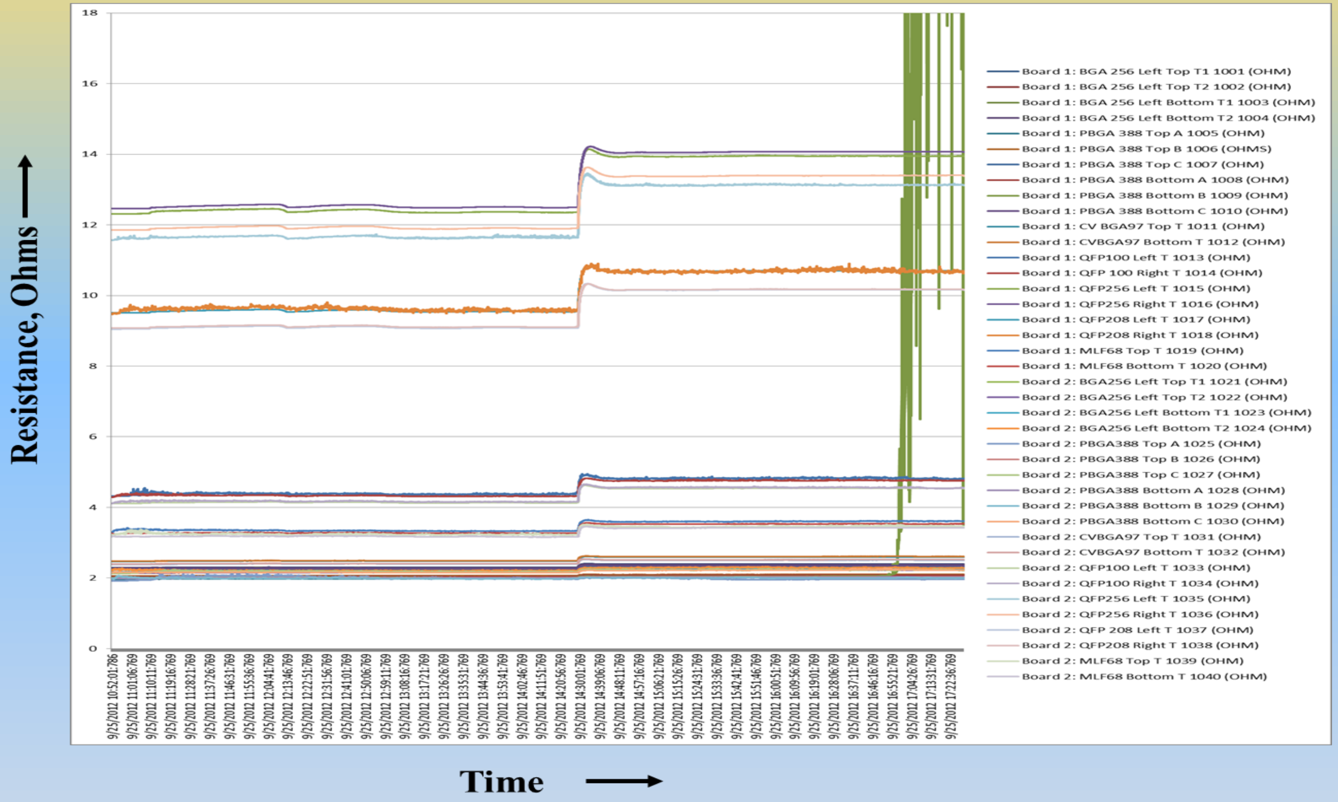
  - John Forgrave and Mark Boyles for their comments/suggestions on the presentation.

Back-up slides

Why do we need? NASA

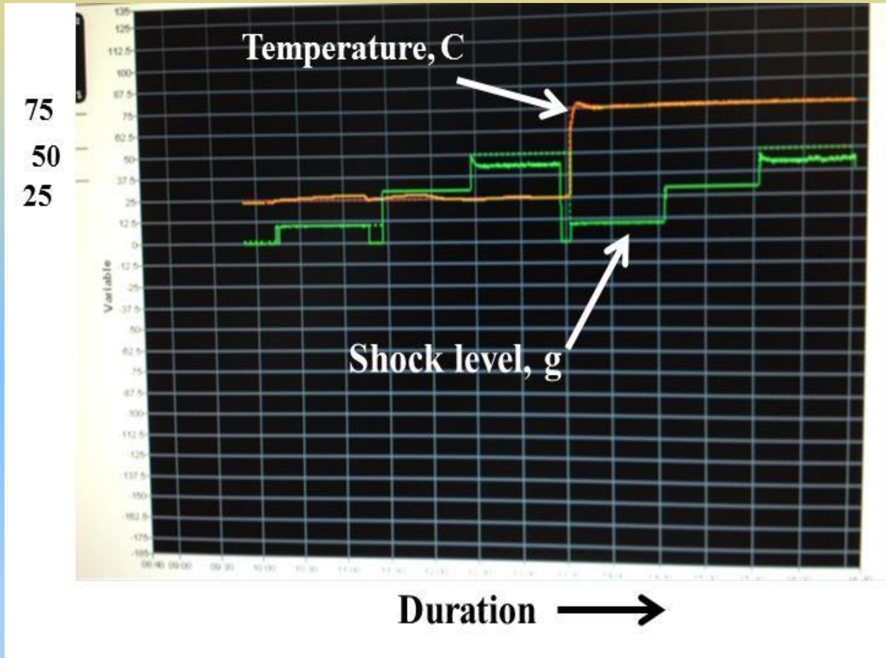
- ✓ Titan (-180ºC, for a proposed Titan *in-situ* mission)
- ✓ Europa (-160ºC, for a proposed Europa surface and subsurface mission)
- ✓ Asteroids (-185ºC, MUSES-CN project)
- ✓ Comets (-140ºC, for a proposed comet nucleus sample return)
- ✓ Earth’s moon (recorded temperature on the moon: -233ºC to +123ºC, moon mineralogy and mapper, M^3)
- ✓ Mars Exploration Rover, MER (-120ºC to +85ºC)
- ✓ MSL (-135ºC to +85ºC) large diurnal temperature change/swing from day to night.
- ✓ Planetary protection requires the hardware to be baked at +125ºC for 72hrs to kill microorganisms to avoid any biological contamination, especially for sample return missions.
- ✓ NASA standard thermal cycling temperature range varies from -55ºC to +100ºC for 200 thermal cycles
- ✓ **HALT system capability is -160ºC to +200ºC**
- ✓ **The present HALT package reliability research study has encompassed the temperature range of -150ºC to +125ºC which cover only some potential future NASA space missions.**

Test Results: Resistance of various daisy chains vs. time at a given dynamic load of g and temperature

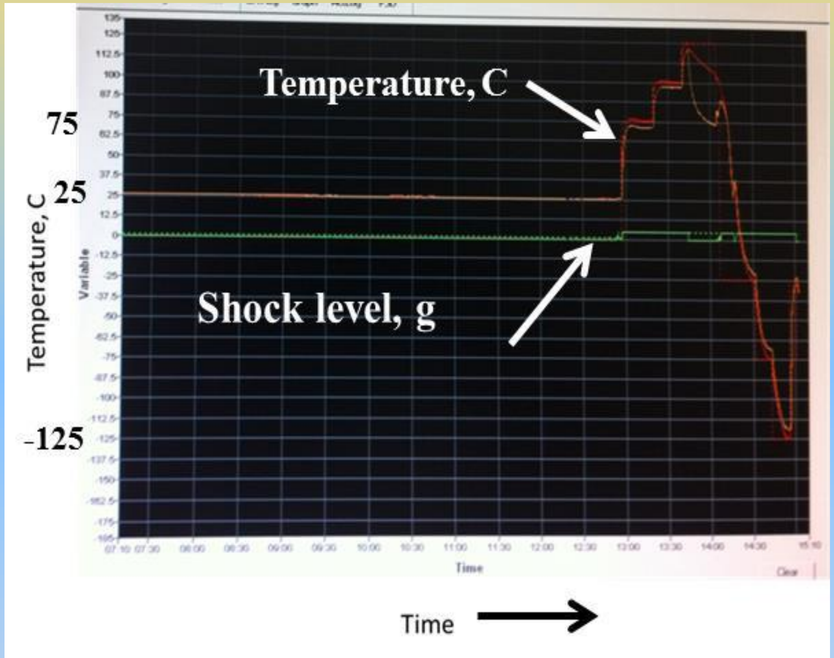


Resistance of various daisy chains vs., time at a given dynamic load of g particularly the daisy-chain resistance anomalous behavior of BPGA Package

Experimental Details-3

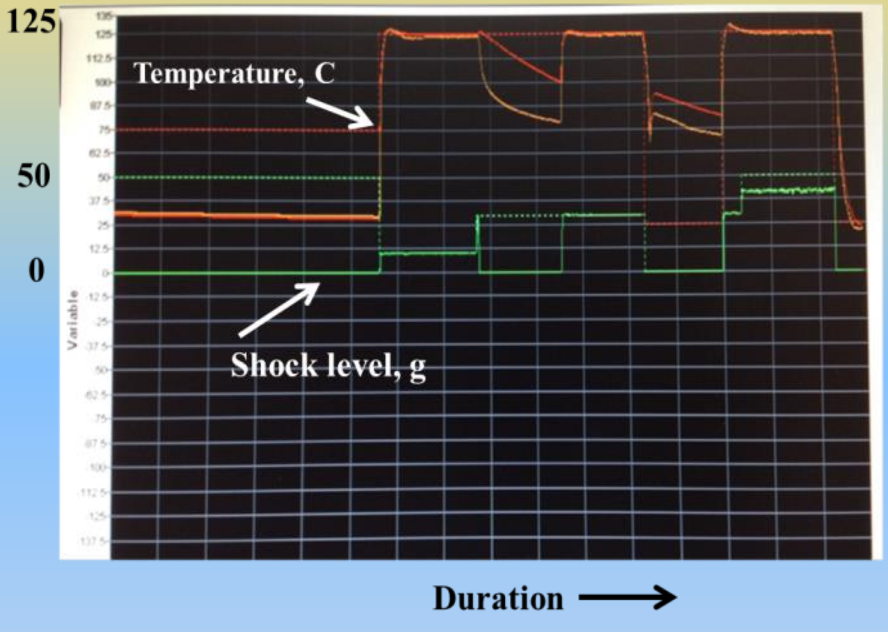


Temperature (25ºC and 75ºC) and g level (10g, 30g, an 40g) vs. test duration of 0.5 hour

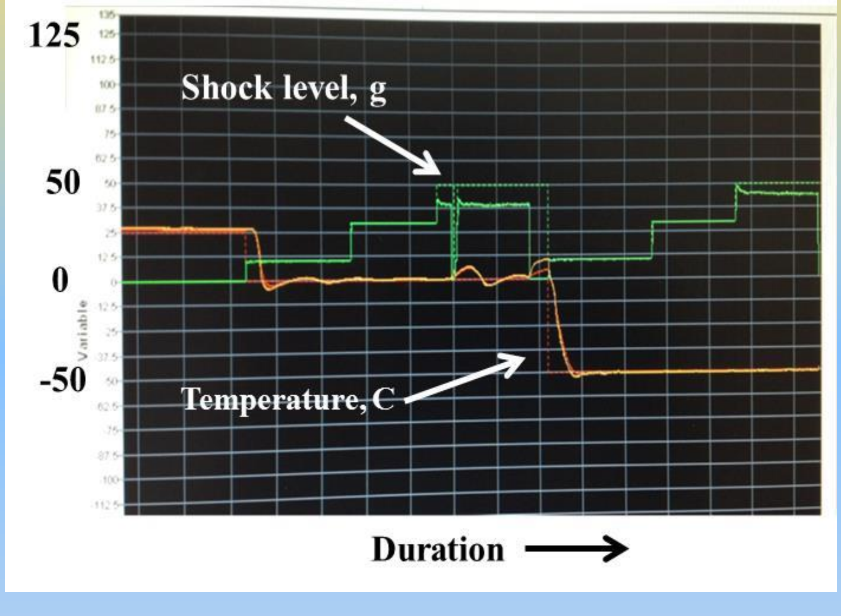


Temperature (75ºC, 100ºC, 125 ºC) and g level (10g, 30g, an 40g) vs. test duration of 10 minutes

Experimental Details-1

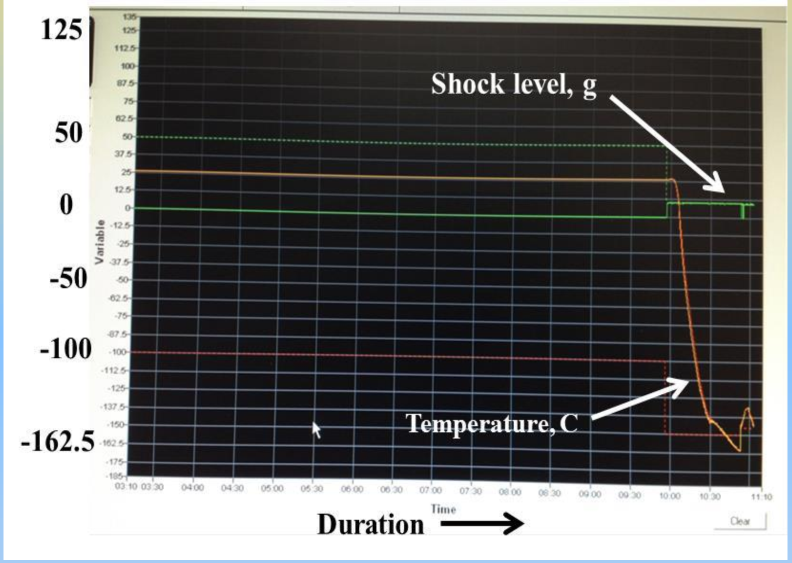


Temperature (125°C), g level (~10g, 30, 40g) vs. test duration of 1 hour

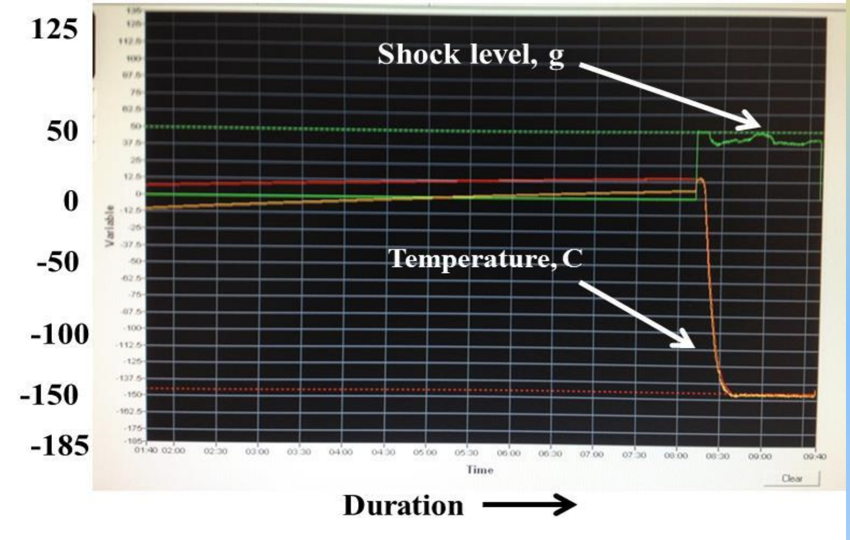


Temperature (0°C, 50°C), g level (~10g, 30, 40g) vs. test duration of 1 hour

Experimental Details-2



Temperature (-150^{o}C), g level (~10g) vs. test duration of 1 hour



Temperature (-150^{o}C), g level (~40g) vs. test duration of 1 hour

Estimating dynamic/thermal load fatigue

$$N_1\,(G_1)^{\text{b-dynamic}} = N_2\,(G_2)^{\text{b-dynamic}}$$

$$N_1\,(\Delta T_1)^{\text{b-thermal}} = N_2\,(\Delta T_2)^{\text{b-thermal}}$$

Estimating dynamic and thermal load fatigue (assume the stresses are linear in nature)

$$N_1\,[(G_1)^{\text{b-dynamic}} + (\Delta T_1)^{\text{b-thermal}}] = N_2\,[(G_2)^{\text{b-dynamic}} + (\Delta T_2)^{\text{b-thermal}}$$

$$T_1\,(G_1)^b = T_2\,(G_2)^b$$

T: Test Time, N: Number of stress cycles,
b: fatigue exponent (thermal: 2.5; vibration: 4) for 63/37 Pb/Sn solder