Solder Column Qualification for Ceramic Column Grid Array (CCGA) White Paper

Aeroflex Colorado Springs
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Introduction

The aerospace industry continues to require increasing electronic system performance while maintaining stringent size and weight requirements for satellite applications. One strategy to meet these requirements is to utilize advanced electronic packaging and component mounting technologies that increase volumetric interconnect densities.

Aeroflex Colorado Springs (Aeroflex) has contracted independent and qualified subcontractors for the assembly, testing, evaluation and qualification of its Ceramic Column Grid Array (CCGA) package technology for space applications. The CCGA technology enables a direct electrical connection between a module substrate (i.e., package) and a circuit board. CCGA is a component mounting technology utilized when performance, reliability and power are the critical requirements. One common electronic component where CCGA packages are typically used is in microprocessors, such as the Intel Pentium 4.

This particular Aeroflex effort was initiated to qualify both the solder column itself, as well as the column attach process (i.e., package level column attach). Board level assembly was accomplished using Aeroflex standard board assembly processes.

The test vehicle used in this study was a 472 pin daisy chain CCGA package. The daisy chain structure was such that an output pin was shorted (connected) to an adjoining input pin, and the next output pin shorted to the next input pin, and so on. The method used to evaluate the interface of the solder column to the package was to measure and monitor the resistance of the daisy chain structure. Increases in resistance were indicators of an opened (i.e., failed) interface. Resistance measurements were taken before, during and after the stress tests.

The package qualification involved two configurations: CCGA packages only (i.e., package level), and CCGA packages assembled to a printed circuit boards (i.e., board level). Only the CCGA package was considered in the qualification Pass/Fail criteria since the board assembly process is customized, specific to a given customer assembly line. Six Sigma Services was used for the column attachment process, and Advanced Product Testing (APT) was used for the qualification testing. National Testing Services (NTS) was used for the Highly Accelerated Stress Screening (HASS).

Summary

The Aeroflex CCGA package passed all tests performed. The attached appendices include the qualification plan and results, as well as results from HASS testing and cross section failure analysis.

Appendix A

Six Sigma Solder Column CCGA Qualification Plan and Test Results

The following qualification plan outlines the requirements to qualify the Six Sigma Services solder column attach process for use on Aeroflex CCGA packages. The 472 pin CCGA package (part number 40-72007-01, with daisy chain configuration) with columns attached was inspected by Six Sigma Services. The subsequent qualification tests were performed by APT, and involved testing of 92 units, including 25 reworked[1] units.

Table 1. Package Level Testing. 472 CCGA package with columns attached.

Evaluation Test	Test Conditions	Sample Plan Tested/ Failed	Criteria & Notes	Summary Tested/ Failed
D-3 Thermal Shock	15 Thermal Shock Mil-Std-883 method 1011.9 condition B (-55C/125C) and 100 cycles. Mil-Std-883 method 1010.8 condition C (-65C/150C)	15/0 (5 reworked[1])	Visual Inspection Resistance tests - pre and post each test step.	15/0
Visual Inspection	Use of Six Sigma Services criteria	5/0		5/0
Lead Integrity	Use of Six Sigma Services test conditions and criteria.	22 leads from 3 parts/0 (Pre and post D-3 test include 1 reworked[1] unit.)	Straight down pull, evaluate columns from entire array area Modified upon approval from Q.A. 15/3/0	15/0
High Temp Storage Life	Mil-Std-810K method 505.1 procedure II (150C for 1000 hours in Nitrogen)	10/0 (5 reworked[1])	Attach to PWB and visually inspect for solder fillet.	10/0

Notes:
1. Rework units are tested units with all pins removed, and then reattached and retested to simulate a reworked manufacturing process.

Table 2. Board Level Testing. 472 CCGA packages assembled to printed circuit boards.

Evaluation/ Test	Test Conditions	Sample Plan Tested/ Failed	Criteria & Notes	Summary Tested/ Failed
Mechanical Shock	2,000 Gs, 5 shocks	15/0	Visual Inspection J-STD-001, Class III Resistance tests pre and post each test step. 3X resistance increase	15/0 Package damage from fixture. No column damage
Vibration	M2007/A, 25Gs, /A, 25Gs, 3minutes / axis	15/0	Visual Inspection J-STD-001, Class III Resistance tests pre and post each test step. 3X resistance increase	15/0 Fractures at board side – some higher resistances
Temperature cycle	-55 to 105 C, 30 min dwell, transfer 5C/min, 500 cycle (Qual point), monitor to $N_{0.5}$	30/0	Visual Inspection J-STD-001, Class III Resistance tests pre and post each test step. 3X resistance increase	30/0 Fractures at board side – some higher resistances

Notes:
1. Testing of the daisy chain package with interposer attached was limited to continuity and resistance testing only.
2. Column attach performed by Six Sigma Services as a contract assembly house. The ceramic metallization is Tungsten/Nickel/Gold. The gold dissolves into the Sn63Pb37 fillet leaving the nickel and tungsten layers. The pads are pre-tinned to remove the gold.
3. Standard Aeroflex board assembly processes were used for assembly of package to board.
4. Advanced Product Testing (APT) performed the qualification tests.

Table 3. Six Sigma Solder Column Attach Qualification

Package Level	Criteria	Rework Units	Test Results	Testing Req	Vendor	Date
Visual Inspect	5/0	2	5/0	NA	Aeroflex	9/8/05
Lead Strength	22/0 3pts	1	15/0	NA	Six Sigma	9/28/05
HT Storage	10/0	5		Pre/Post	Aeroflex	
D-3 T/S,T/C	15/0	5	15/0	Pre/Post	Aeroflex	

Board Level	Criteria	Rework Units	Test Results	Testing Req	Vendor	Date
Mech Shock	15/0	5	15/0	Pre/Post	APT	10/12/05
Vibration	15/0	5	15/0	Pre/Post	APT	10/6/05
Temp Cycle	30/0	5	30/0	Pre/Post	APT	1/16/06

Notes:
1. No failures were found to be attributable to solder column or package to column joint. Failures that did occur (high resistance) were due to fractures at the board due to stress testing (shock and vibration).
2. Post visual inspection showed no degradation of the solder interface to the board or the package. There was also no notable change in the integrity of the solder column.

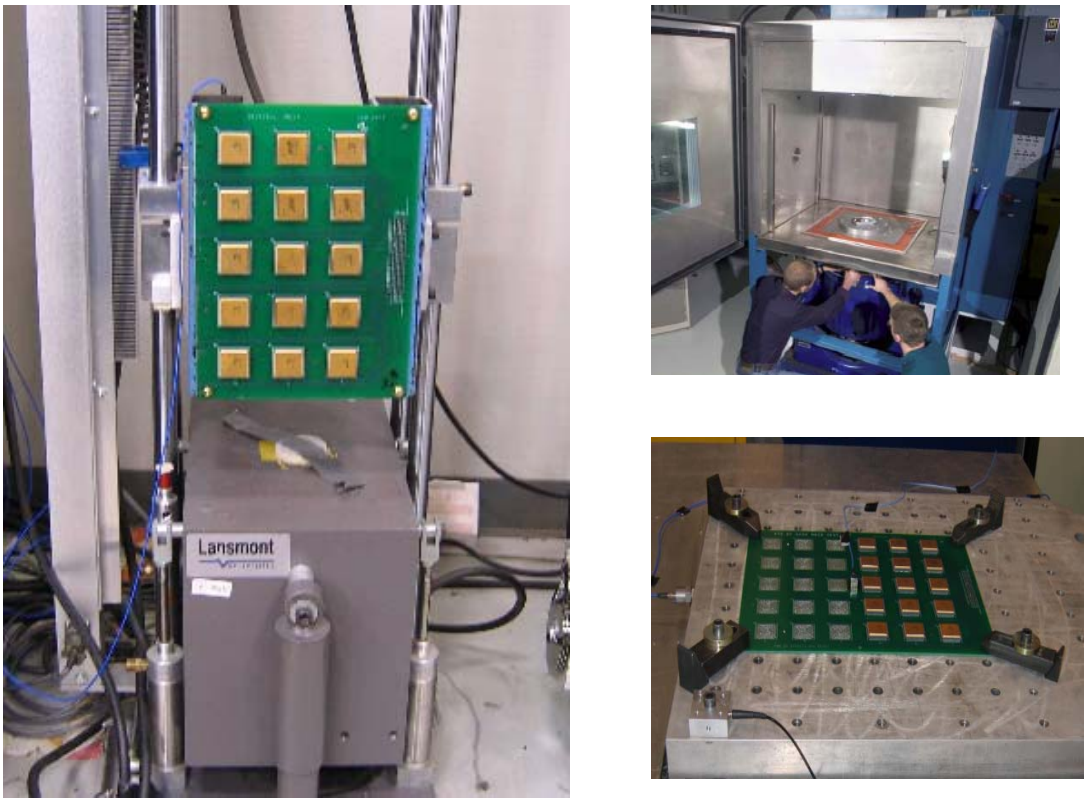


Figure 1. Board level test setup.

Appendix B

CCGA HASS (Highly Accelerated Stress Screening) Test Summary

The goal of the HASS testing was to generate preliminary reliability data at the board level. Thirty 472 CCGA daisy chain packages were assembled to a printed circuit board. The columns attached to these units were 87 mils in length and 22 mils in diameter. The columns were attached to the package by Six Sigma Services. The packages were in turn assembled to the printed circuit board using Aeroflex standard assembly processes. In particular, 63Sn/37Pb eutectic solder (melting temperature of 183^{o}C) was used to assemble the packages to the board. National Testing Services (NTS) performed the subsequent HASS testing.

The solder column is constructed of 80Pb/20Sn solder wrapped in a copper ribbon. The wrapped column is then tinned with eutectic solder. The product is cut in lengths of 87 mils and has a diameter of 22 mils.

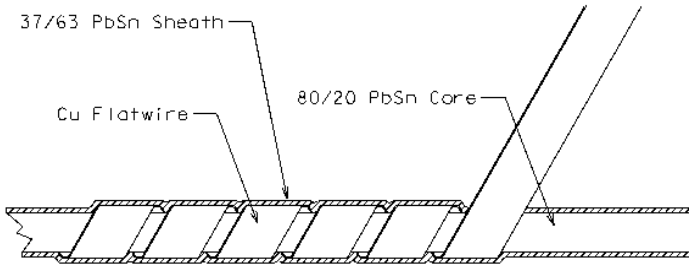


Figure 2. Six Sigma Services solder column construction.

Each assembled package position has four monitored sections.

- IN1: Outer two perimeter columns.
- IN2: Next two inner rows of columns.
- IN3: Next two inner rows of columns after IN2.
- IN4: Center rows of columns.

This design was implemented to help isolate the location of daisy-chain failures. Specifically, the columns furthest away from the center of the package will typically experience the highest level of stress during testing.

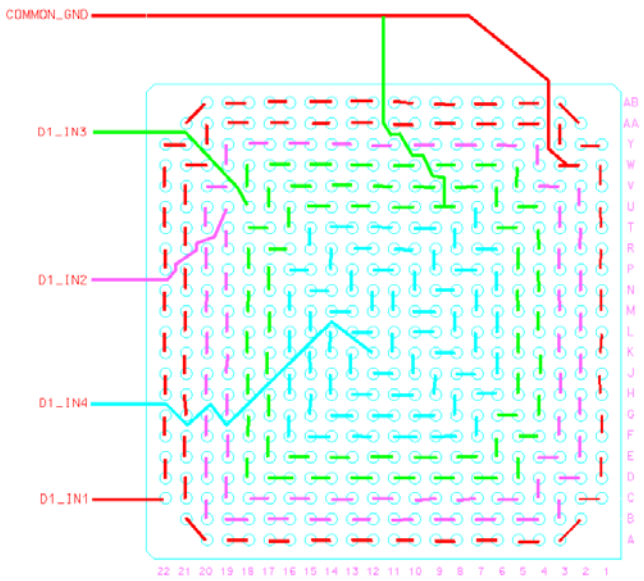


Figure 3. 472 pin CCGA daisy chain structure.

For the HASS testing both temperature and vibration were used to provide stress. Temperature cycling involved ramp rates of 5C/minute between -55C and 105C, with 30 minute dwells. No failures were detected after 500 thermal cycles. (Note that failure is defined as a 2x increase in trace resistance from initial readings.)

The first 28 cycles were completed with 0 or 5 Grms vibration in order to simply evaluate the temperature extremes on the solder columns. No failures were detected. Subsequent thermal cycling included increases in vibration up to 35 Grms. Again, no failures were detected. Further increases in vibration up to 40 Grms resulted in intermittent failures. Final increases to vibration levels of 45 and 50 Grms resulted in many resistance failures. However, it is suspected that these failures are due to failures at the solder column attach interface to the board, as well as failures within the cable interconnects. In other words, there were no detected failures at the column attach interface to the package. It was also noted that the units did maintain some level of continuity during stress, and that the high resistance readings returned to initial resistance values when the stress was removed.

In summary, after 500 cycles of temperature and vibration HASS testing, there were not failures detected in the solder column itself or at the column attach interface to the package.

Notes:
Grms = Gravity root mean square, 1 Gravity = 2.13Grms therefore 30Grms = 14 Gravities

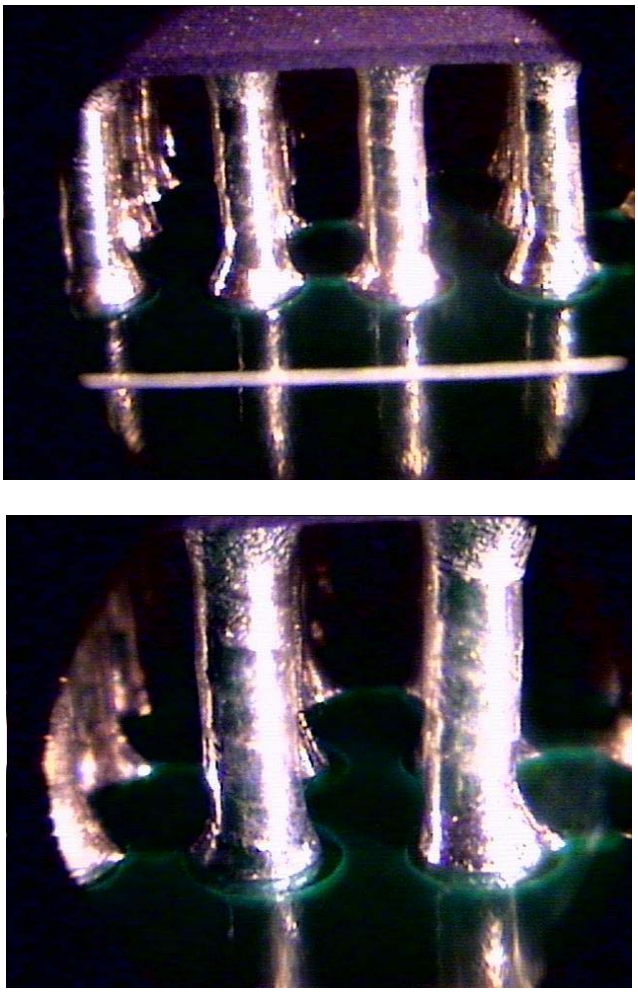


Figure 4. Zero stress solder column images.

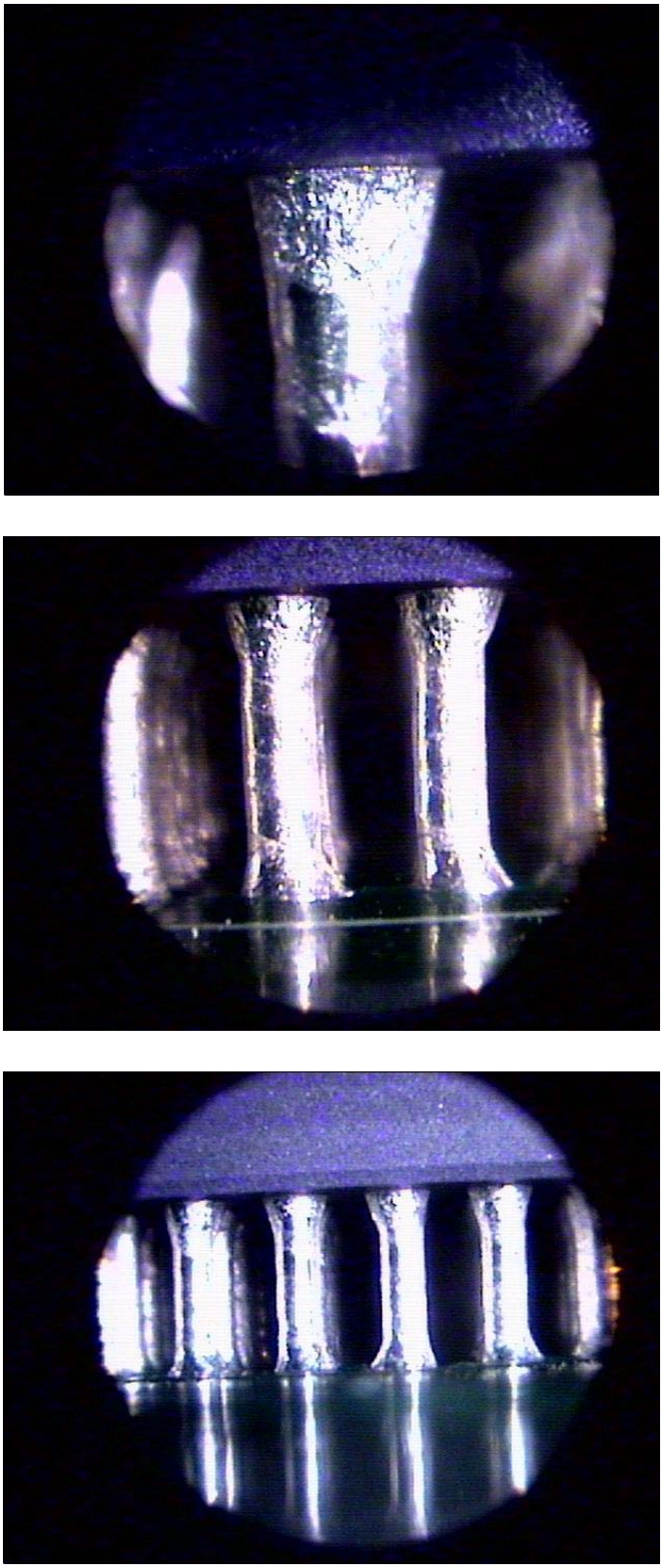


Figure 5. Post-HASS solder column images.

Appendix C

HASS Tabular Data (Resistance in ohms)
Pre-Stress Temperature Cycle Data and Test Results

Full board Full population							
Keithly 177 Microvolt DMM #05261							
Cal Done 8/27/05							
Cal Due 11/11/05			-55	5c/min	105	500	cycles
Lead resistance = 0.110			30 min	32 min	30 min	46000.0	min
Reworked unit positions A2/A3/F3/F4/F5						1066.7	hours
						44.4	days

Pre Stress					
connector labels	IN1	IN2	IN3	IN4	Board Posistion
A1	10.78	10.96	10.92	10.83	A1
A2	10.60	10.66	10.70	10.76	B1
A3	10.43	10.40	10.45	10.41	C1
A4	10.03	10.04	10.07	10.19	D1
A5	9.89	9.85	9.86	9.92	E1
B1	9.81	9.86	9.79	9.85	F1
B2	10.60	10.69	10.85	10.74	A2
B3	10.41	10.49	10.61	10.38	B2
B4	10.17	10.18	10.29	10.15	C2
B5	10.36	10.53	10.58	10.61	D2
C1	9.75	9.81	9.84	9.92	E2
C2	9.79	9.87	9.88	9.97	F2
C3	9.78	9.85	9.98	9.54	A3
C4	10.00	10.06	10.22	9.98	B3
C5	9.83	9.96	9.98	10.06	C3
D1	10.00	9.98	9.94	9.88	D3
D2	9.84	9.91	9.92	10.08	E3
D3	9.42	9.42	9.43	9.54	F3
D4	10.19	10.14	10.29	10.26	A4
D5	9.71	9.74	9.90	9.87	B4
E1	9.96	10.06	10.16	10.14	C4
E2	9.91	9.93	10.00	10.00	D4
E3	9.53	9.51	9.54	9.45	E4
E4	9.14	9.02	9.00	9.07	F4
E5	10.33	10.48	10.57	10.48	A5
F1	10.37	10.39	10.47	10.36	B5
F2	10.19	10.20	10.28	10.30	C5
F3	9.64	9.67	9.69	9.62	D5
F4	9.43	9.47	9.44	9.52	E5
F5	9.70	9.69	9.62	9.61	F5

HASS Tabular Data (Resistance in ohms)
Post-Stress Temperature Cycle Data Test Results

Full board Full population							
Keithly 177 Microvolt DMM #05261							
Cal Done 8/27/05							
Cal Due 11/11/05			-55	5c/min	105	500	cycles
Lead resistance = 0.110			30 min	32 min	30 min	46000.0	min
Reworked unit positions A2/A3/F3/F4/F5						1066.7	hours
						44.4	days

Post stress					
connector labels	IN1	IN2	IN3	IN4	Board Posistion
A1	10.80	11.00	11.00	10.80	A1
A2	10.60	10.70	10.80	10.80	B1
A3	10.30	10.40	10.40	10.50	C1
A4	10.10	10.10	10.10	10.20	D1
A5	10.00	9.90	9.90	10.00	E1
B1	9.80	9.90	9.80	9.90	F1
B2	10.60	10.80	10.90	10.80	A2
B3	10.50	10.60	10.60	10.40	B2
B4	10.20	10.30	10.40	10.20	C2
B5	10.50	10.60	10.60	10.70	D2
C1	9.80	9.80	9.90	10.00	E2
C2	9.80	9.90	9.90	10.00	F2
C3	9.80	9.90	10.00	9.90	A3
C4	10.00	10.10	10.20	10.00	B3
C5	9.90	10.00	10.00	10.10	C3
D1	10.10	10.00	10.00	9.90	D3
D2	9.80	10.00	10.00	10.10	E3
D3	9.40	9.40	9.40	9.60	F3
D4	10.30	10.20	10.30	10.30	A4
D5	9.80	9.80	9.90	9.90	B4
E1	10.00	10.20	10.20	10.20	C4
E2	10.00	10.00	10.00	10.10	D4
E3	9.60	9.60	9.60	9.50	E4
E4	9.20	9.10	9.00	9.10	F4
E5	10.40	10.50	10.50	10.50	A5
F1	10.40	10.40	10.50	10.40	B5
F2	10.20	10.30	10.30	10.30	C5
F3	9.70	9.70	9.80	9.70	D5
F4	9.50	9.50	9.50	9.50	E5
F5	9.70	9.70	9.70	9.60	F5

HASS Tabular Data (Resistance in ohms)
Delta Temperature Cycle Data Test Results

Full board Full population							
Keithly 177 Microvolt DMM #05261							
Cal Done 8/27/05							
Cal Due 11/11/05			-55	5c/min	105	500	cycles
Lead resistance = 0.110			30 min	32 min	30 min	46000.0	min
Reworked unit positions A2/A3/F3/F4/F5						1066.7	hours
						44.4	days

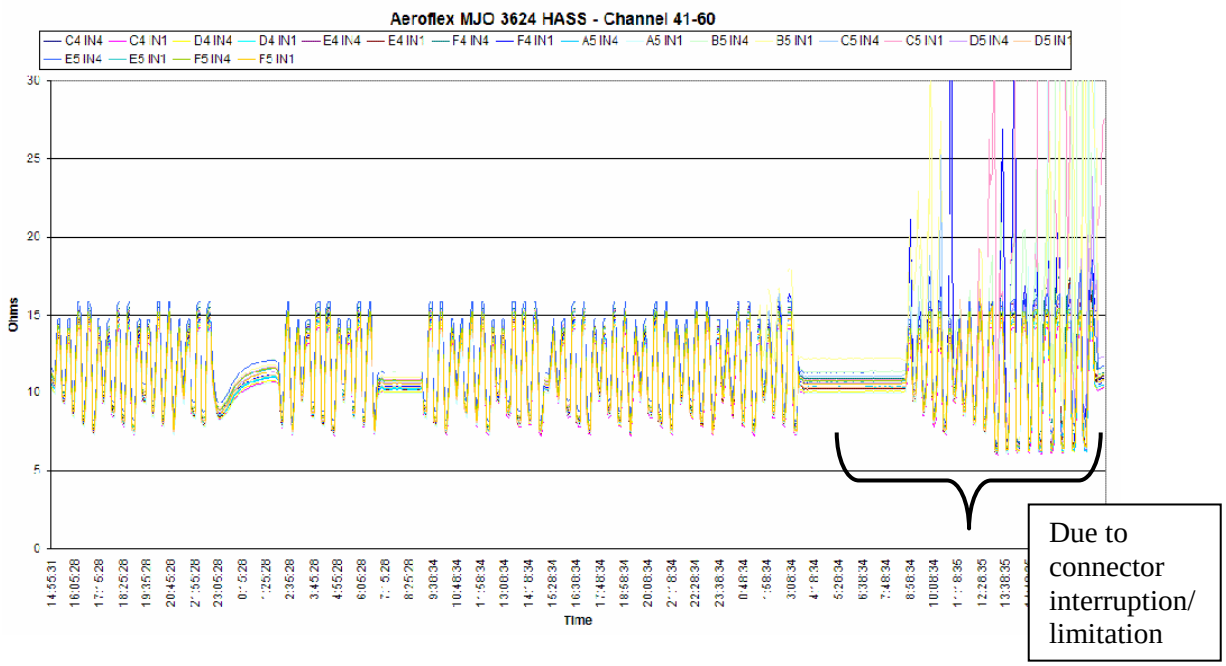
Delta Table	All value deltas are less than 0.5 ohms				
connector labels	IN1	IN2	IN3	IN4	Board Posistion
A1	-0.02	-0.04	-0.08	0.03	A1
A2	0.00	-0.04	-0.10	-0.04	B1
A3	0.13	0.00	0.05	-0.09	C1
A4	-0.07	-0.06	-0.03	-0.01	D1
A5	-0.11	-0.05	-0.04	-0.08	E1
B1	0.01	-0.04	-0.01	-0.05	F1
B2	0.00	-0.11	-0.05	-0.06	A2
B3	-0.09	-0.11	0.01	-0.02	B2
B4	-0.03	-0.12	-0.11	-0.05	C2
B5	-0.14	-0.07	-0.02	-0.09	D2
C1	-0.05	0.01	-0.06	-0.08	E2
C2	-0.01	-0.03	-0.02	-0.03	F2
C3	-0.02	-0.05	-0.02	-0.36	A3
C4	0.00	-0.04	0.02	-0.02	B3
C5	-0.07	-0.04	-0.02	-0.04	C3
D1	-0.10	-0.02	-0.06	-0.02	D3
D2	0.04	-0.09	-0.08	-0.02	E3
D3	0.02	0.02	0.03	-0.06	F3
D4	-0.11	-0.06	-0.01	-0.04	A4
D5	-0.09	-0.06	0.00	-0.03	B4
E1	-0.04	-0.14	-0.04	-0.06	C4
E2	-0.09	-0.07	0.00	-0.10	D4
E3	-0.07	-0.09	-0.06	-0.05	E4
E4	-0.06	-0.08	0.00	-0.03	F4
E5	-0.07	-0.02	0.07	-0.02	A5
F1	-0.03	-0.01	-0.03	-0.04	B5
F2	-0.01	-0.10	-0.02	0.00	C5
F3	-0.06	-0.03	-0.11	-0.08	D5
F4	-0.07	-0.03	-0.06	0.02	E5
F5	0.00	-0.01	-0.08	0.01	F5

HASS Tabular Data (Resistance in ohms)
Pre and Post Stress Mechanical Shock Data Test Results

1/2 board	Mechanical Shock @ 2KG 5X							
Pre Stress								
Labeled	IN1	IN2	IN3	IN4	Board Loc			
A4	10.4	10.5	10.5	10.6	D1			
A5	10.3	10.3	10.3	10.4	E1			
B1	9.6	9.6	9.5	9.6	F1			
B5	10.3	10.3	10.3	10.3	D2			
C1	10.1	10.2	10.1	10.4	E2			
C2	9.8	9.9	9.9	9.9	F2			
D1	9.9	9.9	9.9	9.9	D3			
D2	9.5	9.6	9.5	9.5	E3			
D3	9.3	9.4	9.3	9.5	F3			
E2	9.7	9.8	9.8	9.7	D4			
E3	9.8	9.9	9.8	9.9	E4			
E4	9.4	9.3	9.1	9.3	F4			
F3	10.0	10.2	10.0	10.2	D5			
F4	9.8	9.8	9.8	9.9	E5			
F5	9.5	9.5	9.5	9.6	F5			
Post stress								
Labeled	IN1	IN2	IN3	IN4	Board Loc			
A4	-	-	-	-	D1	Cracked		
A5	10.3	10.3	10.3	10.4	E1			
B1	9.6	9.6	9.6	9.6	F1			
B5	-	-	-	50.2	D2	Cracked		
C1	10.1	10.3	10.2	10.3	E2			
C2	9.8	9.9	9.9	9.9	F2			
D1	10.0	-	-	-	D3	Cracked		
D2	9.5	9.6	9.5	9.5	E3			
D3	-	9.4	9.3	9.5	F3	Same except AA1 noted in IN1		
E2	9.7	9.7	10.3	383.0	D4	Cracked	Same except IN4	
E3	9.8	9.9	9.8	9.9	E4			
E4	9.3	9.3	9.2	9.3	F4			
F3	-	10.3	10.1	-	D5	Cracked	IN2 and IN3 within 0.1V	
F4	9.8	9.9	9.8	9.9	E5			
F5	9.4	9.5	9.5	9.6	F5			
Notes:	Lid popped off: Packages cracked - D1, D2, D3, D4, D5							
	Visual results in 1 noted column with probable crack on F3 around AA1. The columns of this unit were visually with a 7x scope. All damage was found to be at the board. There were lifted trace pads and broken board fillets at their interfaces. No damage was found at the package interface or to the column structure.							
	D1 outside corner noted some column crushing; no breaks							

HASS Tabular Data (Resistance in ohms)
Pre and Post Stress Vibration Data Test Results

Full board 1/2 populated					
Reworked units in positions d1/d2/e4/e5/f4					
Pre Stress Data					
Labeled	IN1	IN2	IN3	IN4	Board Loc
A4	10.2	10.2	10.2	10.2	D1
A5	9.9	9.9	10.0	10.1	E1
B1	9.9	10.0	10.1	10.2	F1
B5	10.1	10.2	10.1	10.2	D2
C1	10.0	9.9	10.0	10.0	E2
C2	9.6	9.7	9.8	9.9	F2
D1	9.7	9.8	9.9	9.8	D3
D2	9.8	9.8	9.8	9.9	E3
D3	9.9	10.0	9.9	9.9	F3
E2	10.0	10.0	10.1	10.1	D4
E3	9.4	9.5	9.5	9.4	E4
E4	9.7	9.8	9.6	9.9	F4
F3	10.1	10.1	10.1	10.1	D5
F4	10.0	10.1	10.1	10.3	E5
F5	9.5	9.6	9.5	9.7	F5
Post Stress Data					
Labeled	IN1	IN2	IN3	IN4	Board Loc
A4	10.2	10.2	10.1	10.2	D1
A5	9.8	9.9	9.9	10	E1
B1	9.9	10	10.1	10.2	F1
B5	10.1	10.1	10.1	10.2	D2
C1	9.9	9.9	10	9.9	E2
C2	9.6	9.7	9.7	9.9	F2
D1	9.7	9.8	9.9	9.8	D3
D2	9.8	9.8	9.8	9.9	E3
D3	9.9	9.9	9.9	9.9	F3
E2	10	10	10	10.1	D4
E3	9.4	9.4	9.4	9.4	E4
E4	9.7	9.7	9.6	9.9	F4
F3	10	10.1	10.1	10.1	D5
F4	10	10.1	10.1	10.2	E5
F5	9.5	9.5	9.4	9.7	F5
Results:	All values are within 0.1V reading				



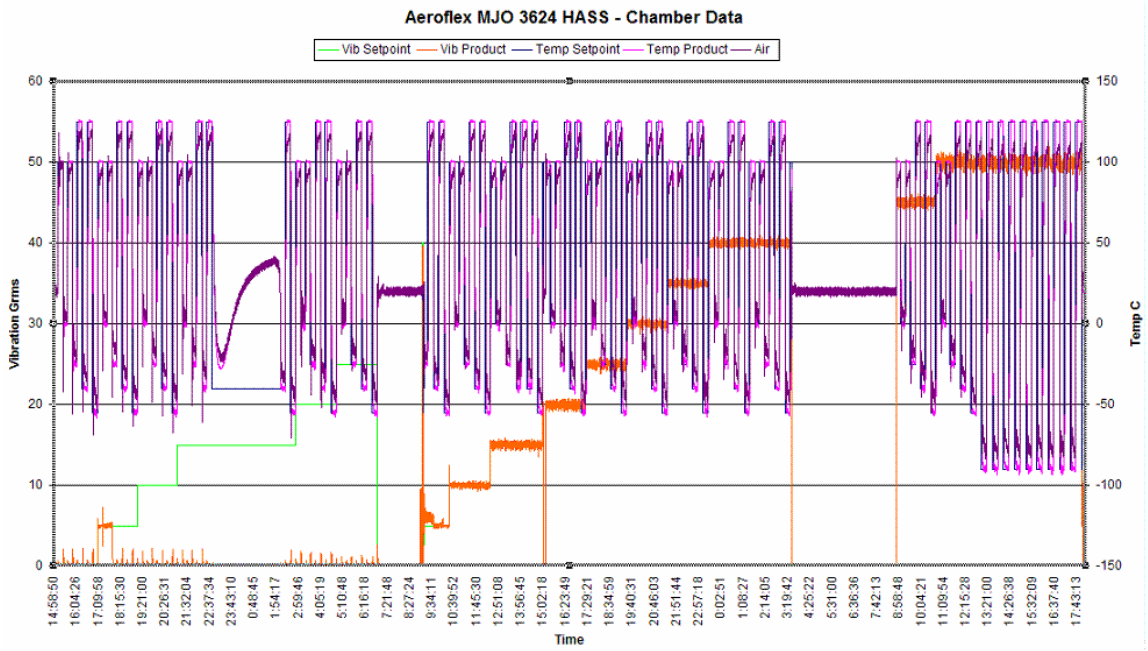


Figure 6. Sample HASS data in graph format.

Appendix D

Cross Section Failure Analysis

Both a stressed and unstressed package were mounted in epoxy and cross sectioned through solder columns. The cross sectioned samples were then delineated with a copper/soft metal etch for approximately 35 seconds. The samples were inspected and SEM photos were acquired using the Hitachi S4800 Scanning Electron Microscope.

Results of the cross section analysis showed no apparent differences between stressed and unstressed packages within solder columns or column attach interfaces to the package.

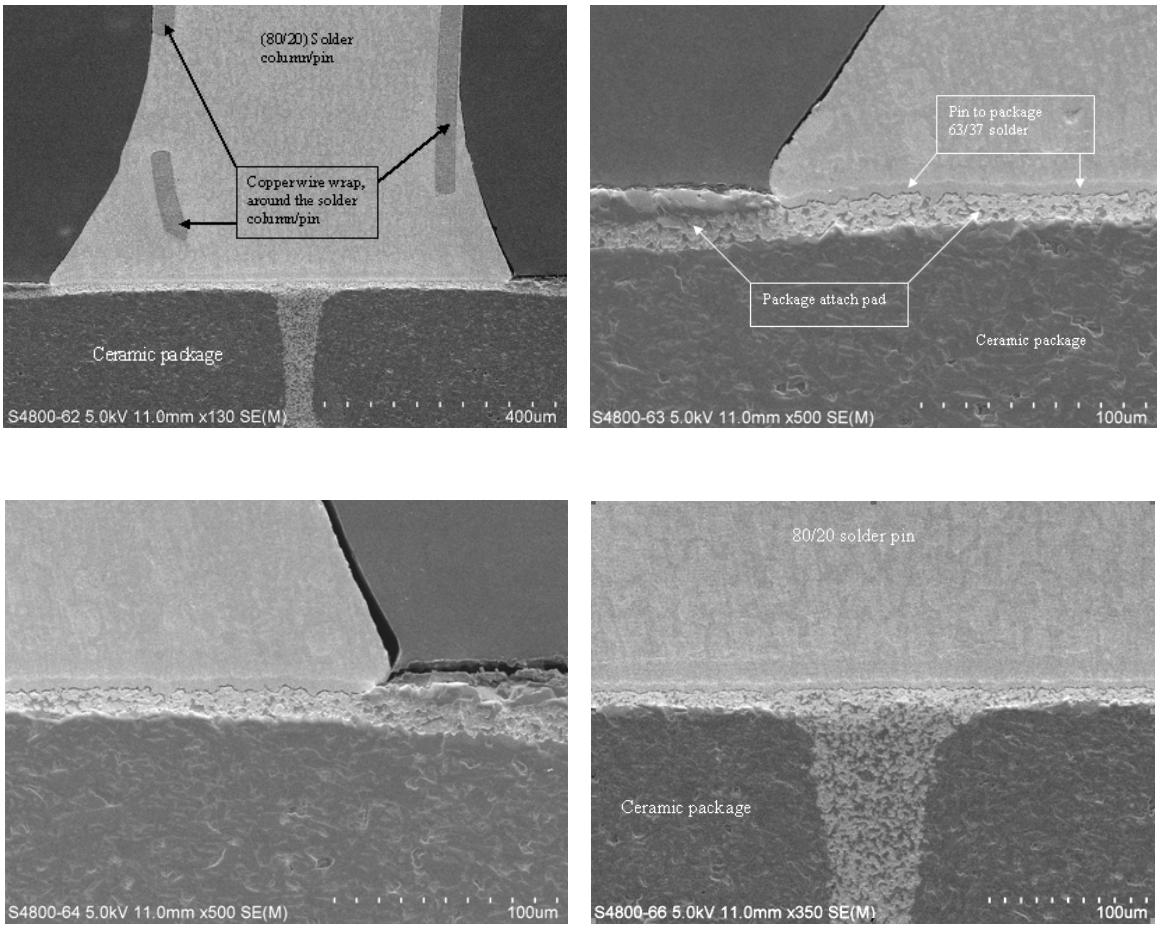
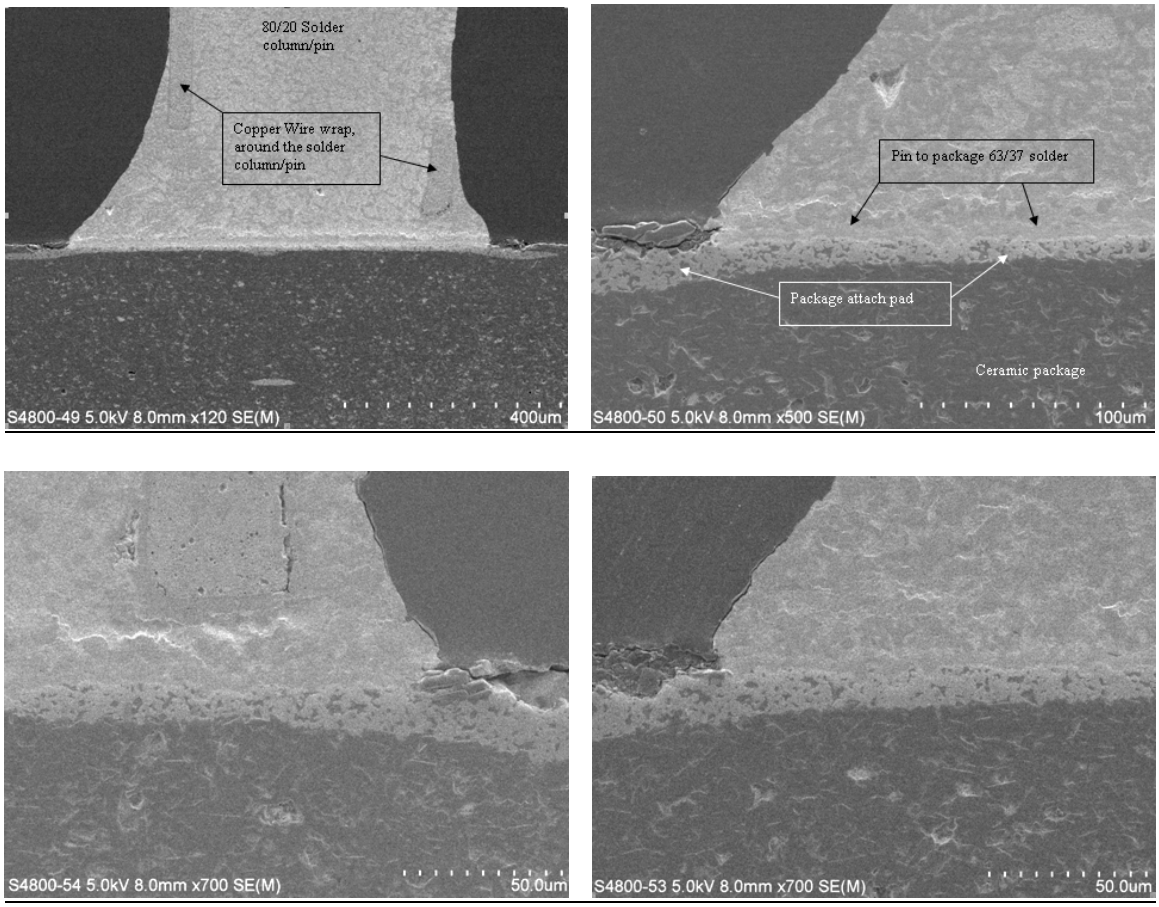


Figure 7. Cross section SEM images of unstressed package.



Figures 8. Cross section SEM images of stressed package.