Vibration and Mechanical Shock Testing

Thomas Woodrow

Executive Summary

Little data has been generated on the performance of lead-free solders under vibration and mechanical shock. What data exists suggests that lead-free solders may be less reliable than eutectic SnPb solder when used on area array components (e.g., BGA's). This presentation is designed to educate the audience on how vibration and mechanical shock tests are typically conducted and on how to interpret test results. Test data from the literature and from several lead-free consortia will also be presented.

Vibration and Mechanical Shock Testing

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Boeing Research & Technology

IPC Midwest Conference
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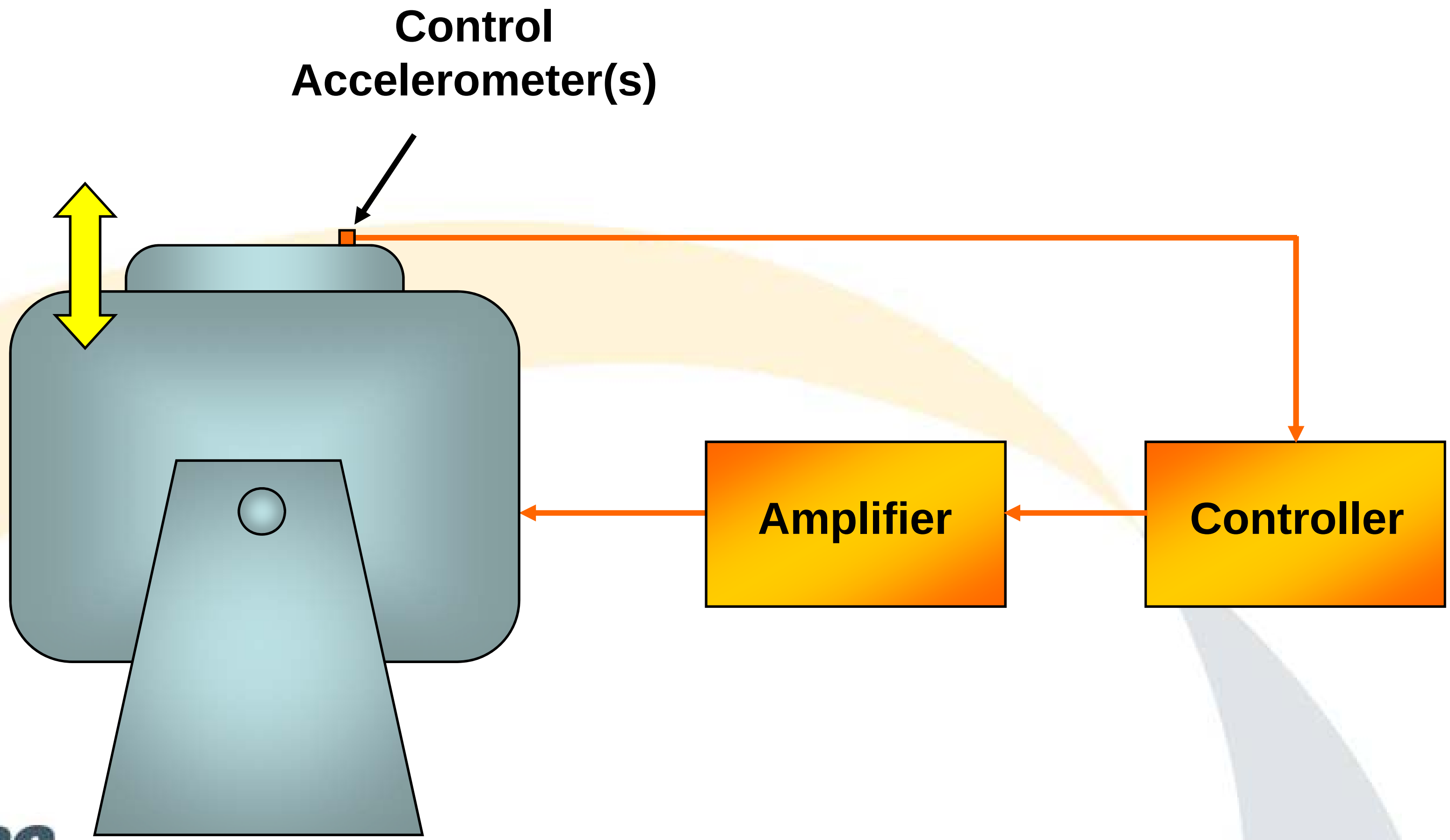
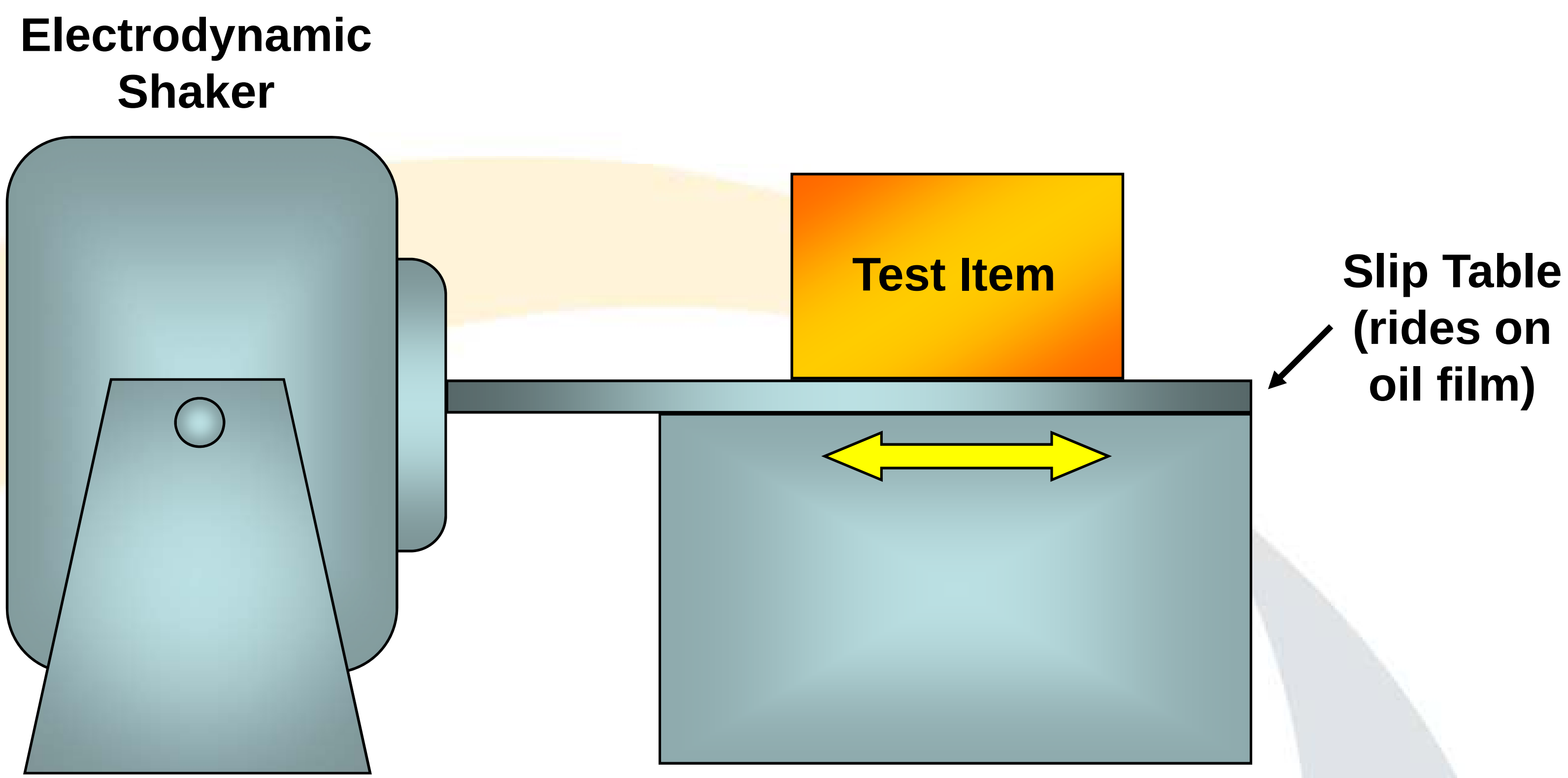
Vibration

Electrodynamic Shaker

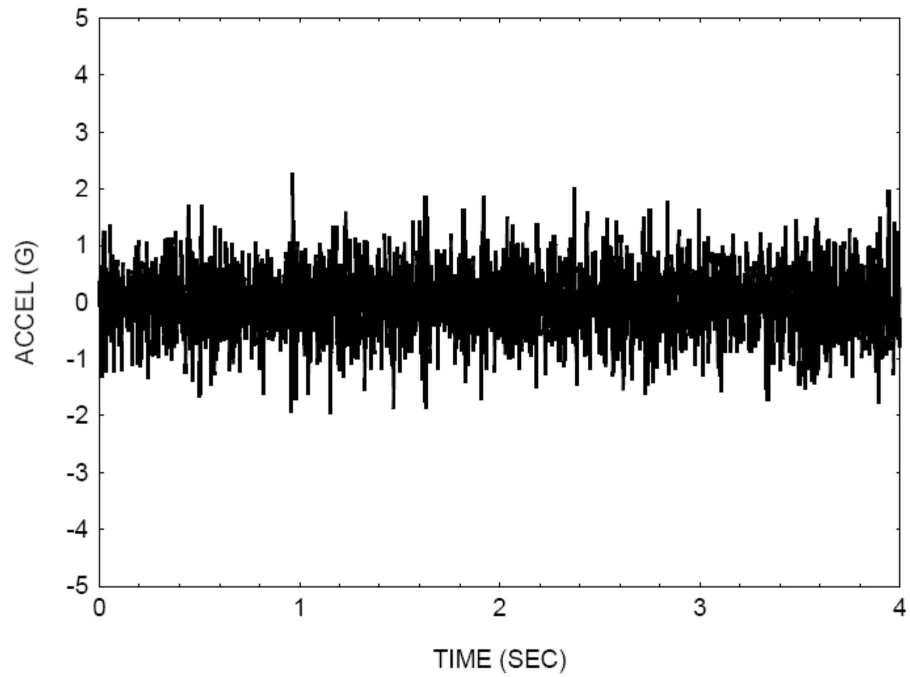


Shaker with Slip Table Attached

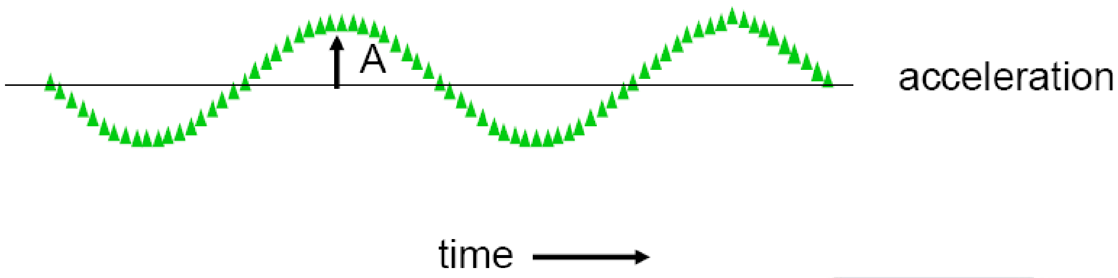


Input At A Given Frequency

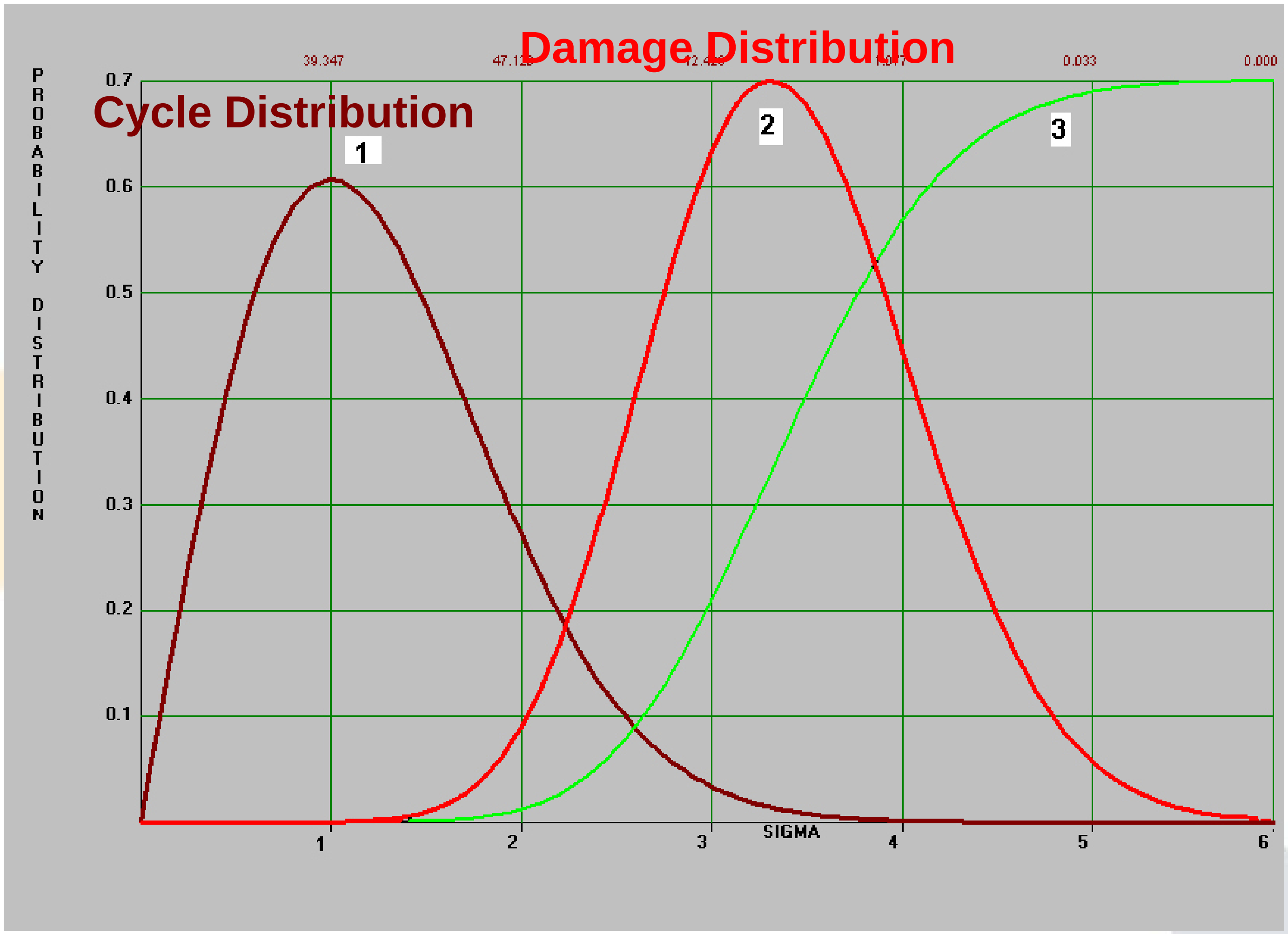
Random Vibration



Sinusoidal Vibration



In Random Vibration, Most of the Damage is Caused by a Few Percent of the Cycles



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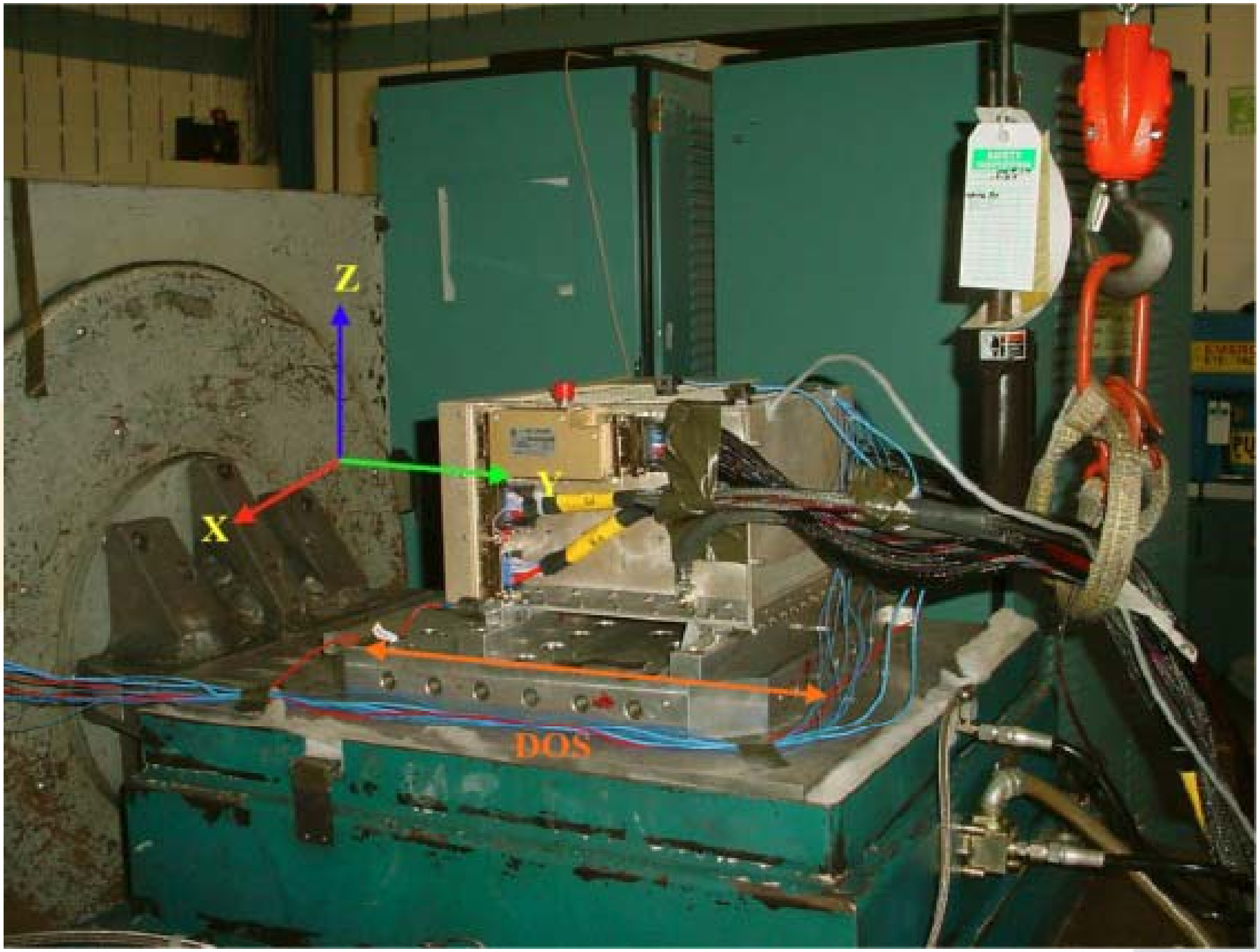
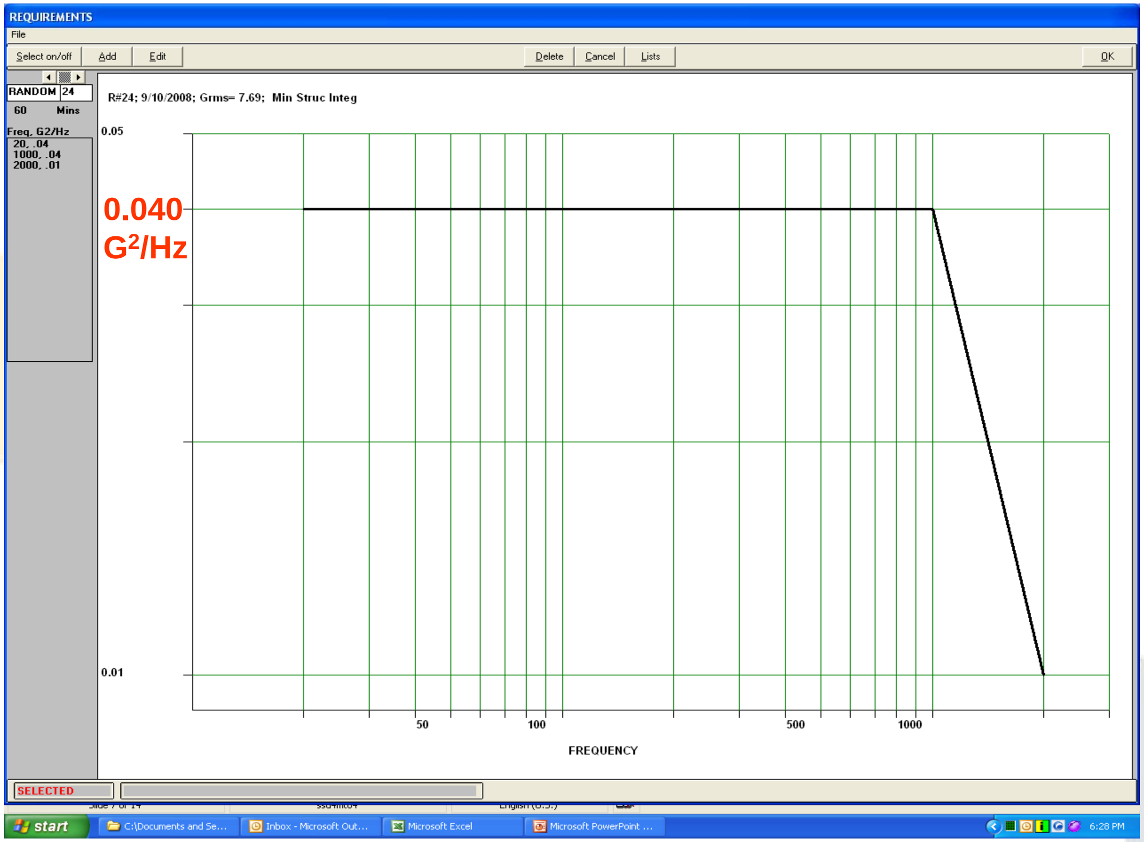
Source: CirVibe, Inc.

Typical Test Setup for LRU Vibration Qual Test

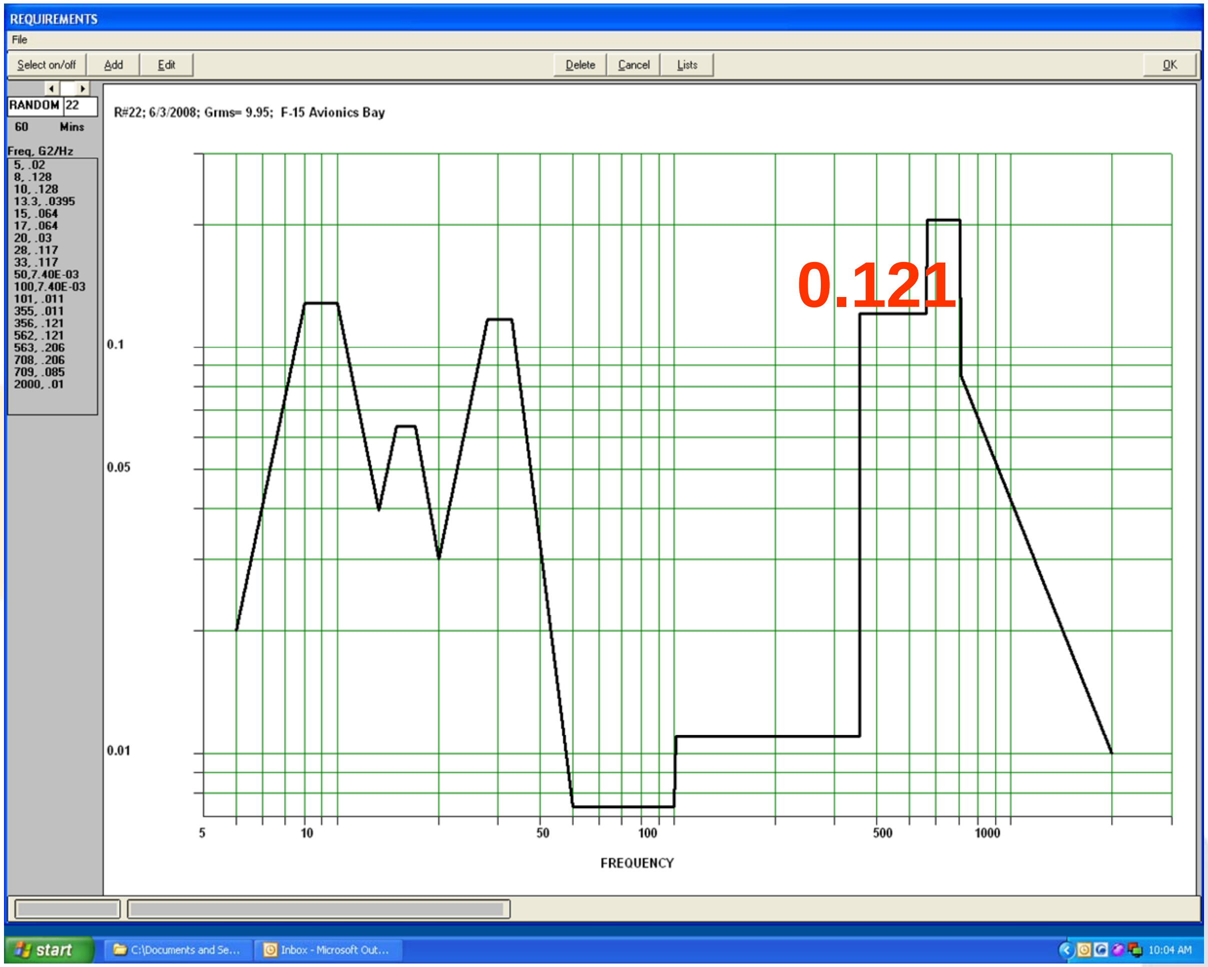


Minimum Structural Integrity Test for Fighter Aircraft x



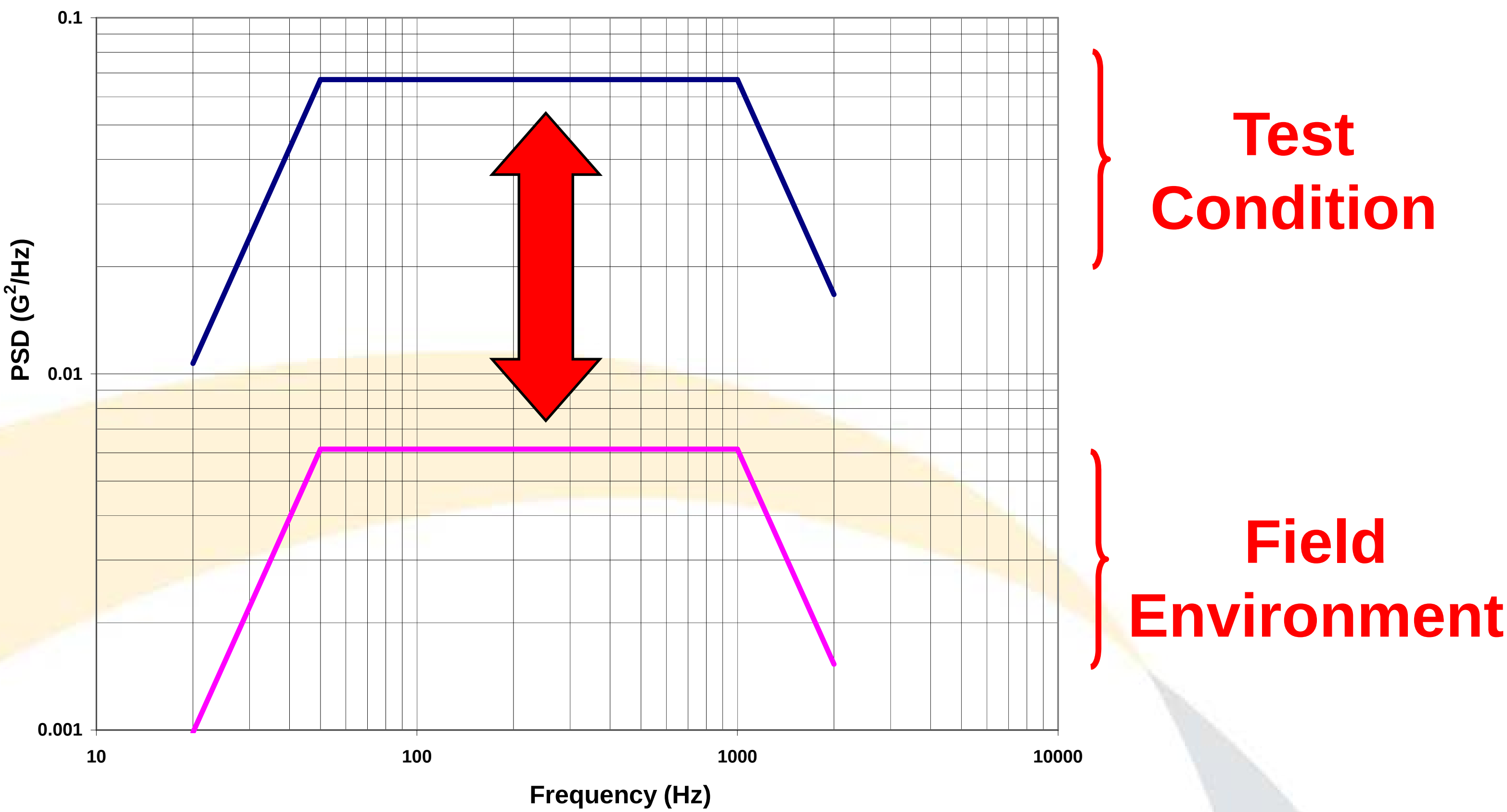
7.7 Grms for 1 Hour

Endurance Test for Fighter Aircraft x



10.0 Grms for 2 Hours

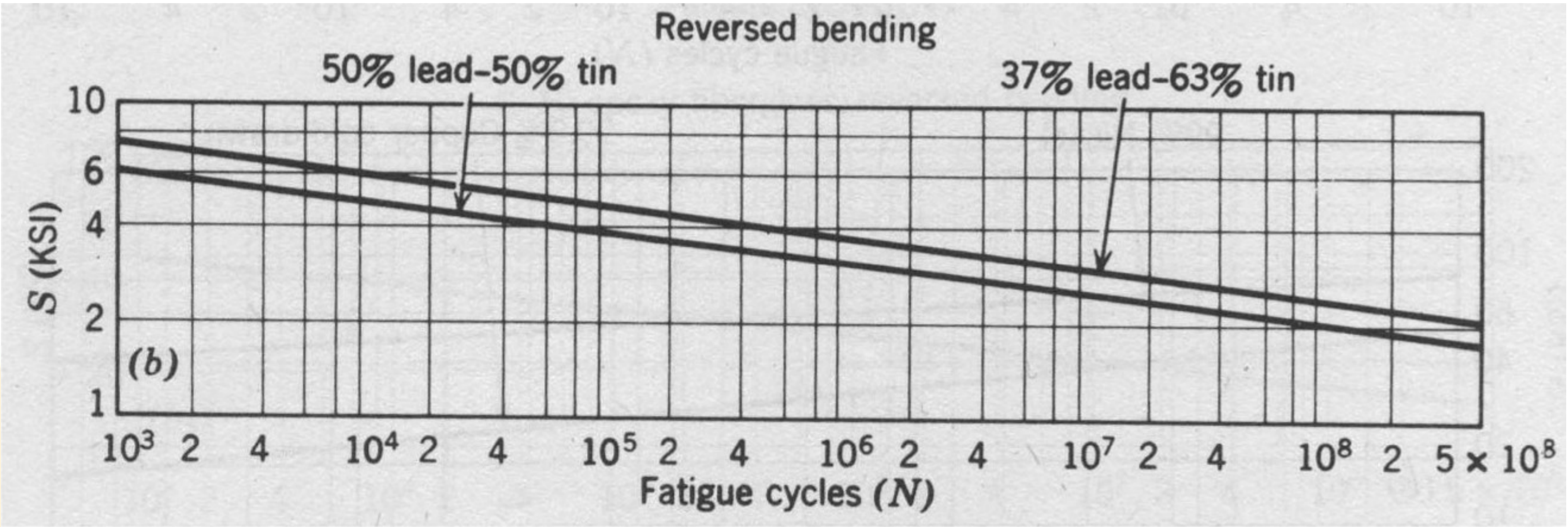
Design of a Qual Test Based on a Desired Field Life



$$\text{Test Duration} = \frac{(\text{Grms in the Field})^{b}}{(\text{Grms in Test})^{b}} \bullet \text{Field Life}$$

$$\text{Test Duration} = \frac{\left(\text{G}^2\text{/Hz in the Field}\right)^{0.5b}}{\left(\text{G}^2\text{/Hz in Test}\right)^{0.5b}} \bullet \text{Field Life}$$

Must have the Solder S-N Plot (Slope = -1/b)



Source: Steinberg, Dave S., *Vibration Analysis for Electronic Equipment*, 2nd Edition, John Wiley & Sons, Inc., 1988.

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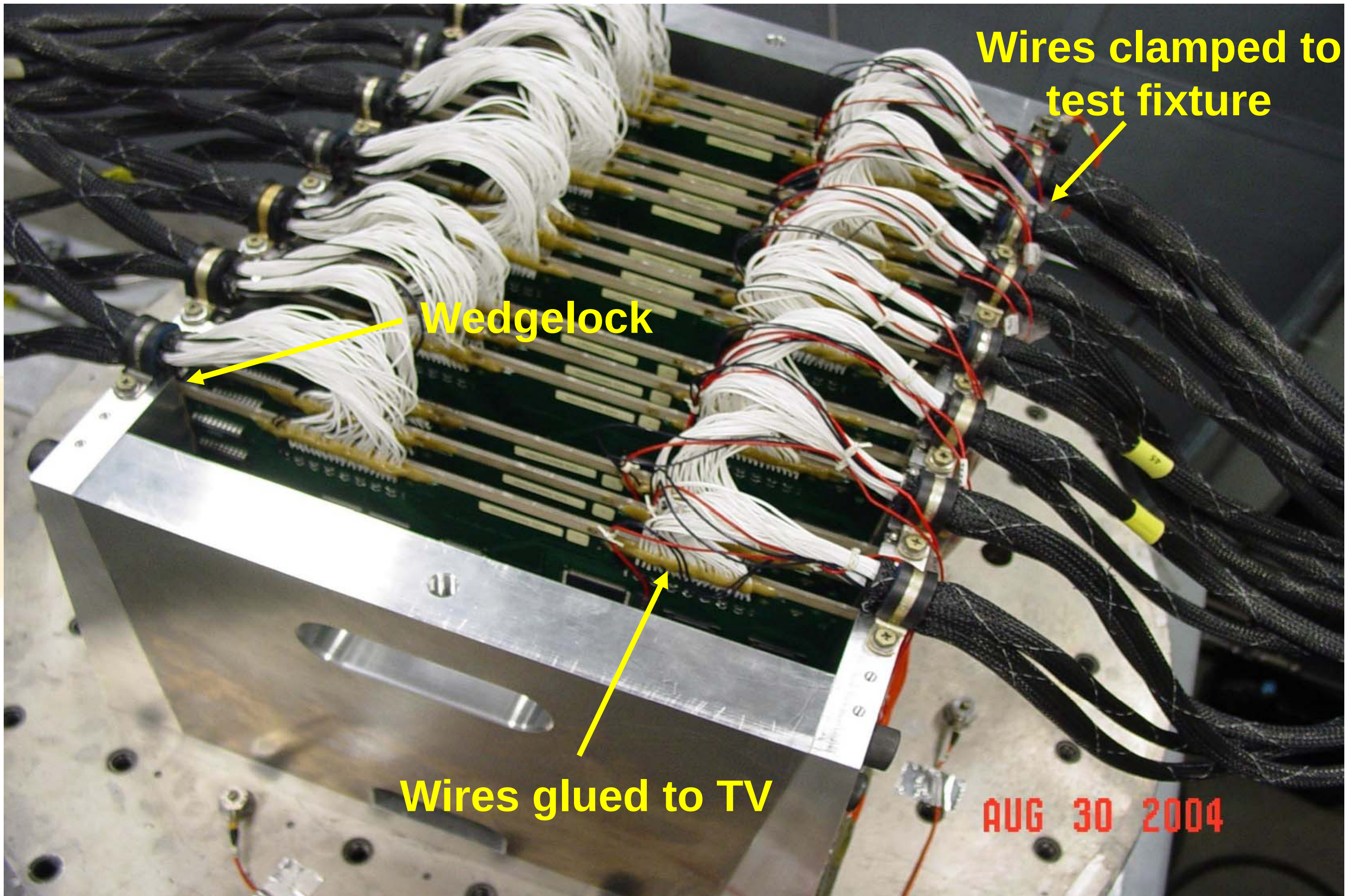
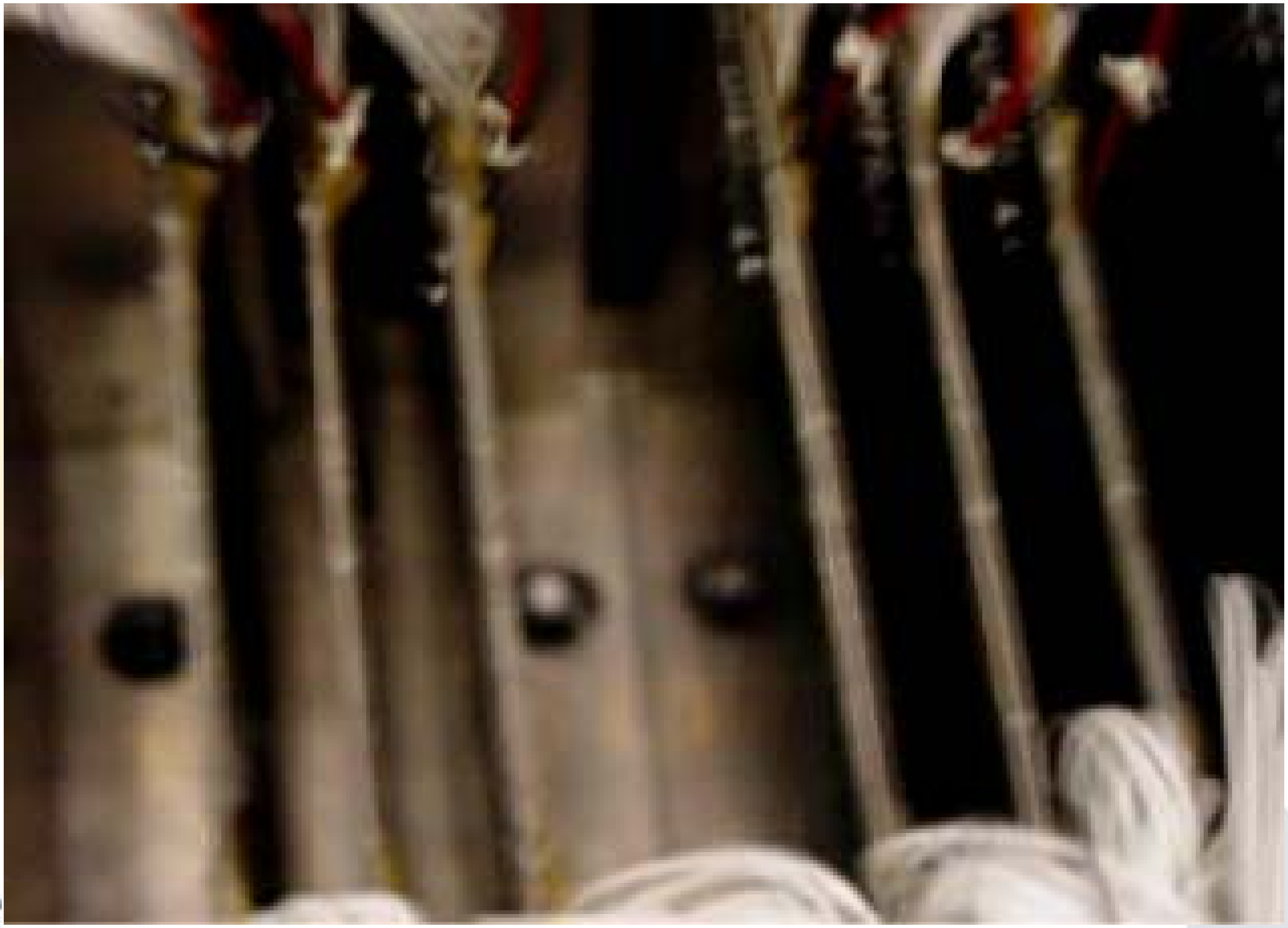
JCAA/JG-PP Lead-Free Vibration Test

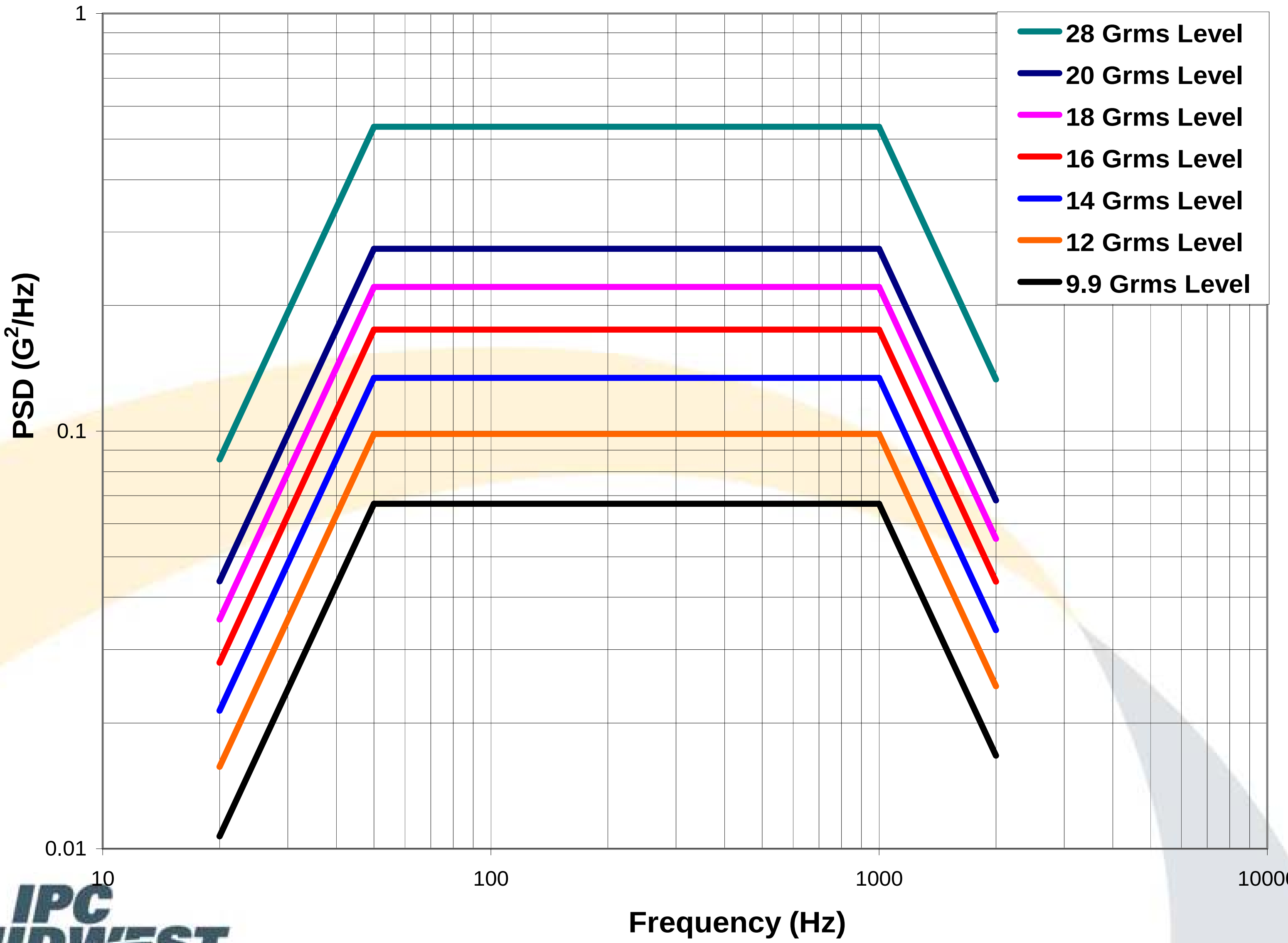
JG-PP Test Vehicles in Fixture



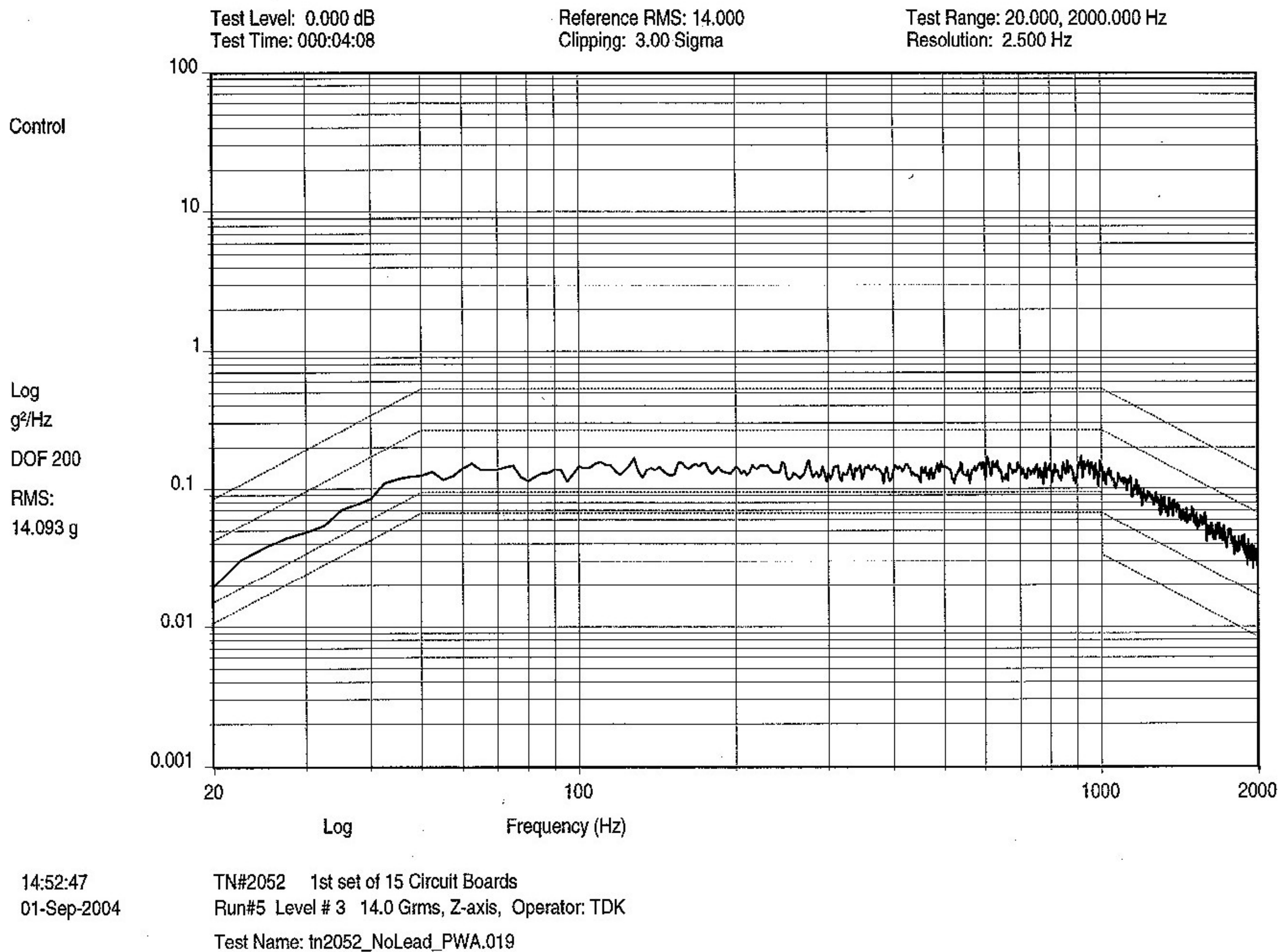
JG-PP Test Vehicles in Vibration Fixture (20 Grms Test Level – Random Vibration)



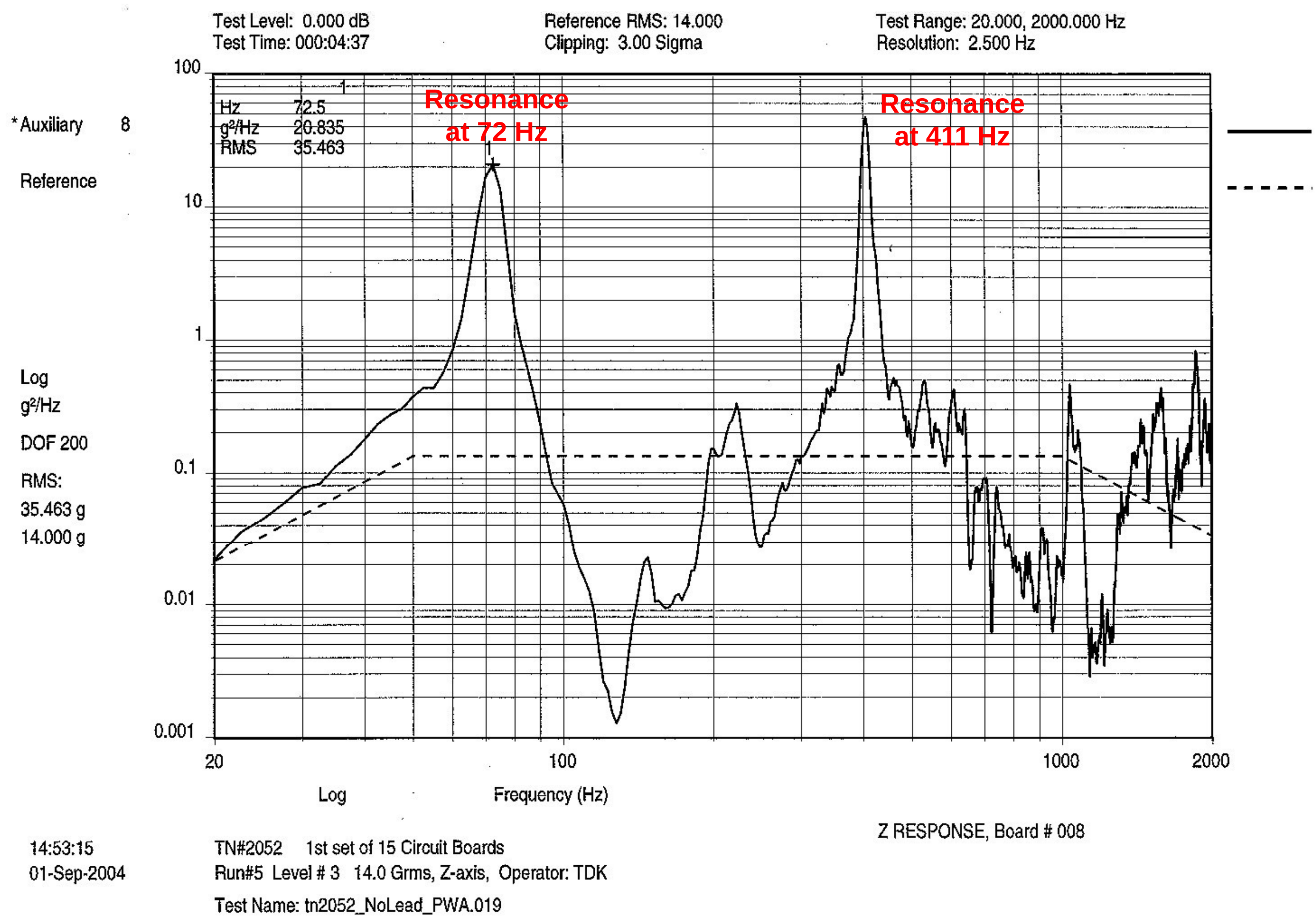
JG-PP Vibration Test Stress Step Levels



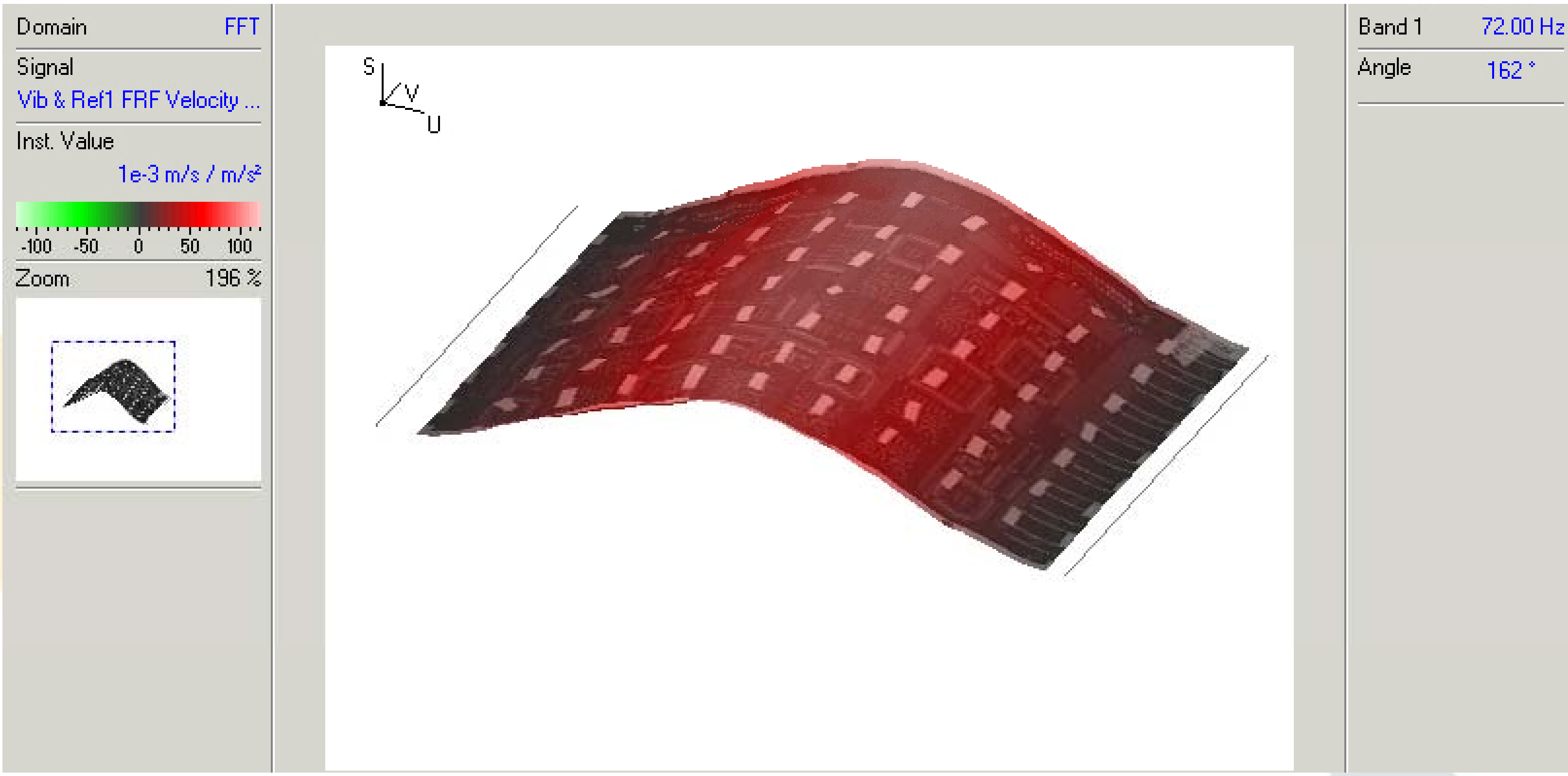
Input (14.0 Grms, Z-axis)



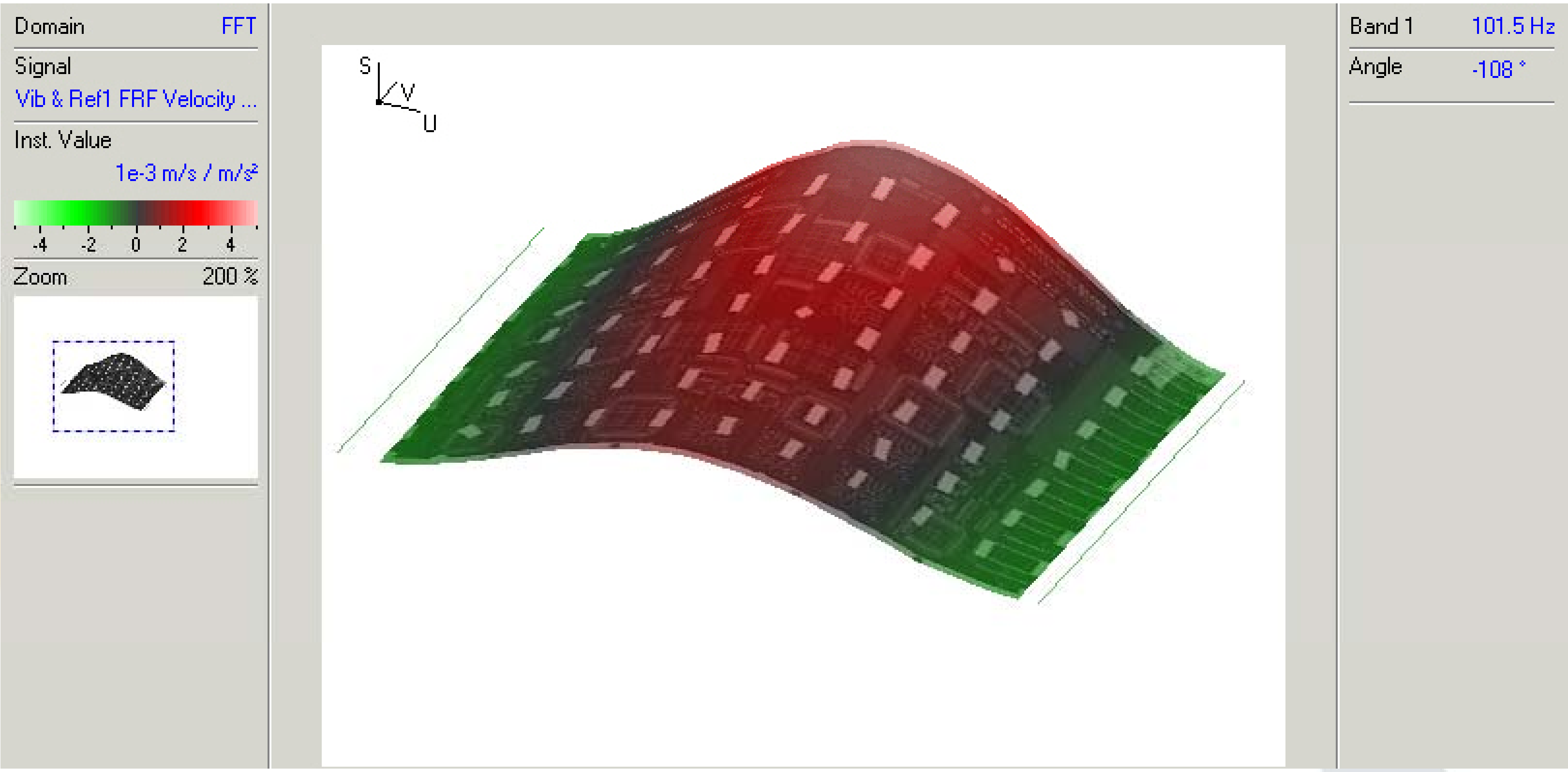
Test Vehicle Response (14.0 Grms, Z-axis)



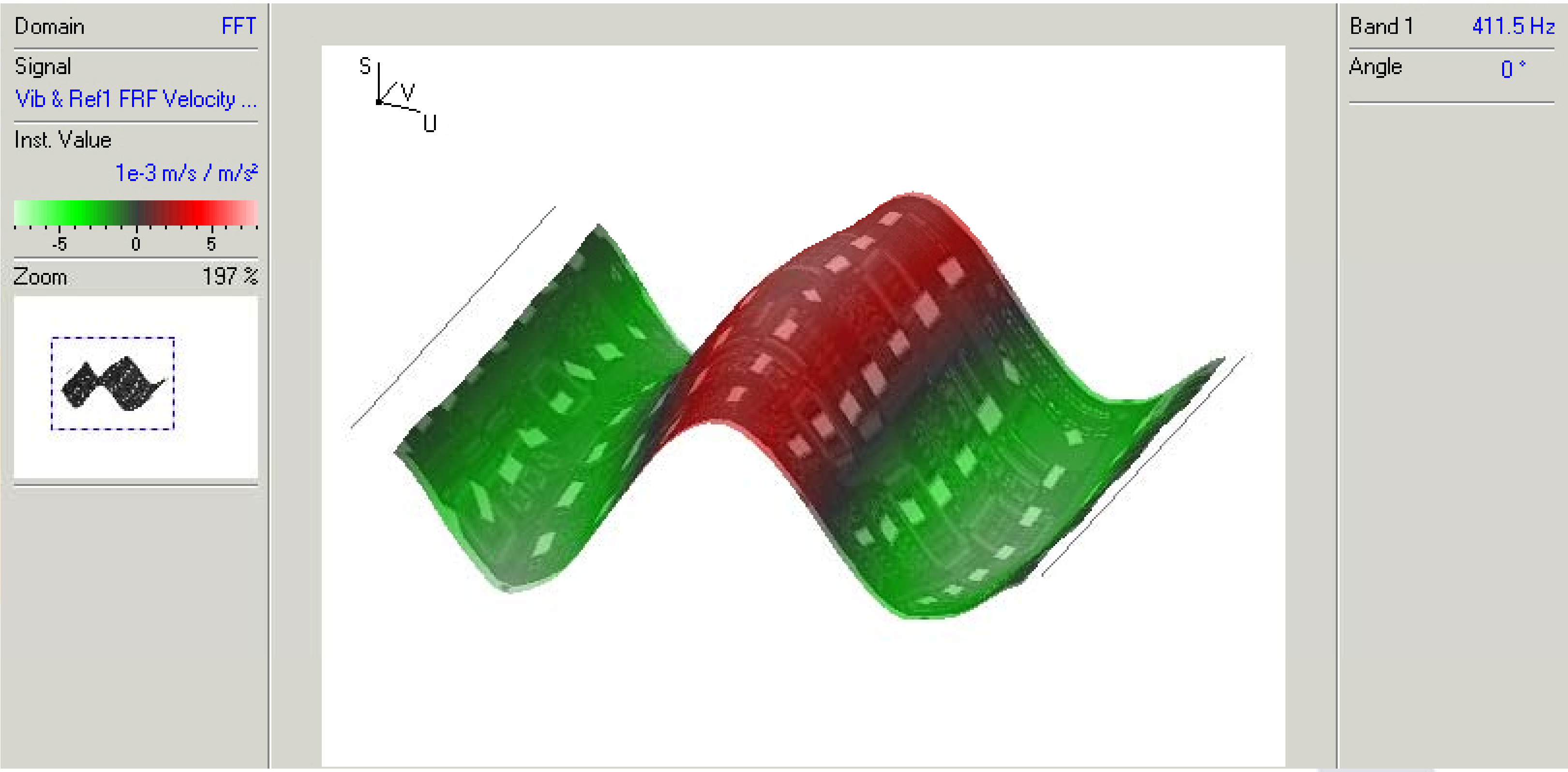
Vibration Test
First Mode (72 Hz)



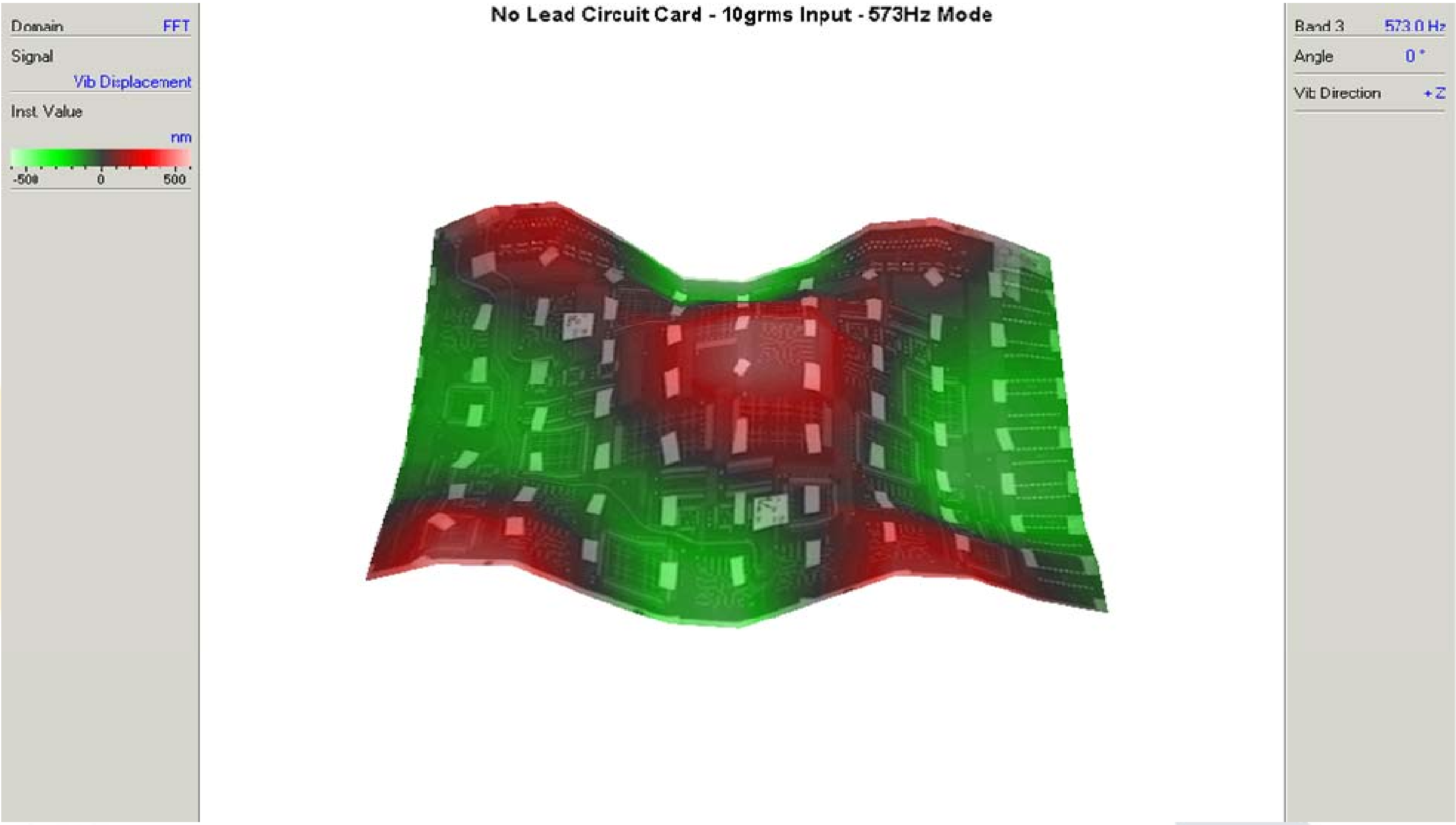
Vibration Test
Second Mode (101 Hz)



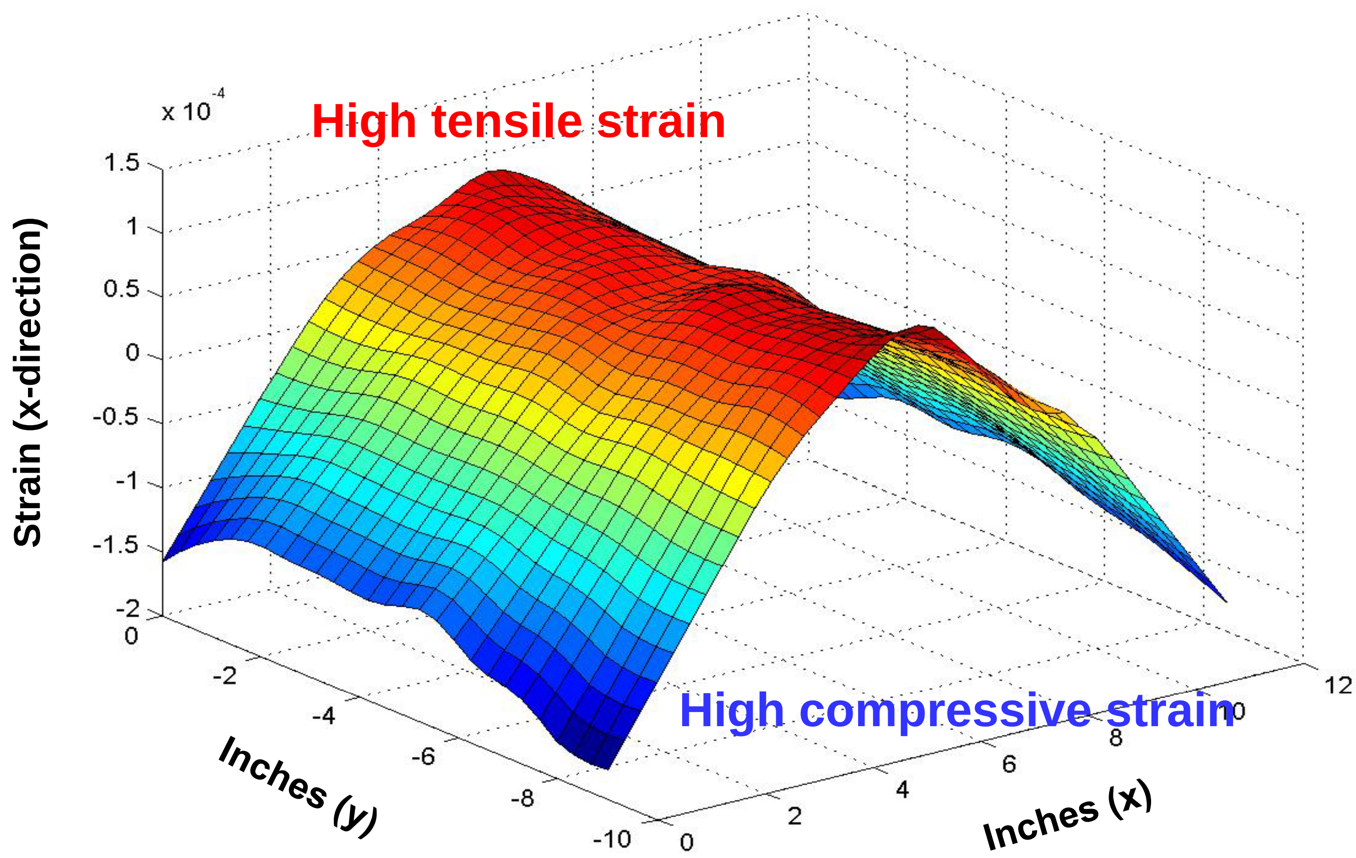
Vibration Test
Seventh Mode (411 Hz)



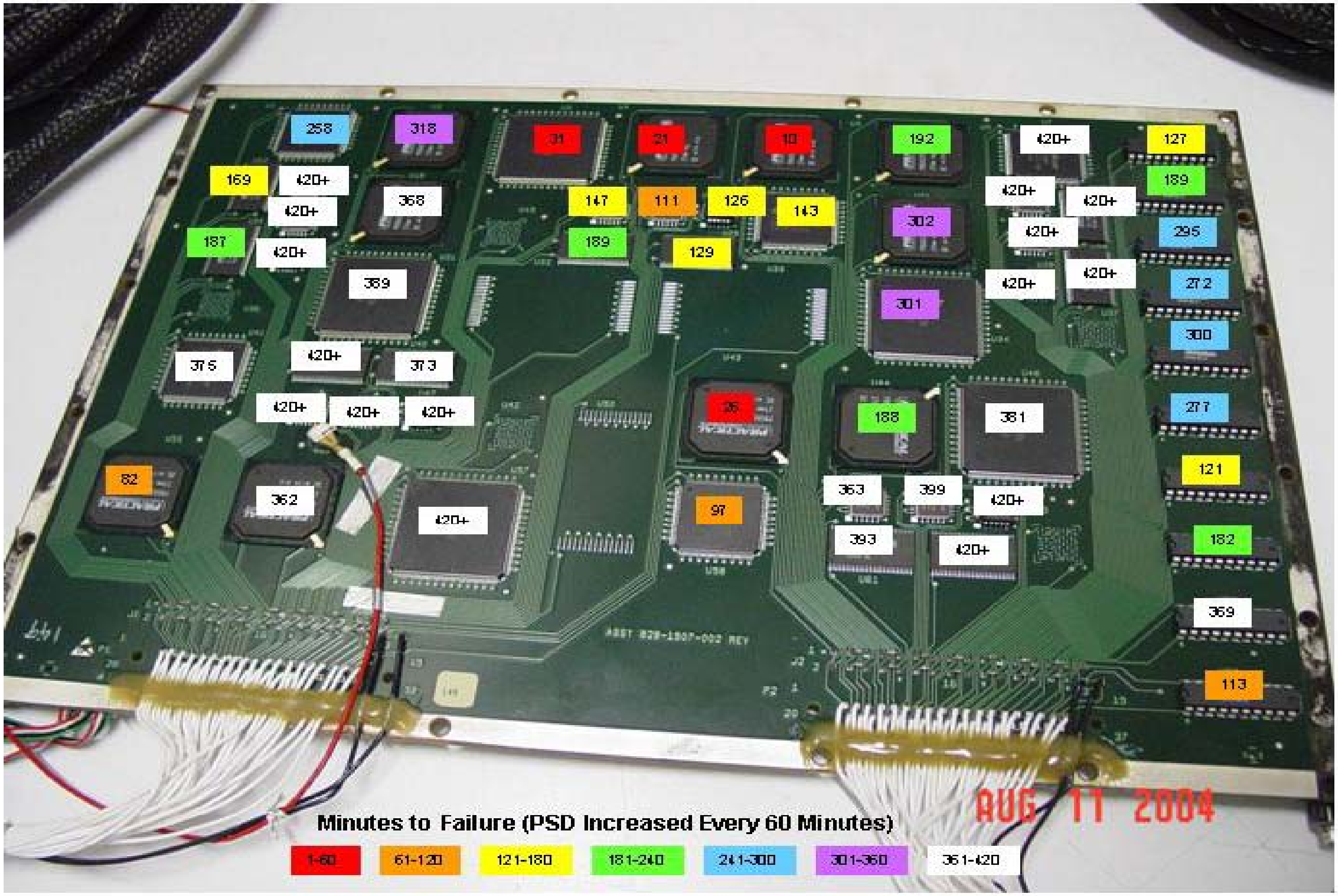
Vibration Test
Mode (573 Hz)

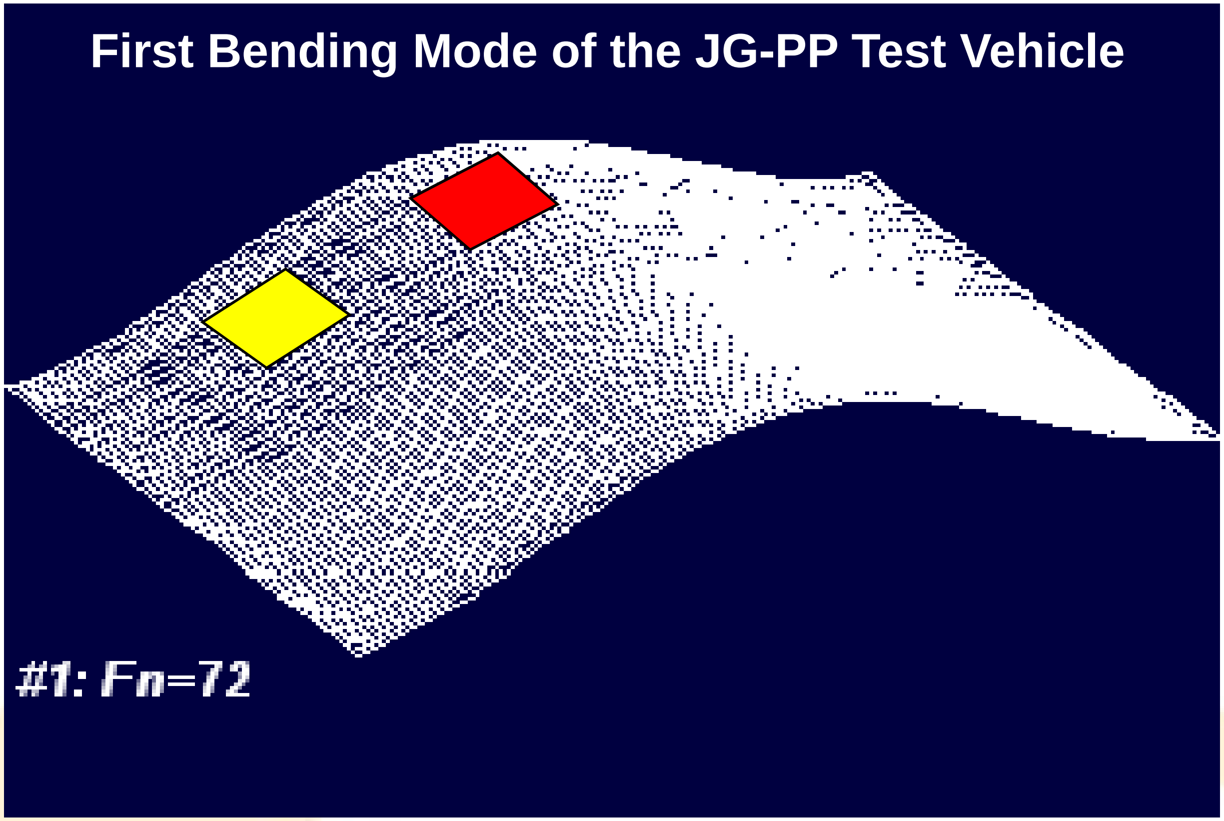


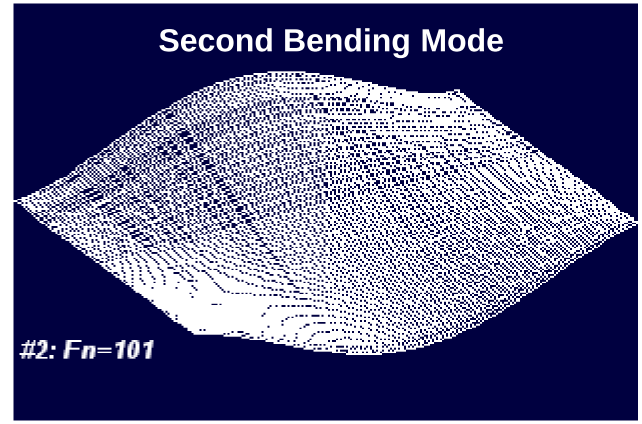
Peak Strains on Test Vehicle for the First Mode (1 G Sine Dwell)

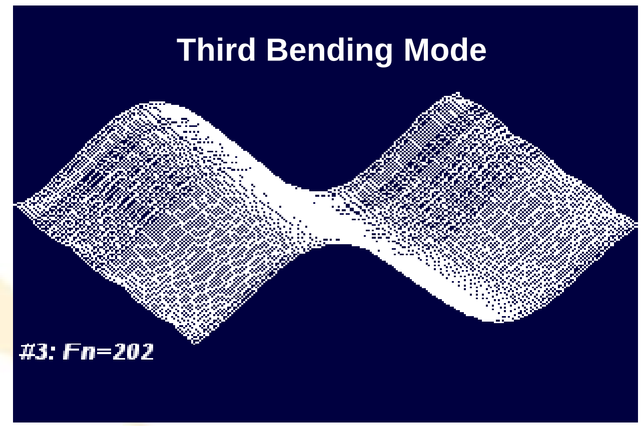


Solder Joints Fail First in Regions of High Strain









The yellow BGA will last 500 times longer than the red BGA simply due to position on the board (at a constant test level).

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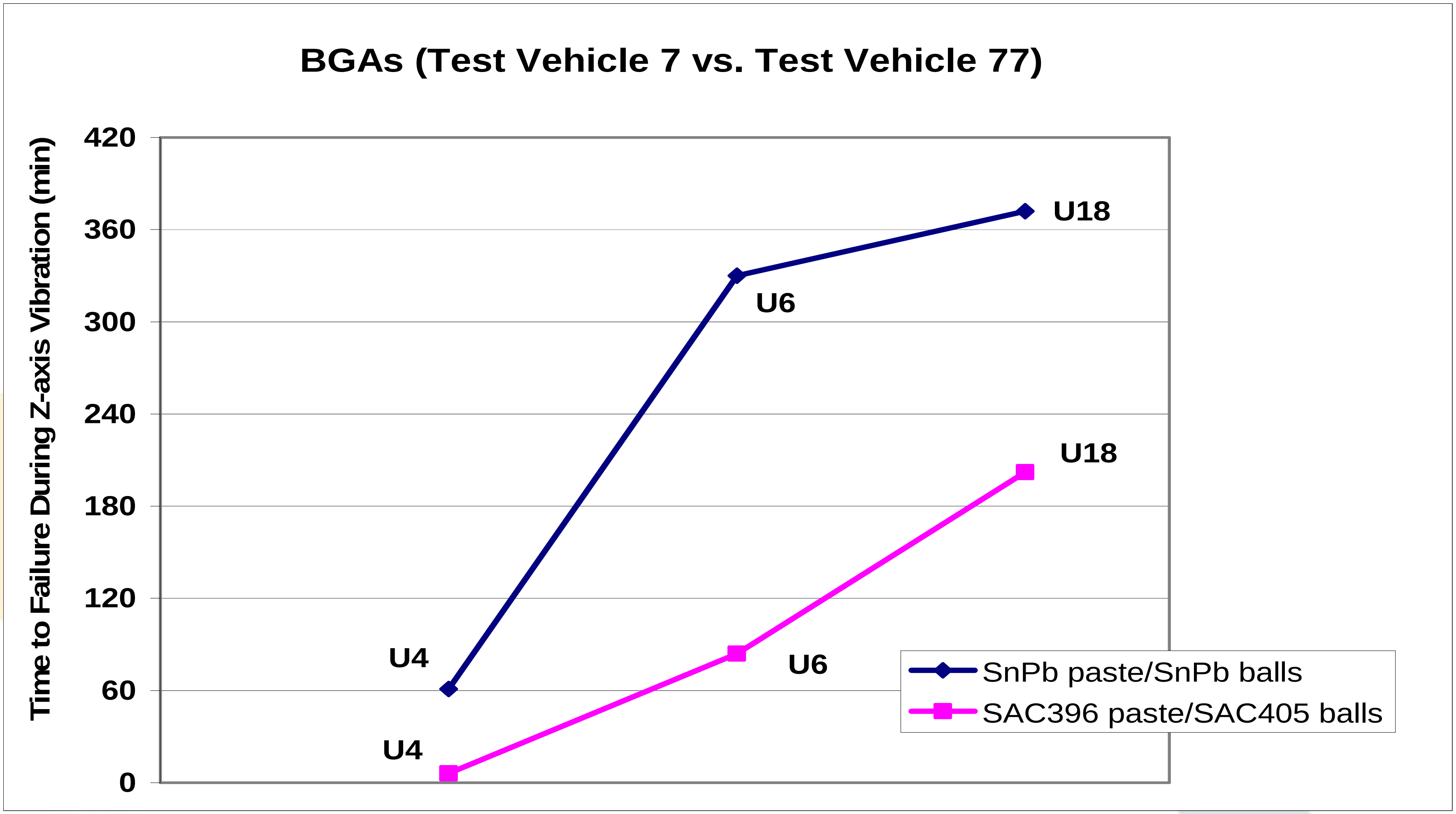
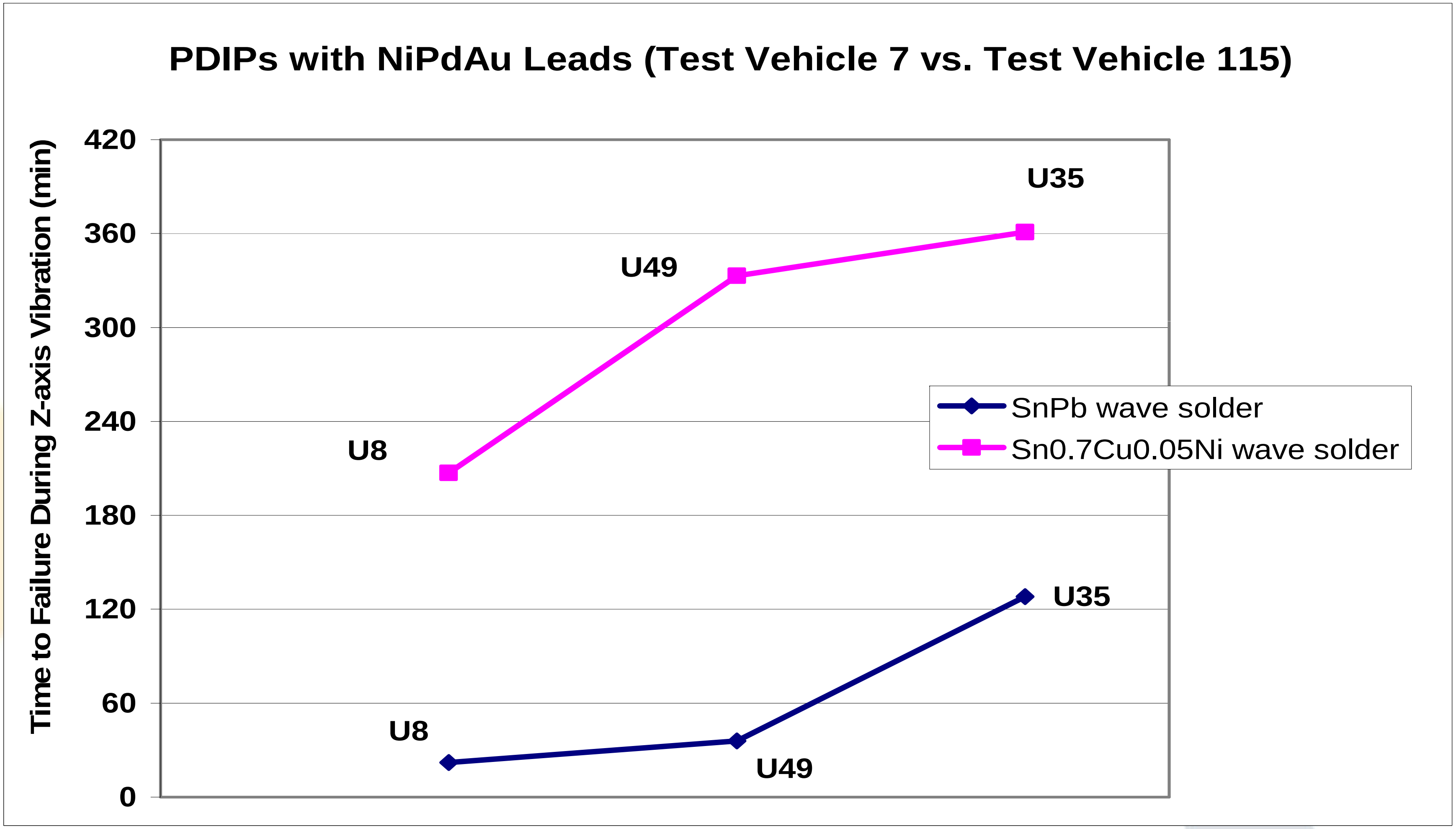
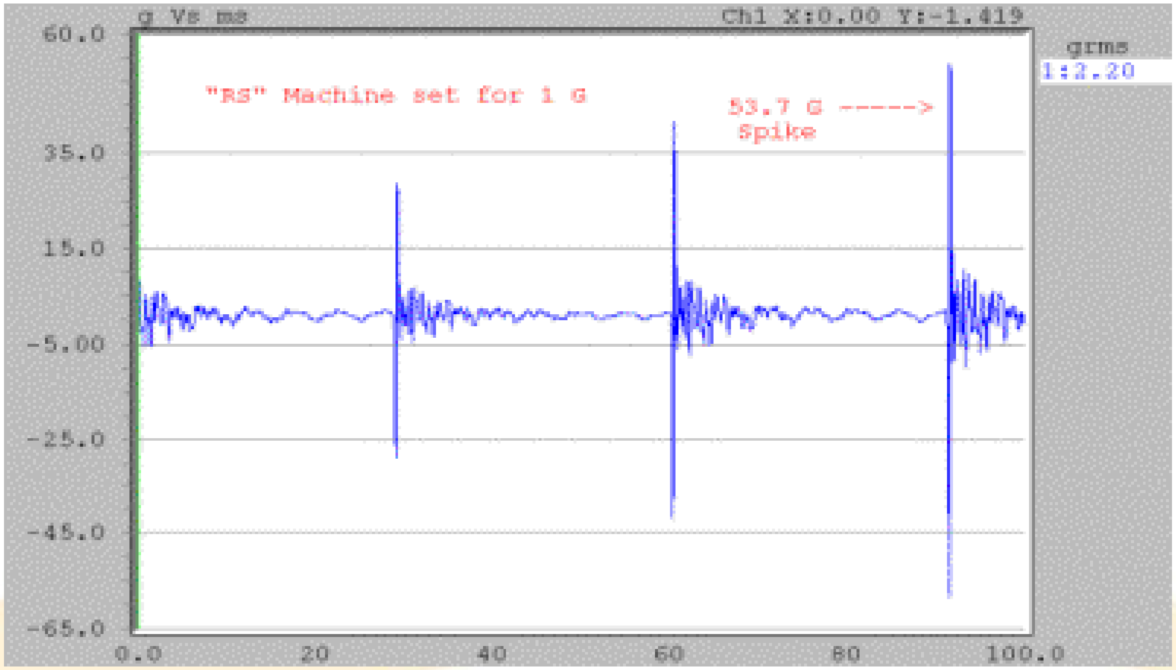
BGA Failure Data from the JG-PP Vibration Test



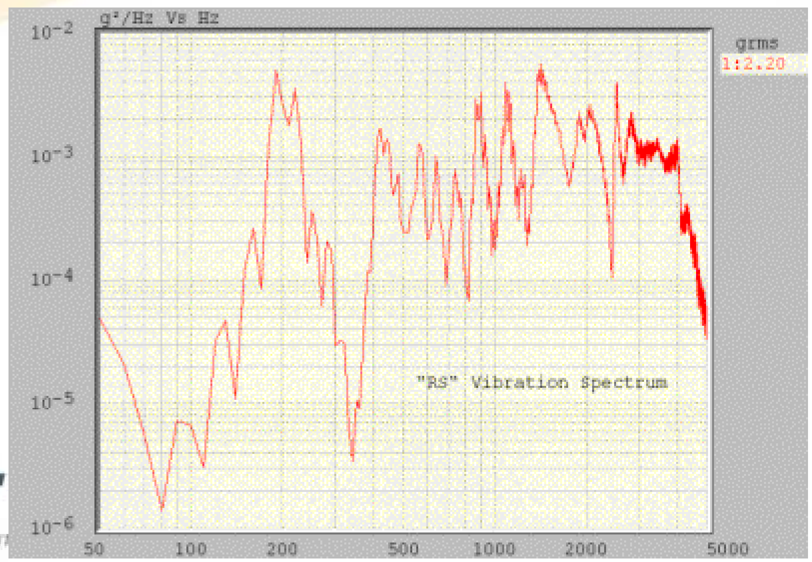
PDIP Failure Data from the JG-PP Vibration Test



Why HALT Should Not Be Used For Vibration Qual Tests



HALT uses pneumatic hammers to produce the vibration. **Very large G spikes** are generated which are not seen with an electrodynamic shaker. Reported G levels are actually a time averaged value.



HALT spectrum has **"holes"** in it which are not seen with an electrodynamic shaker. If a PWA resonance is at the same frequency as a hole, little damage will be done.

Source: UNHOLTZ-DICKIE CORPORATION

Mechanical Shock

Mechanical Shock Testing of Pb-Free PWA's Has Revealed Several Issues

- **SAC is less shock resistant than SnPb.**
- **Pad cratering under BGA's. Pad cratering is much more prevalent with SAC than with SnPb. SAC transmits more energy to the PWB which fractures the laminate and breaks traces.**
- **SAC fragility (an abnormal failure mechanism). Premature failure of SAC BGA's due to "Kirkendall" void formation during thermal aging. Believed to be a problem with the copper plating.**

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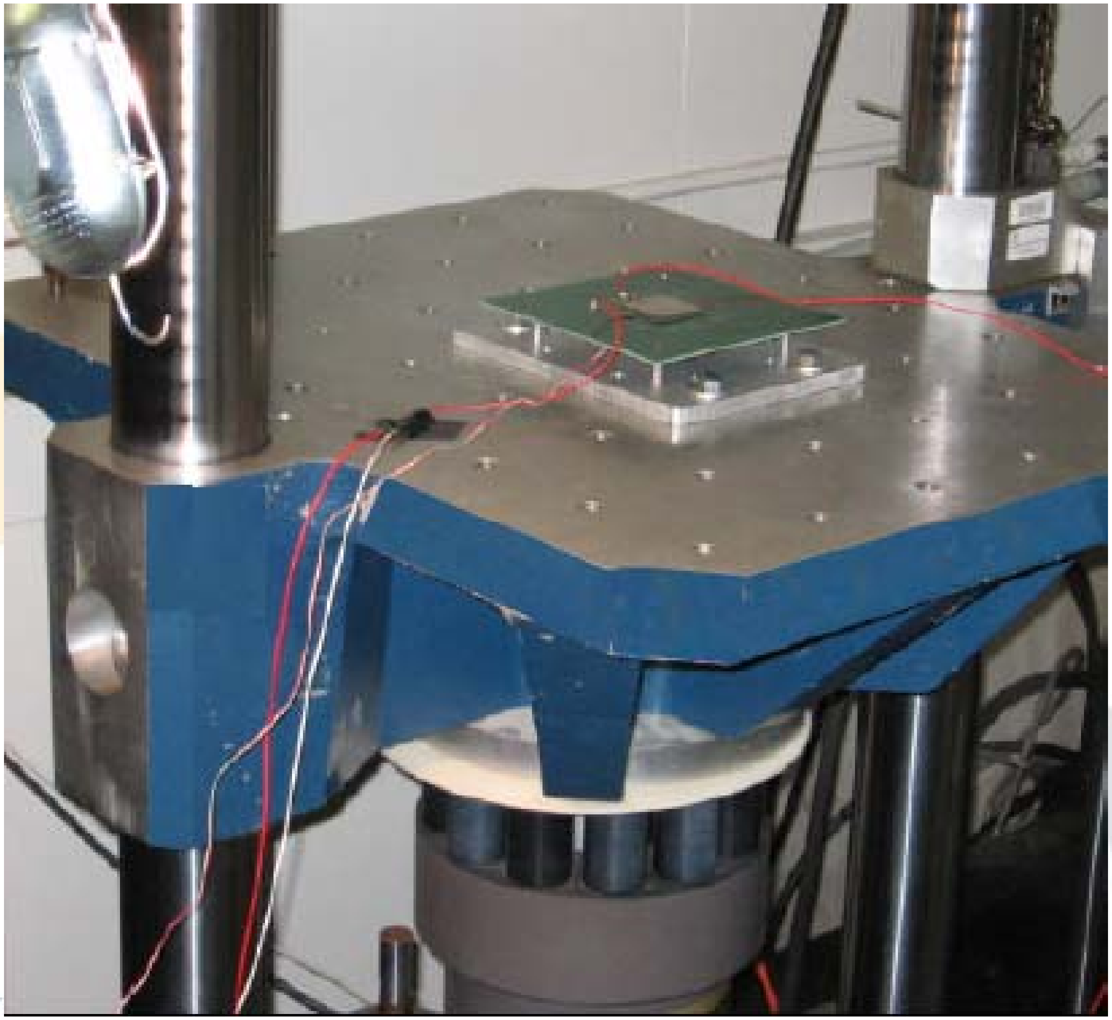
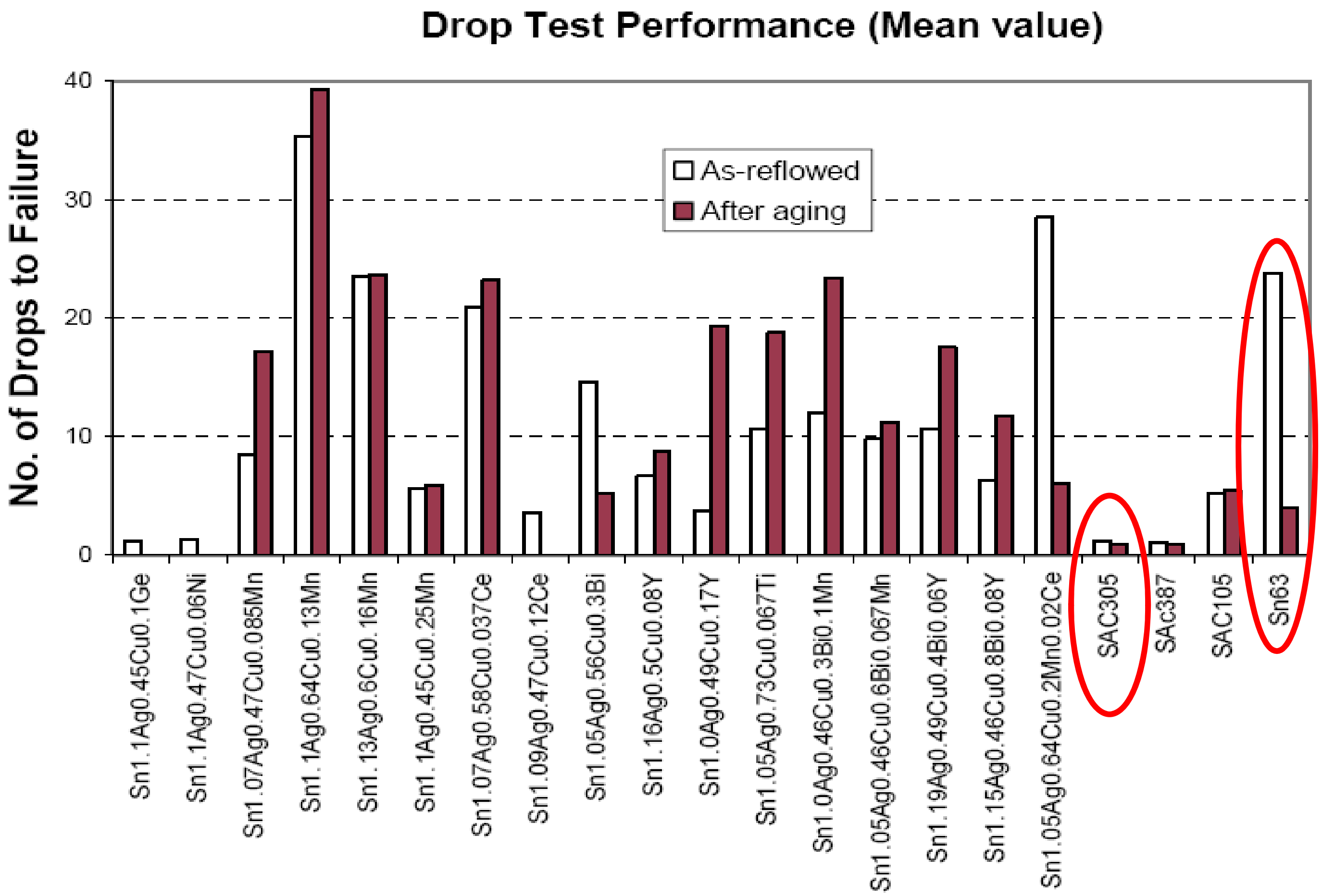
Drop Tester



Cell phone industry discovered that SAC305 had poor drop shock performance. Newly developed alloys perform better in drop shock but may be worse in thermal cycle.

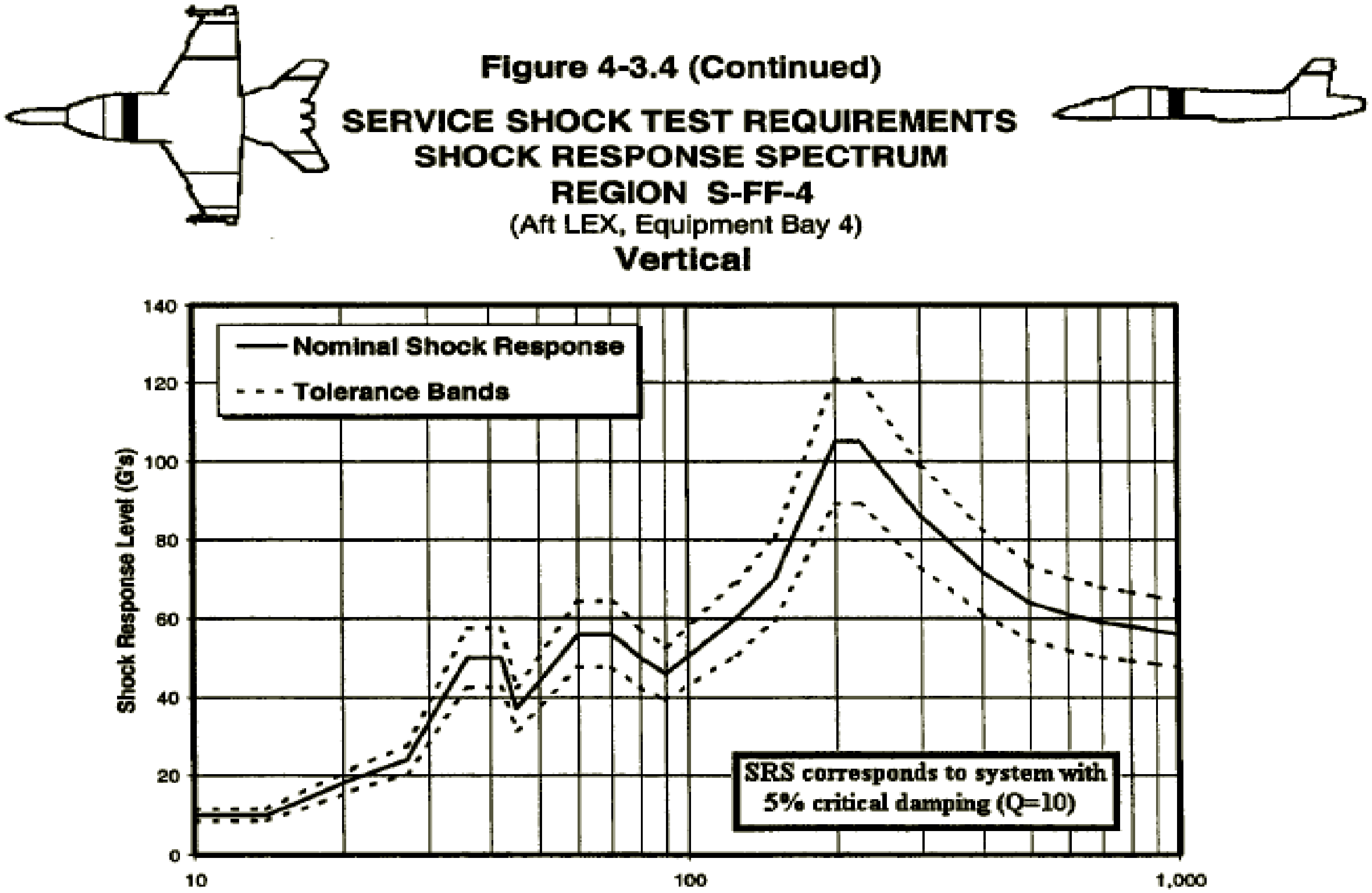


Source: W. Liu, N.-C. Lee, "Novel SACX Solders with Drop Test Performance Outperforming Eutectic Tin-Lead", APEX2007

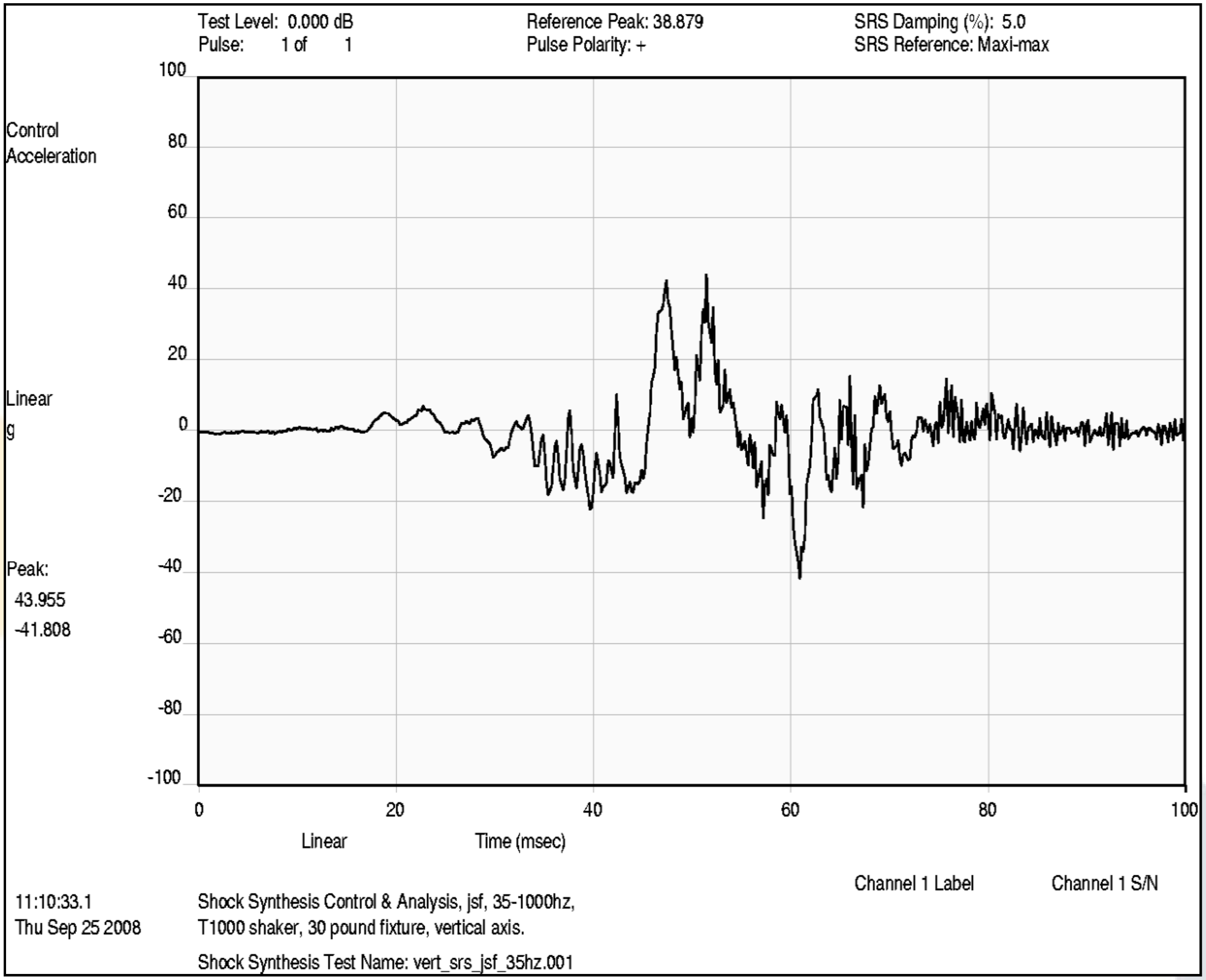
Mechanical Shock Testing on Military Aircraft

- Use an electrodynamic shaker or hydraulic shock machine
- Use a Shock Response Spectrum (SRS) which defines the acceleration at each frequency
- 6 shocks in the axis of interest

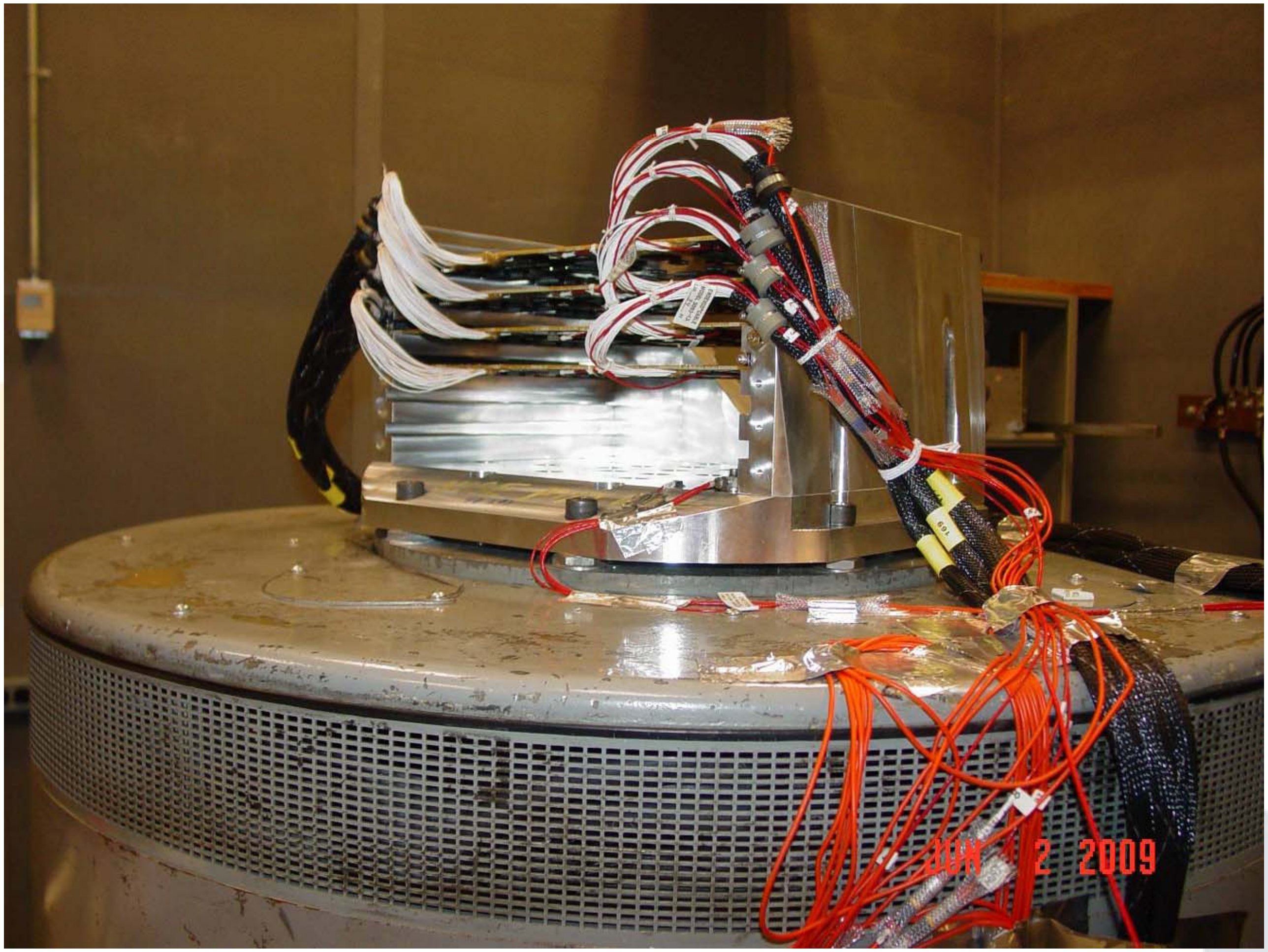
Shock Response Spectrum



Pulse used to generate the SRS on the ED Shaker



NASA/DoD Mechanical Shock Test (300 G's)



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NASA/DoD Mechanical Shock Test Results (BGA U21)

Test Vehicle ID	Solder/BGA Ball	Shocks Survived at Each Test Level (100 shocks per level in the Z-axis)								
		20 G's	40 G's	75 G's	100 G's	200 G's	300 G's	300 G's	300 G's	300 G's
"Manufactured" (ImAg)										
75	SAC305/SAC405	100	100	100	100	100	1			
90	SAC305/SAC405	100	100	100	100	100	30			
89	SAC305/SAC405	100	100	100	100	100	55			
88	SAC305/SAC405	100	100	100	100	100	76			
91	SAC305/SAC405	100	100	100	100	100	78			
30	SnPb/SnPb	100	100	100	100	100	14			
31	SnPb/SnPb	100	100	100	100	100	14			
32	SnPb/SnPb	100	100	100	100	100	42			
33	SnPb/SnPb	100	100	100	100	100	51			
34	SnPb/SnPb	100	100	100	100	100	68			
"Rework" (ImAg)	**These components were reworked**									
191	Flux Only/SAC405	Bad								
190	Flux Only/SAC405	100	100	100	100	100	6			
193	Flux Only/SAC405	100	100	100	100	100	7			
192	Flux Only/SAC405	100	100	100	100	100	8			
189	Flux Only/SAC405	100	100	100	100	100	24			
151	Flux Only/SnPb	100	100	100	100	100	6			
153	Flux Only/SnPb	100	100	100	100	100	11			
149	Flux Only/SnPb	100	100	100	100	100	18			
152	Flux Only/SnPb	100	100	100	100	100	18			
150	Flux Only/SnPb	100	100	100	100	100	26			
"Rework" (ENIG)										
160	Flux Only/SnPb	100	100	100	100	100	47			
	Reworked 1X									
	Reworked 2X									
	Reworked 3X									

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Summary

- SAC is less reliable than SnPb in vibration for area array components.
- SAC less reliable than SnPb in mechanical shock for some components (?).
- Don’t put vibration/shock sensitive components (e.g., BGA’s) on areas of high PWA curvature.
- Accelerated testing will need to be redesigned to mimic actual field lifetimes.

Questions?

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