Qualification of Class L Chip on Board Package Technology for Space

Aeroflex Microelectronic Solutions – HiRel

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Solution-Minded

Performance-Driven

Customer-Focused

Agenda

- Why Class L?
- Development / Qualification
- Design Considerations
- Magnetics
- Wirebond
- Conclusions

Why Class L?

MIL-PRF-38534, Appendix D

- Revision H released September 2010 to establish reliability models for microelectronic hybrids that could not meet the conventional hermiticity requirements of Class H (avionic) and Class K (high reliability/space)
- JEDEC Task Group 13.5 collaborated with US Government (DLA), aerospace and military procuring activities and microelectronic suppliers

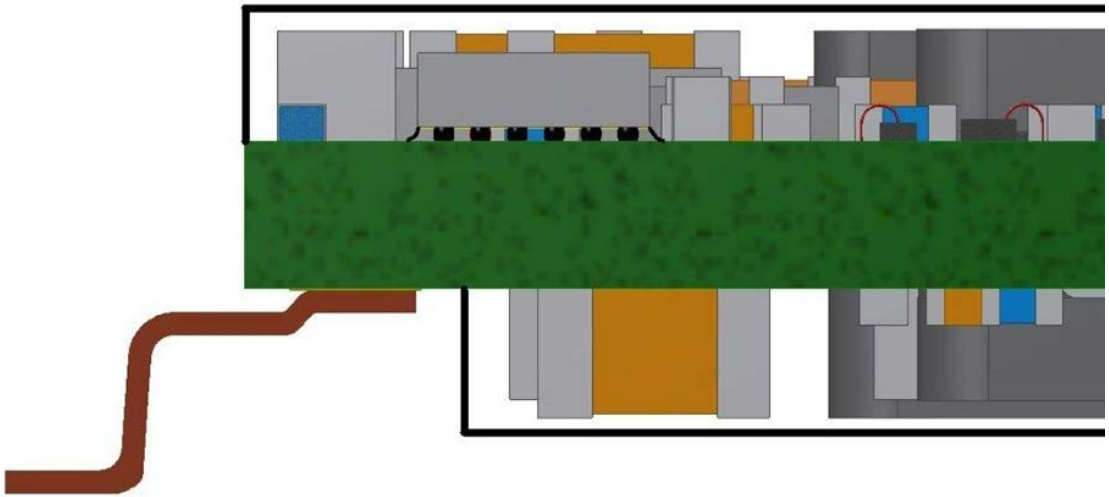
Class F - Avionic (Standard quality class – non-hermetic)
Class L - High Reliability / Space (Highest quality class – non-hermetic)

- Classes are defined by failure thresholds to:
  - Thermo-mechanical
  - High moisture
  - Highly accelerated environmental stress testing

Aeroflex Class L Package Construction

Class L Package Construction

- Polyimide Printed Wiring Board (PWB)
- Chip Scale Ball Grid Array (BGA) FET's and control IC's
- Surface Mount Technology (SMT) passives
- Planar magnetics (transformers)
- Aluminum wire bond
- High purity molding epoxy



PDM Development - Milestones

- Chip scale BGA assembly processes and flows developed
- Wafer bumping vendors identified and qualified
- Internal chip scale BGA design rules defined
- Failure Mode and Effects Analysis (FMEA) completed
- Underfill voiding optimization completed
- Magneto-strictive effects optimization completed
- Underfill compliance with TM5011 requirements completed
- Finite element modeling techniques developed to predict reliability of chip scale BGA assemblies, lead integrity
  - Solder fatigue analysis
- Additional finite element modeling developed to predict module reliability
  - Lead fatigue analysis
  - Thermal analysis

PDM – Power Distribution Module

TRL-9 Heritage Overlay of Process Re-Use

- **The following is a summary of Aeroflex Chip-On-Board Heritage:**

Description	Number of Units in Orbit or Scheduled	Orbit	Time on Orbit	Program Type	Size	#Die Bonds # Wire Bonds (WB)
Custom Interface Control Board	> 4,000	GEO	Over 10 Years	Commercial Telecom	4.1" x 2.2" x 0.575H	108 Solder Die, 81 Epoxy Die, 387 WB
Voltage Gate Regulator	> 12,000	GEO	Over 7 Years	Commercial Telecom	1.8" x 0.6" x 0.155" H	140 Die 233 WB
Amplifier Control Board	> 120	GEO	Planned	Commercial Telecom	5.5" x 5.0" x 0.893" H	385 Die 744 WB
Low Profile DC/DC Converter	4	LEO	2 Years	Weather Satellite	6.4" x 5.6" x 0.972" H	103 Die 404 WB
Low Profile DC/DC Converter	4	LEO	2 Years	Weather Satellite	6.4" x 5.6" x 0.972" H	99 Die 156WB
*BIE: Voltage Monitoring & Telemetry Board	31	N/A Supply Vehicle	Launch Plan First: 9/18 2nd: Dec '13 3rd: In 2014	ISS Re-Supply Vehicle	6.6" x 5.6" x 0.300" H	190 Solder Die 372 Epoxy Bonds 915 WB
*BIE: Over Charge Protection Board	31	N/A Supply Vehicle	Launch Plan First: 9/18 2nd: Dec '13 3rd: In 2014	ISS Re-Supply Vehicle	6.6" x 5.6" x 0.300" H	118 Solder Die 97 Epoxy Bonds 312 WB
DC-DC Converter	>500	LEO	Planned	Commercial Telecom	4.8" x 3.0" x 0.632H	206 Solder Die 62 Epoxy Die 172 WB

Process Heritage Overlay

- Chip & Wire "Globtop" Heritage
- SMT Heritage

- Chip & Wire & SMT Heritage, plus
- Planar Magnetics

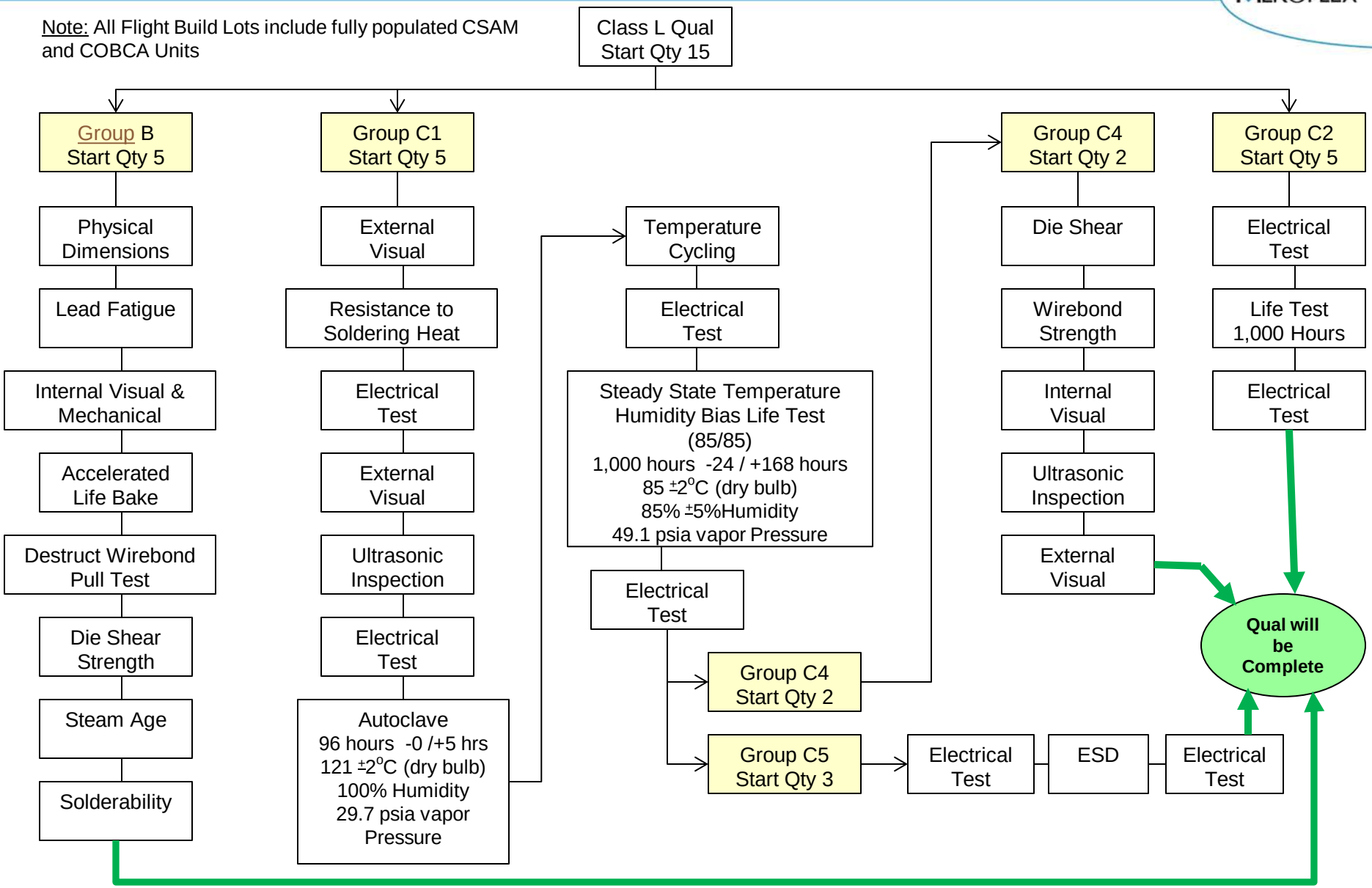
- Chip & Wire & SMT Heritage

- Chip & Wire & SMT Heritage, plus
- Planar Magnetics, plus
- Chip Scale BGA

- **There are no new processes required in the production of Aeroflex's Power Distribution Module (PD.M.) Product Family = No Inventions, All Heritage**

*** BIE – Battery Interface Electronics**

Qualification Overview



Qualification Overview

- The Aeroflex flow on the prior slide we propose is more stringent since evaluation units run through a serial combined flow for the boxed area below. Other delta areas to be discussed are circled in Red

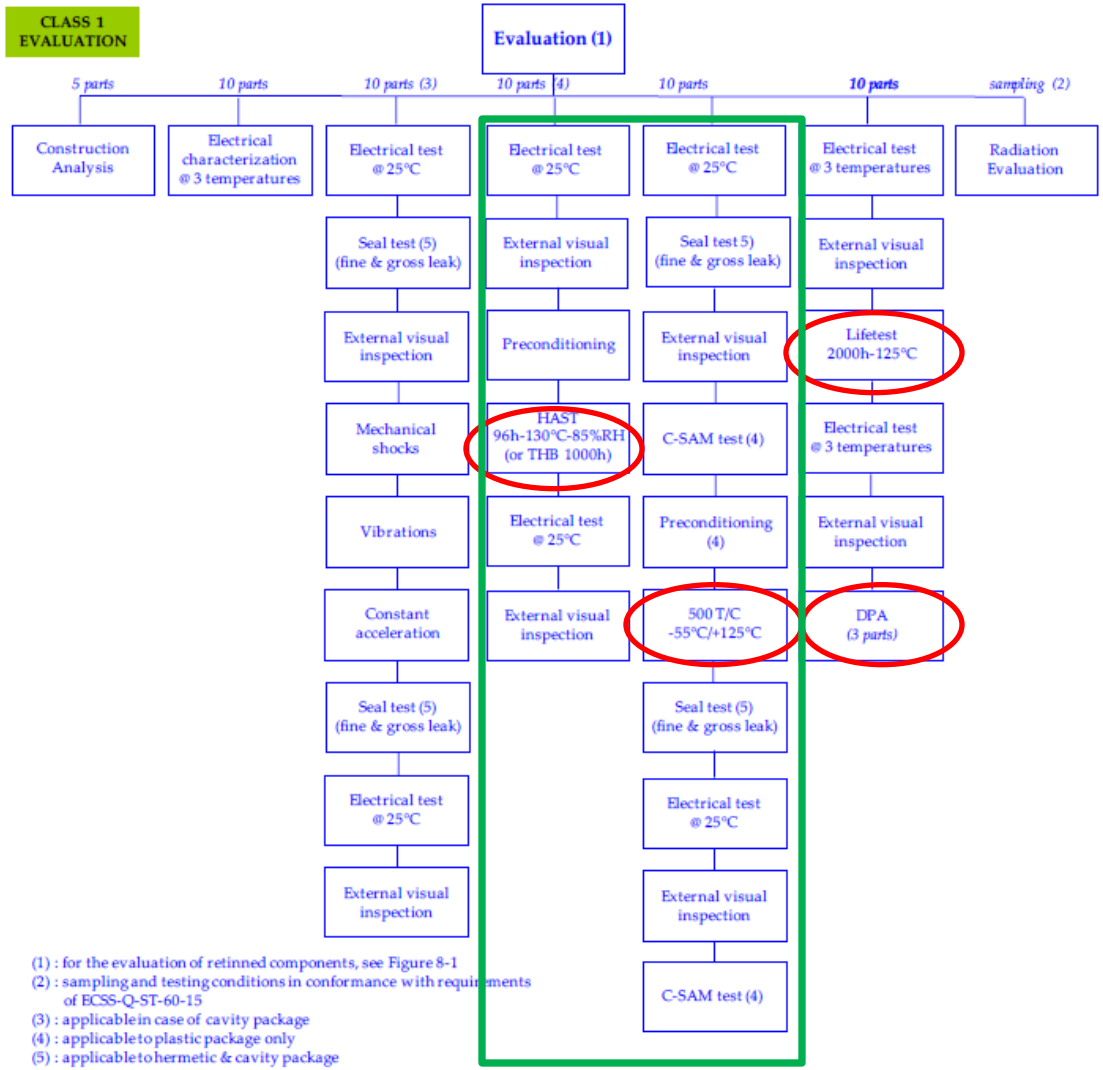


Figure 4-1: Evaluation tests flow chart for Class 1 components

ECSS vs. Class L Delta Notes:

ESA Flow vs. Aeroflex Qual

1. Life Test 2K Hours vs. 1K Hours
2. DPA is essentially Aeroflex Group B
3. Aeroflex serial flow of Autoclave, then Temp Cycle, then Steady State Temperature Humidity Bias Life Test is more stringent then 2 separate branches of HAST (or THB) and Temp Cycle in our opinion
4. Sample Size for number of parts is smaller for Aeroflex Class L Qualification vs. ESA Flow

Qualification Overview

- Aeroflex is currently in production on a QML Class L “pathfinder” device
- Class L flowcharts have been submitted to DLA for review / approval
  - Plan is to meet MIL-PRF-38534 Class K Element Evaluations
- Demonstrate Class L capability through MIL-PRF-38534
  - Subgroup 1 in accordance with MIL-STD-883 Methods 1010, 1014, 2002, 2009, 2026, 2030, 2036 on 5 units
    - Flow allows for use of either Autoclave, Steady State Temperature Humidity Biased Life Test, or HAST
      - Aeroflex will perform Autoclave for Pre-Temperature Cycling screen and Steady State Temperature Humidity Biased Life Test post Temperature Cycling screen
  - Subgroup 2 in accordance with MIL-STD-883 Method 1005 on 5 units
  - Subgroup 4 in accordance with MIL-STD-883 Methods 2009, 2011, 2014, 2019, and 2030 on 2 units
  - Subgroup 5 in accordance with MIL-STD-883 Method 3015 on 3 units
- Qualification results will be submitted to DLA within the next 6 months

Qualification: Group B Subgroup 1 Traveler

- **Group B Qualification Activity**
- **Conducted in accordance with "MIL-PRF-38534 Table IX.b" as per 1490-1090**

Samples will be randomly selected after the completion of 100% pre-potting inspection.

QUANTITY: 5

Operation	Procedure QAP21-|Rev		Date Out	Mach No.	Oper Init.	Qty In	Qty Pass	Qty Fail	Remarks
Group B S/G 1-7	Option 2 only					MIL-PRF-38534			Table IX b
Physical Dimensions	259								2 Devices
Lead Fatigue	SOP-QA-1069								T/M-2004 3(0) B2 (lead fatigue) D (leadless chip carriers) B1 for rigid leads Leads 15(0)
Resistance to Solvents									**Not required – Parts Laser Marked**
Internal Visual & Mechanical	265								1 Device
Accelerated Life Bake / In	221								2 Devices 200°C, 24 Hours
Out									
Destruct Wirebond Pull (Sample is qty of wires)	221								22 Wires each min. or all if less TX,RES,Cap,Dio, :3IC, 5L-L
Die Shear Strength	220								2 Devices; 22 elements min. or all if less TX,RES,Cap,Dio,IC etc..
Steam Age In	257								1 Device
Out									
Solderability	257								1 Device 15 Leads min. or all
Seal									**Not required for non-cavity**

Qualification: Group C Subgroup 1 Traveler

Aeroflex planned screens for these steps.

GROUP C: S/G 1 — **QUANTITY: Small lot = 5(0), Large Lot = 22(0) devices**

OPERATION	Procedure QAP21	Rev.	MIL-STD 883 T/M	JEDEC Method	Condition	Date Out	Mach No.	Oper. Initial	Qty Pass	Qty Fail
External Visual	212		2009							
Resistance to Soldering Heat	PS20-1084		2036							
Electrical	307				Per Device Spec					
External Visual	212		2009							
Ultrasonic Inspection			2030	J-STD-035						
PIND	243		2020		A or B, 5 passes	Not required for non-cavity				
Electrical	307				Per Device Spec					
Autoclave OR	SOP-QA-1069			JESD22-102	96 hours –0, +5 hours 121±2°C, (dry bulb) 100% Humidity, 29.7psia vapor Pressure					
Steady State Temperature Humidity Bias Life Test (85/85)	SOP-QA-1069			JESD22-101	1,000 hours -24 +168 85±2°C (dry bulb) 85±5% Humidity 49.1 psia vapor pressure					
OR Highly Accelerated Temperature and Humidity Stress Test (HAST)	SOP-QA-1069			JESD22-110	96 hours –0, +2 hours 130±2°C, (dry bulb) 85% ±5% Humidity, 33.3 psia vapor Pressure					
Temperature cycling	222		1010		100 cycles, –55 C to 125 C					
Electrical	307				Per Device Spec					
Autoclave OR	SOP-QA-1069			JESD22-102	96 hours –0, +5 hours 121±2°C, (dry bulb) 100% Humidity, 29.7psia vapor Pressure					
Steady State Temperature Humidity Bias Life Test (85/85)	SOP-QA-1069			JESD22-101	1,000 hours -24 +168 85±2°C (dry bulb) 85±5% Humidity 49.1 psia vapor pressure (2/)					
OR Highly Accelerated Temperature and Humidity Stress Test (HAST)	SOP-QA-1069			JESD22-110	96 hours –0, +2 hours 130±2°C, (dry bulb) 85% ±5% Humidity, 33.3 psia vapor Pressure					
Electrical	307				Per Device Spec					
Constant Acceleration			2001		3,000 G, Y1 direction	Not required for non-cavity				
Random Vibration			2026		Condition F	Not required for non-cavity				
Mechanical Shock	244		2002		Cond B, Y1 Direction	Not required for non-cavity				
PIND	243		2020		A or B, 1 pass	Not required for non-cavity				
Electrical	307				Per Device Spec					
Gross Leak	272		1014			Not required for non-cavity				

1/ Ultrasonic inspection may be performed at the end of S/G 1 in lieu of S/G 4
2/ After 240 hrs. read and record electrical test data required and proceed for completion of 1000 hrs.

Qualification: Group C Subgroup 2 Traveler

QUALIFICATION TRAVELER
NON-HERMETIC, NON-CAVITY DEVICES (CLASS L)

CIRCUIT #: _____ **GROUP C TRAVELER #** _____ **J.O. #** _____

GROUP C: S/G 2 **QUANTITY: Small lot = 5(0), Large Lot = 22(0) devices 1/**

OPERATION	Procedure QAP21	Procedure Rev.	MIL-STD 883 T/M	JEDEC Method	Condition	Date Out	Mach No.	Oper. Initial	Qty Pass	Qty Fail
Electrical	307				Room					
					Cold					
					Hot					
Life Test IN	248		1005	JESD22-A108	1000 hrs @ 125° C Time IN					
OUT					Time OUT					
Electrical	307				Room					
					Cold					
					Hot					

1/ Samples from the Preconditioning test to be used for S/G 1

Qualification: Group C Subgroup 4 Traveler

QUALIFICATION TRAVELER
NON-HERMETIC, NON-CAVITY DEVICES (CLASS L)

CIRCUIT #: _____ **GROUP C TRAVELER #** _____ **J.O. #** _____

GROUP C: S/G 4 **QUANTITY: 2(0)**

OPERATION	Procedure QAP21	Rev.	MIL-STD 883 T/M	JEDEC Method	Condition 2/	Date Out	Mach No.	Oper. Initial	Qty Pass	Qty Fail
Samples will be randomly selected after the completion of 100% pre-potting inspection										
External Visual	212		2009							
Ultrasonic Inspection 1/			2030	J-STD-035	Compare with initial results (refer to note 1/ under S/G 1 table)					
Internal Visual & Mechanical	265		2014							
Bond Strength	244		2011		44 wires minimum.					
Die Shear	220		2019		5 elements from each attach process					

1/ The Ultrasonic Inspection will be performed at the end of S/G 1 to compare with the initial results
2/ S/G 4 samples will be processed up to Pre-seal inspection and will not be potted

Qualification: Group C Subgroup 5 Traveler

QUALIFICATION TRAVELER
NON-HERMETIC, NON-CAVITY DEVICES (CLASS L)

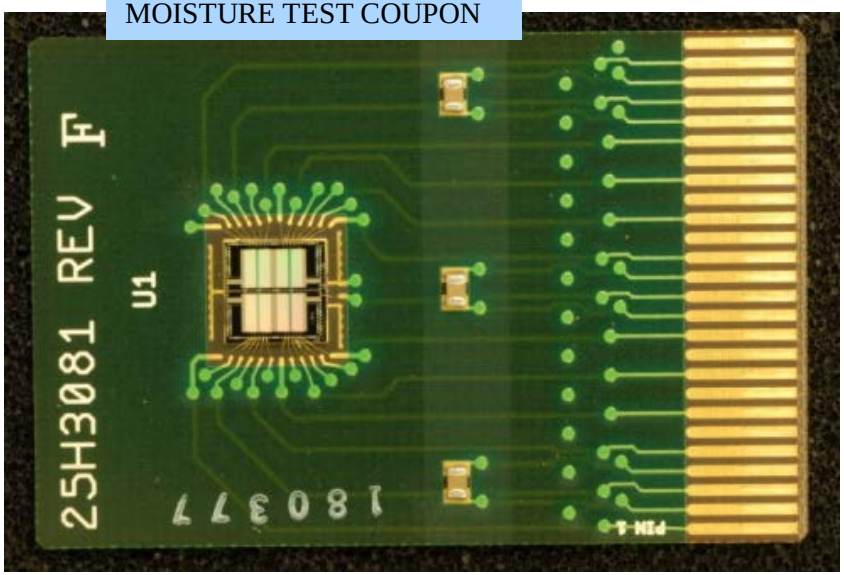
CIRCUIT #: _____ **GROUP C TRAVELER #** _____ **J.O. #** _____

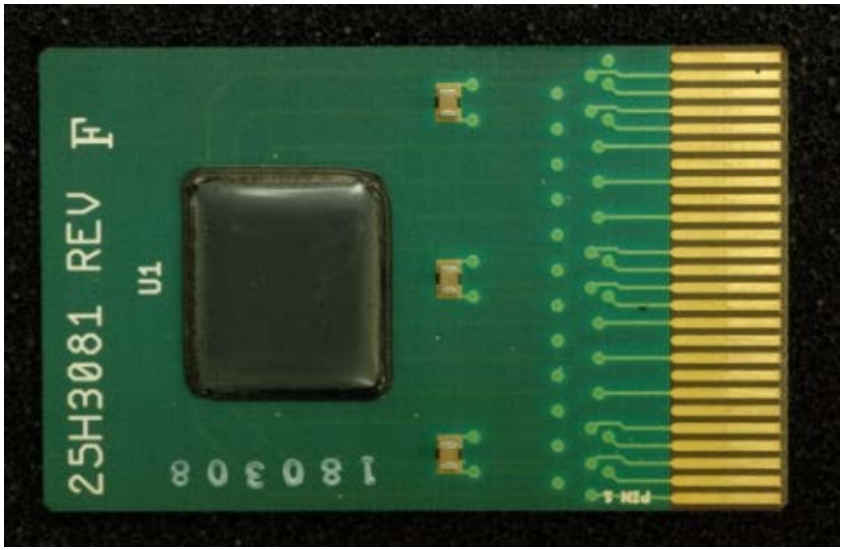
GROUP C: S/G 5 **QUANTITY: 3(0)**

OPERATION	Procedure QAP21	Procedure Rev.	MIL-STD 883 T/M	JEDEC Method	Condition	Date Out	Mach No.	Oper. Initial	Qty Pass	Qty Fail
Electrical	307		3015		Group A S/G 1					
ESD			3015		ESDS					
Electrical	307		3015		Group A S/G 1					

Production Travelers					
Date Codes					
Serial Numbers					

Qualification: Molding Epoxy Ionic Purity



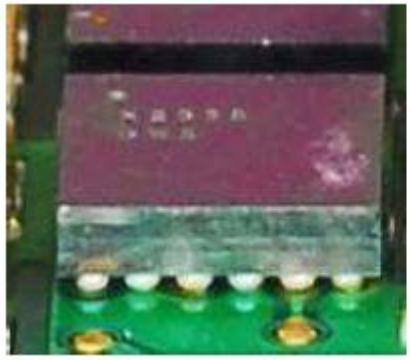


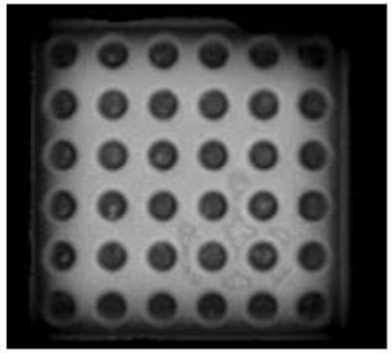
- Aeroflex uses a Sandia Labs developed moisture sensitivity test vehicle
- Encapsulated with each lot of high purity encapsulating epoxy
- Subjected to biased HAST and autoclave to validate epoxy's cleanliness in an accelerated high moisture environment

Design Considerations: Chip Scale BGA

- PDM utilize chip scale BGA on PWB
  - Density advantage
  - Assembly advantage
  - CTE mismatch mitigation
- Aeroflex strategy for success
  - Small dice (< 3mm)
  - Large Ball (~300um dia)
  - Underfill
  - Analysis
  - Deep Thermal cycle testing

- Power MOSFETs
  - 3mm x 3mm, 36 balls (300µm dia, 6 x 6 array)
- Control ICs
  - 6 balls (300 micron dia, 2 x 3 array)
  - 8 balls (300 micron dia, 2 x 4 array)
  - 49 balls (300 micron dia, 7 x 7 array)
  - 56 balls (300 micron dia, 7 x 8 array)
- Small Signal MOSFETs
  - 1mm x 1mm, 4 balls (300µm dia, 2 x 2 array)





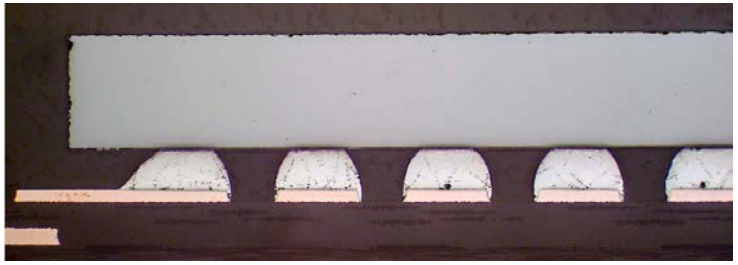
Design Robustness: Chip Scale BGA

- **Destructive Physical Analysis (DPA) per MIL-STD-883**
  - **Method 5009.1**
    - **Solder Ball Shears IAW MIL-STD-883**
  - **Method 2011.8**
    - **Solder Ball Pull Test IAW JESD22-B115.**
    - **Die Shear Strength IAW MIL-STD-883**
  - **Method 2019.8**
    - **Flip Chip Pull off Test IAW MIL-STD-883**
  - **Method 2031.1**
    - **Cross sectioned samples**
    - **Photographs of devices before and after testing**
    - **Sonoscans**
- **Long Term Temperature Cycling**
  - **-55^{o}C to + 125^{o}C, 20 min dwell, 7^{o}C/min ramp rate**
  - **Evaluated at 100 cycle increments**
  - **PASSED 3,500 cycles**

IAW – in accordance with

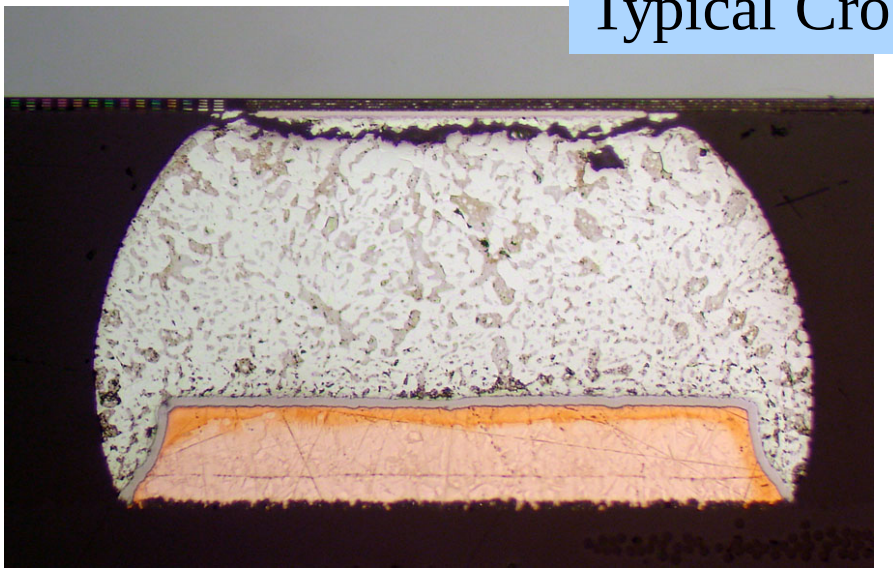
BGA reflow solder: Extreme Temp Cycle

- **Process Delta Qualification @ -65ºC to 150ºC**
- **Post 350 cycles, non-underfilled and underfilled**

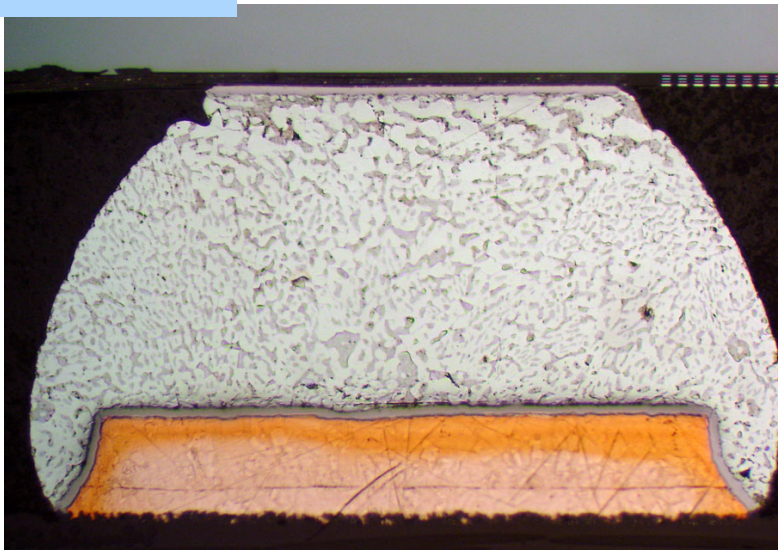


Typical Cross-Section

Non-underfilled



Underfilled



Qualification: Planar Magnetics

- Designs utilize Planar Magnetics
- Bonded to each other and PWB
- Magnetic level mechanical stress testing showed good behavior
  - ~4,000g centrifuge
  - Deep thermal cycling
  - Magnetics in final module will also be supported by molding epoxy

Qualification: Planar Magnetics

Planar Transformers

- Aeroflex has developed a robust Planar Transformer design
- The custom qualification plan developed surpasses the requirements of MIL-PRF-27, MIL-STD-981, MILSTD-1547 and NASA EEE-INST-002 Level 1 requirements.
- Qualification has passed Subgroups 1-3 testing and currently in Subgroup 4 Life Test
- EVALUATIONS
  - 12 units assembled per specification
  - Subjected to 100 Thermal Cycles, in 25 cycle increments, 2,500G Centrifuge performed between cycles. PASSED
  - Split into 2 groups of six
    1. First group centrifuged to failure
    2. Second group subjected to Thermal Cycles and Centrifuge to failure (25 thermal cycles at the temperature extremes of -40°C to +120°C at a ramp rate of 3-10 °C/min, followed by 2,500G centrifuge)

Qualification: Magnetics - Results

Transformer Design – Centrifuge to Failure

1. Six parts – pre-conditioned w/100 Thermal Cycles then subjected to a series of increasing G-level Centrifuge tests until failure
   - 2,500Gs to 4,000Gs (500G increments) PASSED
   - @ 4,500Gs 4 of 6 Failed. Ferrite cores broke apart
2. Six parts subjected to a series of additional Thermal Cycles at 2,500G Centrifuges until failure
   - 125 Cycles to 300 Cycles (25 cycle increments) PASSED
   - @ 350 Cycles 2 of 6 Failed. Ferrite cores broke apart

- No adhesion failures.
- Excellent margin to flight requirements.

Wire bond DOE: Al Wedge to organic PWB

- **Purpose of Evaluation**
  - Demonstrate performance of Al wire bonding, in accordance with a modified MIL-PRF-38534 Appendix D, Class L non-hermetic cavity stress screening (reduced time 500 vs 1000hrs)
- **Coupon Description**
  - Quantity (4) PDM Devices
  - Each device mounted on a wire-bondable organic PWB
  - Wire Type: 1.25 mil AL / 1% Silicon Wire
- **Coupon Construction and Screening Background**
  - 100% NDPT at 2.5 +/- 0.2 grams: no anomalies
  - 100% Electrically tested - PASSED
  - 4 parts encapsulated per production process, re-tested 100%, PASSED

NDPT – Non-Destructive Pull Test

Wire bond DOE: Al Wedge to organic PWB

- **Environmental Stress Screening**

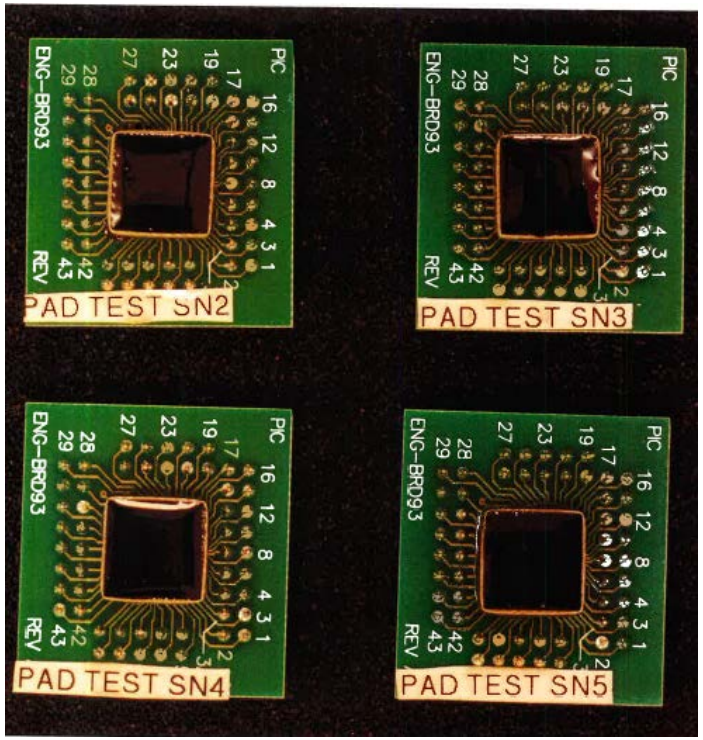
S/N 002 & 004 parts subjected to:	S/N 003 & 005 parts subjected to:
▼ 85°C / 85% Humidity at 96, 154, 250 hours	▼ Autoclave per JESD-A-102
▼ 100 Temp Cycles	▼ 100 Temp Cycles -55°C to +125°C
▼ 250 hours of 85°C / 85% Humidity	▼ HAST

- **Mechanical Analysis post Environmental Stress Screening**
  - **Cross-sections performed**
    - **No Mechanical aberrations (intermetallics or indication of interfacial delam or lift of wires to PWB) detected from modified 38534 appendix D abbreviated Class L exposure**
  - **Mechanical Analysis images follow**

- **Conclusion:**
  - **Class L wirebond process DOE was successful – Aeroflex is proceeding with planned PDM production & then full qualification**

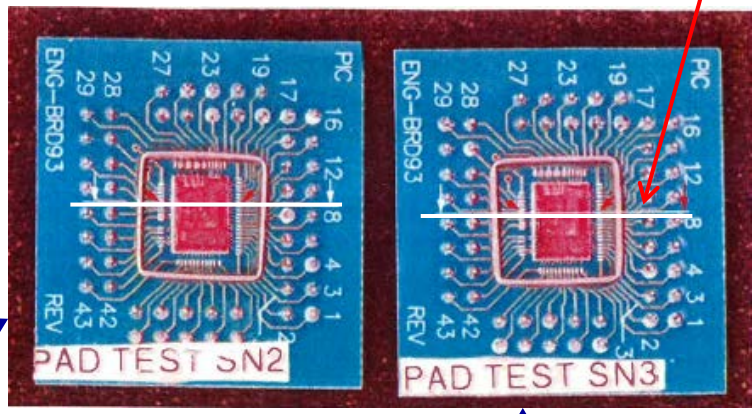
Wire bond DOE: Al Wedge to organic PWB

Coupon Sample Images



Metallographic Sectioning post Screening

White line cross-section location



S/N 002 subjected to:

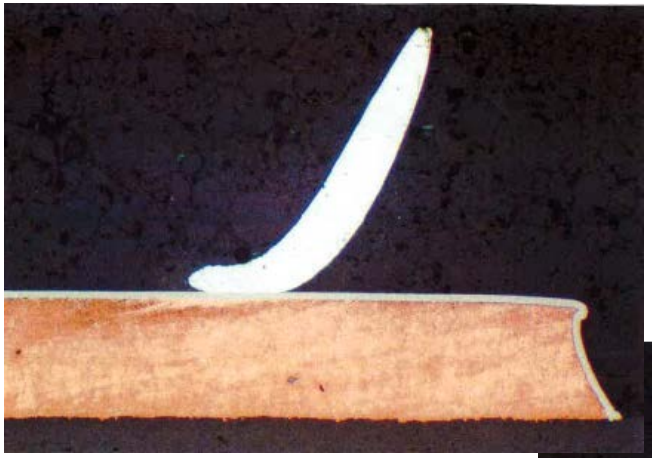
- 85°C / 85% Humidity at 96, 154, 250 hours
- 100 Temp Cycles
- 250 hours of 85°C / 85% Humidity

S/N 003 subjected to:

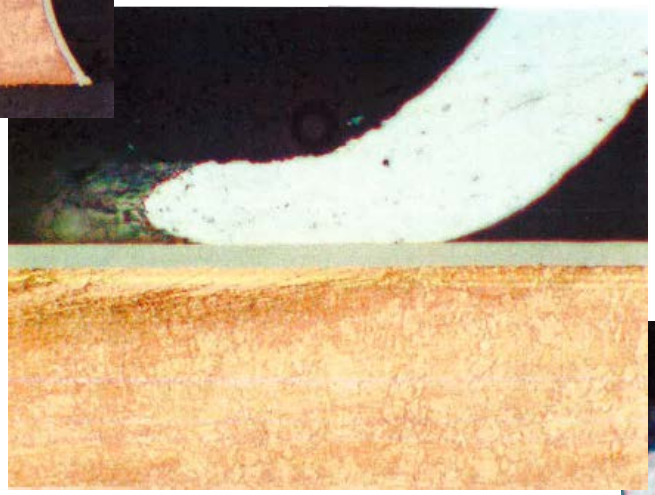
- Autoclave per JESD-A-102
- 100 Temp Cycles -55°C to +125°C
- HAST

Wire bond DOE: Al Wedge to organic PWB

Metallographic View of PCB Pad Wire Bond after 1-Micron Diamond Polishing



200X Magnification



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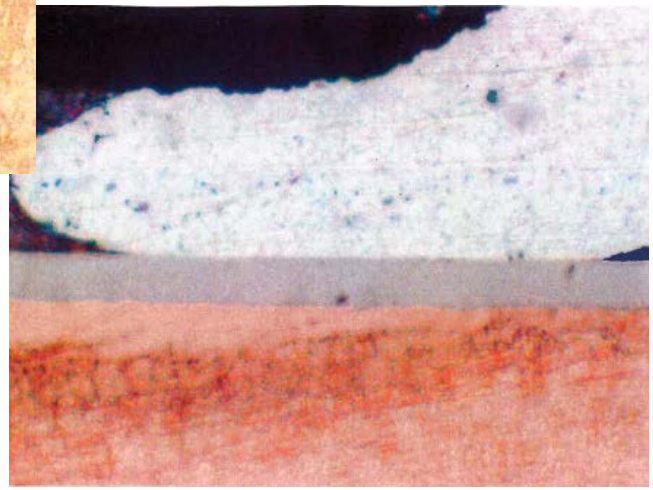

2,560X

Summary

- Aeroflex has manufactured and delivered COB non-hermetic modules to customers that are in space today
  - TRL-9 qualified to customer source control drawings
- The introduction of Class L, MIL-PRF-38534, Appendix D, establishes a standard for the Aerospace and Defense industry for the “Highest quality class [for] non-hermetic” devices
- Aeroflex considers Class L “highly accelerated” screening requirements to be more stringent than the legacy qualifications previously use to achieve the TRL-9 designation
- Aeroflex has demonstrated that its heritage processes are capable of yielding fully qualified COB non-hermetic modules in compliance with MIL-PRF-38534, Appendix D Class L