Test Flows for Space PEMs

Harry Shaw, Jeannette Plante, and Brandon G. Lee
Goddard Space Flight Center/NASA

In the past PEMs were not considered to be appropriate for space mission applications because of their commercial connotation. However, the use of PEMs has been gradually increasing and is expected to continue to increase for several reasons. PEMs have been gaining attention as alternatives to military standard parts, which do not keep up with technological changes. Their advantages in size, weight, cost and performance also encourage their use. Customers demand "faster, cheaper, better and more reliable products" in order to meet their needs for state-of-the-art technology.

The risks associated with PEMs are evolving over time as the technology improves and established manufacturers learn how to control their processes for high yield. Manufacturers with less experience may produce parts with well-understood failure mechanisms: moisture induced failures and ion driven internal corrosion. PEMs are almost always sold as commercial-off-the-shelf (COTS) components, so small volume users cannot dictate screening testing or that the manufacturer perform reliability testing. It is extremely difficult, if not economically impossible, for small volume users to procure single packaging lot date codes and to have any traceability to wafer lot (and certainly not single wafer lot date code). These drawbacks point to the greatest underlying concerns associated with PEMs:

- Are the parts reliable on some level?
- How do we establish what the Level is?
- How do we upscreen to achieve a level appropriate for use in NASA spacecraft?
- How do we establish accelerated test conditions without complete knowledge of the encapsulation materials?
- Lastly, where QML PEMs are available, should NASA treat them in the same manner as QML hermetic, full temperature range devices?

An examination of PEMs manufacturer's websites indicates that there is a wide variation in the reliability validation done by them. Some do "one-time" qualification testing while others do regular life, moisture and burn-in testing.

Goddard Space Flight Center (GSFC) projects are using PEMs and an analysis has been done on three manufacturer's PEMs as part of the PEMs assessment activity. The following process was used:
- Understand the testing that space users are applying for upscreening.
- Understand the testing the manufacturers are doing including, the frequency of the test and sample criteria.
- Determine a test flow based on the particular requirements of the program.
- Eliminate tests done regularly by the manufacturer on the candidate parts or parts sufficiently similar to the project candidates.
- Establish a test flow for the project and address particular electrical performance parameters that need to be screened or monitored in qualification testing.

The three manufacturers being considered for a GSFC instrument are Maxim, On Semiconductor, and Analog Devices.

PEMs screening and qualification tests have been developed and recommended by those involved in high reliability space applications including NASA/GSFC, the Jet Propulsion Laboratory (JPL) and the Johns Hopkins Applied Physics Laboratory (APL). Though they have similar goals for achieving space level reliability their approaches to screening and qualification testing are slightly different and vary based on different spaceflight missions. Those approaches have been reviewed to establish the most suitable testing flow for the GSFC project. Some of these flows are still drafts and unpublished so they are shown for illustration only.

The testing flows consider mission life and in some cases mission environmental conditions. They generally consider tests that fall into three categories: moisture resistance, operating characteristics over the entire temperature range and device life under high temperature. Table 1 and 2 show the comparison of the upscreening flows found. The following are the major tests used in the upscreening flows and by the manufacturers of PEMs:

• Visual Inspection:
Visual inspection is conducted in the beginning and end of both screening and qualification to examine any defects present such as broken wire bonds, cracked die, misaligned leads, etc.
• Burn-In:
Used to remove infant mortals from the lot, a 10% PDA is generally applied.
• Acoustic Microscopic Imaging (AMI):
Acoustic Micro-Imaging (AMI) is a popular Non-Destructive Analysis (NDA) method to identify material boundaries and voids that can induce moisture absorption and CTE mismatch stress.
• Radiographic Examination (X-ray):
Radiographic Examination, or X-ray shows the part's internal defects such as broken wires and lead connections, cracked leads and extraneous material. Real-time X-ray is often used to obtain high-resolution images in various planes by rotating the device inside the chamber. Recent findings indicate that X-ray may be destructive because it deposits ionizing doses into the semiconductor, so care must be taken when using this tool.
• Temperature Cycling:
Temperature Cycling is conducted to determine the resistance of devices to alternate exposure at mission temperature extremes. Physical damage caused by thermal expansion and contraction during the testing can lead to defects including cracking and delamination of packages and internal structures. It can also lead to changes in the electrical characteristics resulting from mechanical damage.
• Life Testing:
Life testing is performed under biased conditions to identify latent failure mechanisms and to quantify part reliability. It can detect design, metal integrity, silicon contamination, manufacturing, and assembly-related defects. High Temperature Operating Life (HTOL) is a life test.
• DPA:
Along with X-ray inspection, the purpose of Destructive Physical Analysis is used to gain knowledge of device construction technology. DPA involves destructive cross-sectioning and chemical etching to inspect internal features such as wire bonds and die attach.
• Moisture Testing:
Moisture testing drives moisture into the package that can lead to moisture-induced defects such delaminations and cracks. Pressure Pot, 85˚C/85 RH, and HAST tests are moisture tests. Highly Accelerated Stress and Temperature (HAST) testing is quickly replacing 85/85 testing. It serves the same basic function as 85/85 in typically 10% of the situations, making HAST tests useful for immediate feedback and corrective action at the production level. A biased HAST test can provide a Burn-in condition while doing moisture testing.
• Electrostatic Discharge (ESD):
ESD Testing is used to establish how susceptible the parts are to ESD damage. Mil-Std-883 Method 3015 is used. The purpose of this test is to measure the relative ability of the part to withstand accidental electrostatic discharge. Both the Human Body Model and the Machine Model are used in testing. Devices are divided into groups and tested at specified increments across the ESD test range.
• Radiation Hardness Assurance (RHA):
Just as military products must be assured for operation in the ionizing radiation environment of space, commercial PEM parts do too. A collective knowledge about the affect of the plastic material on radiation performance has not been achieved, but investigations are starting and continuing. Radiation tolerance is believed to be a function of the silicon's design and materials and less a packaging issue.

Maxim's, On Semiconductor's and Analog Devices' test flows were reviewed. Maxim performs electrical testing, burn-in and post burn-in electrical test on a weekly basis; while temperature cycling, high temperature with bias and HAST testing with bias are conducted quarterly. On Semiconductor conducts qualification testing of interest to NASA, but not the screening required. They are performing life testing, Temperature Cycling and HAST yearly. Analog Devices performs very little long-term bias or temperature testing.

Maxim selects test samples on a package and semiconductor technology basis. ON samples on this basis as well. Analog Devices samples in this way and also by location. Research is still being done to find out if Maxim and ON do testing by location as well. Table 3 shows the results of the research done to understand the flows and methods used by these manufacturers.

Further research and study should be continued to gain more knowledge about PEM manufacturer flows and data. Also to better understand how user test flows can be reduced without negative impact to the reliability of the parts used by the projects.

Table 1. Space PEMs Screening Tests: Five References Compared

Projects **Screen Test**	**Ref 1**	**Ref 2**	**Ref 3**	**Ref 4**			**Ref 5**
				< 1yr	**1-5yrs**	**10-15 yrs**	
Pre-Encapsulation Visual Inspection	No	MIL-STD-883 TM 2010 CONDITION B	No	No	No	No	Yes, the nearest applicable standard.
Initial Electrical Measurement	No	FUNCTIONAL OR DYNAMIC DC ANDAC TESTS 25C PER DEVICE SPECIFICATION	Mil-Std-883 TM 5005	+25C; -55C	-55C; -15C;+55C;+70C	Yes, Not specified	Yes, mission temp profile extreme.
Life Test	No	No	No	No	2000hrs at +70 C	Not specified.	No
AMI	In accordance with IPC JEDEC J-STD-020 Level 1 and Level 2: 100% Level 3: MIL-STD-1916, VL IV, Normal Attribute Sampling	MIL-STD-883 TM2030	YES	Top, bottom, thru	Top, bottom, thru	Top, bottom, thru	No
Interim(pre-burn-in) electrical parameter	In accordance with device specification [4/]	No	No	No	No	No	No
Post AMI Electrical Measurement	No	NO	No	+25C; -55C	-55C;-15C;+55C;+70C	Yes, Not specified	No
Serialization	Yes	No	No	No	No	No	No
High Temperature Storage	No	MIL-STD883 TM1001.8, JEDEC 22-A103	No	No	No	No	No
Burn-In	**Static Burn-in** Level 1: • MIL-STD-883, TM 1015, Condition A or B, -48 hrs minimum for [Note 1] -240 hrs minimum for [Note 2] Level 2 and Level 3: •MIL-STD-883, TM 1015, Condition A or B - 48 hrs minimum for [Note 1] - 160 hrs minimum for [Note 2] **Dynamic Burn-In** Level 1: • MIL-STD-883, TM 1015, Condition D, 240 hrs for [Note 3] Level 2 and Level 3 • MIL-STD-883, TM 1015, Condition D, 160 hrs for [Note 4]	MIL-STD-883 TM1015.7 CONDTION D, Dynamic Burn-In 160HRS @ 125 °C	72/160hrs. Max	Dynamic, 5V for 72hrs at +55C	Dynamic, 5V for 72hrs at +55C	Dynamic, 5V for 72hrs at +55C	No

Post Burn-In Electrical Measurements	Final electrical Test In accordance with device specification, except parameters specified in 311-INST-001 shall be tested as a minimum. a. Static tests@ 25°C, Max, Min rated operating temp. b. Dynamic and functional tests@ 25°C, Max, min operating temp. c. Switching test @ 25°C, Max, Min operating temperature.	DC PARAMETRIC FUNCTIONAL AND AC PARAMETRIC TESTS AT AMBIENT TEMPERATURE OF –55,25 AND 125.	Mil-Std-883 TM 5005	+25C; -55C	-55C;-15C;+55C;+70C	Yes, Not specified	No
Temperature Cycling	MIL-STD-883 TM1010 Condition C(or the manufacture's specified storage condition, whichever is less), 20 cycles minimum	Mil-Std-883 TM 1010 Cond B 40 CYCLES AT 125C	Mil-883 TM 1010 10cycle	-60C to +25(10cy)	-60 to +60C(10cy)	Yes, Not Specified	No
External Visual	In accordance with GSFC PEM Guidelines, paragraph 7.1	MIL-STD-883 TM2009,JEDEC-STD-22 METHOD B100	Yes	No	No	No	No
Radiography (X-ray)	No	MIL-STD-883 2012	No	No	MI-STD-883 TM 2012	MI-STD-883 TM 2012	Yes, MIL-STD-883. TM 2012
DPA (sample)	No	No	yes	No	No	No	No
Calculating PDA(<10%)	Level 1: 5% Leve2 and Level 3 10%	No	yes	No	No	No	
Packing and Shipping	IPC/ JEDEC J-STD-033 [5/]	No	No	No	No	No	No

Note:

1/: Applicable to Digital (CMOS, PMOS, NMOS, BiMOS); Linear (MOS Line Driver/Receiver); Linear (MOS Analog Multiplexer/Switch); Mixed Signal, MOS A/D and D/A Converters, and similar technologies

2/: Applicable to Linear (Voltage Regulator, Voltage References); Linear (Pulse with modulators); Linear (Timers), and similar technologies.

3/: Applicable to Digital (TTL, ECL, DTL); Linear(Op-Amp, Instrument Amp, Sample/Hold, Comparators); Linear(Active filters); Mixed Signal, Non-MOS A/D and D/A Converters; Linear Non-MOS Line Driver/Receiver; Linear Non-MOS Analog Multiplexer/Switch, and similar technologies.

4/: Optional test point. If delta parameter are not required.

5/: 48 hours @ 125°C, or the manufacturer maximum storage temperature, whichever is less. Reference IPC/ JEDEC J-STD-033 for further guidance. Vapor barrier bags (MIL-B-8 1075, Type I), packed with approved dust-free desiccant (MIL-D-3464, Type II), and moisture indicator card(MIL-I-8835, MS51015) shall be used.

Table 2. Space PEMs Qualification Tests: Five References Compared

Projects **Qual Test Condition**	**Ref 1**	**Ref 2**	**Ref 3**	**Ref 4**			**Ref 5**
				< 1yr	**1-5yrs**	**10-15 yrs**	
Pre-Conditioning	Moisture intake JESD 22-A113, Paragraph 3.1.5. (168 hrs, +85%RH) Reflow simulation with flux, clean, and dry JESD 22-A113, Paragraphs 3.1.6, 3.1.7, 3.1.8, and 3.1.9(Use vapor phase profile +219 °C, no preheat)	No	(5 pieces max.) SMD to be machine soldered	No	No	No	No
Visual Inspection		No	yes	No	No	No	No
Life Test (or HTOL)	MIL-STD-883 TM1005 Condition D 1000 hours at max operating junction temperature	Mil-Std-883,JQA108	No	JEDEC-JESD22-A108(5V for 72 hour at +55)	JEDEC-JESD22-A108(200hrs at +70C)	JEDEC-JESD22-A108(not specified)	JEDEC-JESD22-A108, following by mission temp extreme and ambient
Electrical Testing	Per device specification	No	No	+25C,-55C(after Life Test)	-55C;-15C;+55C;70C(after Life Test)	Yes. Not specified(after Life Test)	Following by electrical test at mission temp extremes and ambient
Temp Cycle	No	883 TM1010 Cond C, JEDEC 22-A-104	20 cycles	No	No	883 TM 1010, 1000cyc, -50C to +150	JESD-22-A 104. Following by electrical test at mission temp extremes and ambient
HAST with Bias	JESD 22-A110, with continuous bias(250hours, +130°C, 85%RH)	JEDEC 22-A-110	No	No	No	JESD22-A110(96hrs @ +130/85%RH)	No
Temp cycle, humidity and bias	No	JEDEC 22-A-100A	No	No	No	No	No

Power and Temp cycling	No	JEDEC 22-A-1O5A	No	No	No	Power cycle only (1000cycle at max rated power)	No
Thermal Shock	No	883 1011, JEDEC 22-A-106	No	No	No	No	No
Solder heat Resistance	No	JEDEC 22-B-106A	No	No	No	No	No
Solvent Resistance		883 TM2015	No	No	No	No	No
ESD Sensitivity Test	No	883TM3015, JQA2	No	No	No	EIA/JESD22-A114-A	No
Radiation Hardness Test(RHA)	No	883 TM1019, ASTM F1192-88	No	No	No	No	MIL-STD-883, TM 5005. Group E or equivalent
Solderability		883-TM2003&2022	No	No	No	No	No
Lead Integrity		883 TM2004	No	No	No	No	
85C/85%RH	No		yes	No	No	No	JESD-22-A101. Following by electrical test at mission temp extremes and ambient
High Temp Storage	No	883 TM 1008, JQA 103	No	No	No	No	No
Bake out	No		16 hrs	No	No	No	No
Salt Atmosphere	No	JEDEC 22-A 107A	No	No	No	No	No
Outgassing	No	ASTM E595	No	ASTM E 595-93	No	ASTM E 595-93	No
Flammability	No	UL-94-V OR V1	No	No	No		No
Traceability (Date C.)	No	No	No	No	No	Wafer Lot preferred	No
Traceability (QML)	No	No	No	No	No	QML Vendor Preferred	No
Current Density Cal	No	No	No	No	No	Worst Case	No
Data Retention	No	No	No	No	No	1000 hrs @ +150C	No
SAM	No	No	yes	No	No	No	No
DPA	SEM(883TM2018); Bond Pull(883TM2011); Decap Internal Visual (883,2010); Die shear (883 TM2019)	No	yes	No	No	No	MIL-STD-1580
Reflow Phase	No	No	220C, 1 pass	No	No	No	No
Internal Water Vapor Content	883TM1018	No	No	No	No	No	No
Final Visual Examination	No	No	yes	No	No	No	No

Table 3. Tests Performed by the Manufacturers

MAXIM Commercial	**MAXIM Military**	**ON Semiconductor** (all testing is reported in a yearly summary by test hours)	**Analog Devices** (Performed quarterly. Number of lots tested is based on percent of total production)
Life Testing - quarterly	**Rapid-Response Reliability Monitors** **Operating Life Test** Weekly	**Autoclave + Moisture Level Preconditioning**	**Autoclave + Moisture Level**
Burn In - weekly	**Pressure Pot** - Weekly	**Bond Pull Strength**	**Temperature Cycle**
Pressure Pot Test – one time qual	**X-Ray** - Daily	**Bond Shear**	**Thermal Shock**
HAST or 85/85 Test – quarterly	**Solderability** - Monthly	**Destructive Physical Analysis**	**Highly Accelerated Stress Test (HAST)**
Temperature Cycling Test - Quarterly	**Mark Permanency** Monthly	**Electrostatic Discharge**	**High Temperature Storage Test (called life test by mfr)**
High-Temperature Storage Life Test - Quarterly	**Solder Thickness** Monthly	**High Temperature Bake**	
E.S.D. and Latch-Up Testing – Qualification Only	**Open Short Test** Quarterly	**High Temperature Operating Life**	
	Long-Term Reliability Monitor Program (Quarterly) **Operating Life Test (Op Life)** 1000 Hours	**HAST with Bias**	
	Biased Moisture Life	**Moisture Level Preconditioning**	

Test (85/85) 1000 Hours **OR** **Highly Accelerated Stress Test (HAST)** 100 Hours	
Temperature Cycle 1000 Cycles	**Solderability**
High-Temperature Storage 1000 Hours	**Temperature Cycling + Moisture Level Preconditioning**
Autoclave (Pressure Pot w/o Bias) (PPT) 168 hours	