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Use of Plastic Commercial Off-The-Shelf (COTS) Microcircuits for Space Applications

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1. ABSTRACT

Commercial-off-the-shelf (COTS) plastic encapsulated microcircuits (PEM) are candidate-packaging technologies for spacecraft due to their lower cost, lower weight, enhanced functionality and speed. PEMs can weigh half as much as their counter part ceramic packages. A lighter package results in a smaller overall payload for the same board functionality, a concern of critical importance for space missions because the payload mass dictates the launch vehicle requirements. Engineers within the commercial and aerospace industries are using trade-off and risk analysis to aid in reducing spacecraft system cost while increasing performance and maintaining high reliability. Establishing and implementing a parts program that effectively and reliably makes use of these state-of-the-art, but potentially less reliable, devices has become a significant portion of the job for the parts engineer.

Assembling a reliable high performance electronic system, which includes COTS components, requires that the end user assume a risk. Companies have developed methodologies by which they use accelerated stress testing to assess the product and reduce the risk involved to the total system. Currently, there are no industry standard procedures for accomplishing this risk mitigation for use of COTS in space.

PEMs are a subset of commercial off the shelf parts. NASA programs are struggling with the prospect of using PEMs in their respective projects. Most of the projects are considering the use of PEMs on a case-by-case basis. One of the issues facing the space industry is that most PEMs are not screened by the manufacturer to their equivalent hermetic counterpart (if one exists). Therefore, projects must screen and qualify PEMs for each of their applications. The main purpose of qualification and/or screening of any component is to mitigate risk to the end user. Commercial parts are not qualified or recommended by industry to stringent levels of reliability and quality required for NASA's space missions. Therefore, the COTS parts/packages need to be assessed by each NASA program/project to reduce the risk significantly for short and long duration NASA missions. Assembling a high performance electronic system with COTS PEMs components requires that the end user know the risk associated with such implementation. To minimize the risk involved, users employ accelerated stress testing to assess the packages and reduce the risk involved to the total system that depends on the duration of the mission. There are no standard risk mitigation techniques to accomplish this result. With the increased use of PEMs in NASA's Space applications there is an increased need to develop an assessment and reliability strategy that can be versatile enough to be used in all NASA Programs/Projects. This paper will discuss a proposed methodology intended for qualification of PEMs by NASA.

2. INTRODUCTION

Plastic Encapsulated Microcircuits (PEMs)(Spell out) are much more readily available than hermetic devices, mainly because market forces (cost and volume) encourage most designs to be developed first as plastic-encapsulated [1,2]. At any given time, more part functions are available in plastic than in ceramic [3]. The U.S. military and government, the major purchasers of hermetic parts, have become relatively small portions of the total electronics market. It is estimated that hermetic parts accounted for less than 0.25% by the year 2000 [4]. With package technology moving to surface mount, development of ceramic packages has lagged further in the microelectronic market, making adaptation of plastic-packaged integrated circuits to government and military applications even more critical. With global competition, industrial research in materials and manufacturing processes will continue to focus on PEMs. In general, PEMs weigh about half as much as ceramic packages [3]. A lighter package results in a smaller overall payload for the same board functionality, a concern of critical importance for space missions because the payload size dictates the launch vehicle requirements.

The cost of a packaged electronic part is determined by several factors: die, package, volume, size, functional complexity, assembly cost, screening yield, and the specified qualification-required tests. Hermetic packages usually have a higher material cost and are fabricated with more labor intensive, manual, processes due to smaller volume requirements. In addition, hermetically packaged integrated circuits purchased to military specifications can have material costs up to ten times more than plastic packaged integrated circuits because of the rigorous testing and screening included in the procurement costs [5]. When both types were screened to customer requirements, it is estimated that purchased components for plastic packaging of integrated circuits cost 12% less than their hermetic counterparts, primarily due to the economics of high volume production [6]. COTS do not necessarily cost a NASA project less to use than full US MIL spec. parts. [7] Appropriate reasons for projects to select COTS are for mission essential functionality or for availability if the build schedule is tightly constrained. There are a number of reliability related issues with using COTS PEMs for space, independent of the device technology, including traceability, lot conformance, relevance of manufacturer data, screening, change control, radiation hardness and obsolescence.

Qualification tests estimate expected life and design integrity of a device. They are destructive by nature. Most tests are not conducted at the application conditions, but incorporate accelerated levels of stress to accelerate failure mechanisms, often at known sites in a device. The main purpose of qualification and/or screening of any component is to mitigate risk to the end user. Many of the new NASA missions follow the "faster, better, cheaper" philosophy which is intended to mitigate as much risk as prudently possible for a reasonable cost.

3. RELIABILITY OF PEMs

The reliability of plastic-encapsulated microelectronics has increased tremendously since the 1970s, due largely to improved encapsulating materials, die passivation, and manufacturing processes. In particular, modern encapsulating materials have low ionic impurities, good adhesion to other packaging materials, a high glass transition temperature, high thermal conductivity, and coefficients of thermal expansion matched to the leadframe. Advances in passivation include fewer pinholes or cracks, low ionic impurity, low moisture absorption, and thermal properties well matched to the substrate.

The forces driving these improvements are the system manufacturers that have placed increasingly stringent quality and reliability requirements on PEM suppliers. At the start of 1995, an Average Outgoing Quality factor of less than 20 ppm and failure rates of less than 1 failure in 10^8 device hours were not uncommon [8]. It is expected that these numbers will continue to decrease. Perhaps the best endorsement for PEMs is from automotive manufacturers. For example, automotive qualification includes sample temperature cycling for 1000 cycles, thermal shock (liquid-to-liquid) for 500 cycles, 85°C and 85%RH testing for 1000 hr, life testing for 1000 hr, high-temperature reverse bias for 1000 hr, intermittent operational life testing for 20,000 cycles, and autoclave (live steam) testing for 96 hr. The number of rejects allowed for all these tests is zero. Most vendors pass these tests without problems, indicating a broad, industry-wide ability to meet or exceed harsh automotive standards [9].

Even with modern improvements to PEMs reliability there are still uncertainties associated with using PEMs in space environments. Some missions require the electronics to operate in a relatively benign environment while other missions are more severe. Currently, users of electronics for space applications screen and derate all parts, plastic or hermetic, for each application. When high-rel hermetic packages are procured, the manufacturer has generally screened them (with the cost passed on to the end user). This is not the case for PEMs. The end user must decide on how best to screen and/or qualify parts for their particular application. Sometimes the screening is intended to assure that parts can be used outside of the manufacturer's specified limits. The University of Maryland CALCE Center has termed the process to use parts in this manner as 'uprating' [10]. The choice to *uprate* can come with various legal consequences. Most manufacturers have advocated that using a part outside its intended temperature range will automatically invalidate any implied warranty.

4. REQUIREMENTS FOR SPACE

NASA has traditionally categorized space level EEE parts by reliability assurance level, with Grade 1 as the most reliable, intended for use in mission critical and life support applications, Grade 2, moderate reliability for general purpose applications and Grade 3 for non-mission essential, higher risk applications. Grade 1 parts are generally US MIL Class S, V or K parts, Grade 2, Class B, Q or H and Grade 3 may be MILSTD- 883 compliant. These levels offer cost option tradeoffs because the procurement cost for Grade 1 parts is typically higher than for Grade 2, which in turn is higher than for Grade 3.

Using Grade 1 parts or their equivalent should be the user's first choice when available, since reliability risk is minimal and acquisition cost is competitive. When Grade 1 parts are not available, and commercial grade is to be used, it is highly recommended that some upscreening be performed to ascertain reliability and radiation risk. Commercial parts are highly at risk when used in a high reliability application (e.g., space). In particular, plastic parts must be evaluated for package defects as well as electrical and radiation performance. Commercial parts are almost always manufactured on multiple foundry/processes, assemblies, and screened by different test facilities. Upscreening, and or qualification by the user, are expensive and can jeopardize parts due to mishandling. Great care is therefore taken in its planning and execution.

Upscreening and qualification is only valid for the lot being tested and results cannot be extrapolated to other lots. This is especially true for radiation results. Performing upscreening and qualification on a part does not make it equivalent to a Grade 1 part. It does however considerably reduce risk and quantify its merit by the test results (fallout). Estimates made by two independent groups, one an industrial consortium, another from the US Army arrived at estimates of $13,500 and $15,000 respectively for the cost of screening microcircuits. [7] Upgrading costs for microcircuits make COTS upgraded to Grade 2 almost as expensive as off-the-shelf Grade 1 parts. Again, COTS only makes sense for essential functionality or to meet size weight or availability constraints. The cost effectiveness of COTS becomes even more dubious when radiation is considered [7].

It is reasonable to assume that COTS active parts are not designed or manufactured to meet any particular level of radiation hardness, for Total Ionizing Dose (TID) or Single Event Effects (SEE). Therefore, Radiation Hardness Assurance assessments have to be performed on every lot. This is true, even for follow-up buys of previously procured part types, because process improvements, die shrinks etc. occur almost continuously with COTS parts and such changes can negatively impact radiation performance. COTS screened to Grade 2 cost about twice as much as Grade 2 parts and one and a half times as much as Grade 1. This reinforces the conclusion that COTS microcircuits are not a low cost alternative to inherently space level parts.

5. PEMS PRESENT A RISK FOR SPACE

Using PEMs in space flight applications raise concerns about traceability and lot conformity. Figure 1 illustrates an example of a label from a bag containing MIL-STD-883 compliant microcircuits from a major international supplier. The globalization of microelectronic manufacturing has created major problems of traceability. Mixing of sub-lots with different histories is possible for PEMs. Manufacturers may mix sub lots together on the same reel without clearly identifying them.

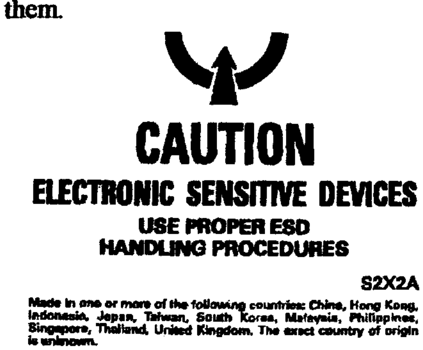

Figure 1: Lack of Traceability for COTS

Although manufacturers may claim traceability to raw material lots, wafer runs etc. if sub-lots are mixed together in bulk packaging or in the bowl feeders supplying tape-and- reel machines this traceability is difficult to maintain. Insight into the precise make-up of lots received may be impossible for the small-scale space parts buyer so sample based evaluations such as DPA and radiation hardness assurance (RHA) may not be effective. NASA has already had experiences where COTS lots have been found by DPA to contain multiple (up to 5) die lots or exhibit bimodal levels of Total Ionizing Dose (TID) sensitivity (centered on 5 and 20 krads). [7]

It has been reported by one PEMs manufacturer that their FIT data was organized by date code and that one date code usually represents as many as 650 million microcircuits. This does illustrate the inherent risks of relying on manufacturer data and clearly shows an intense effort is needed to gain confidence in the data. It is also clear that gaining the necessary insight requires a close relationship with a supplier willing to share intimate details of their processes.

Today the use of PEMs in space warrants knowing the outgassing properties of PEMs because of the various molding compounds used by different manufacturers in the fabrication of PEMs. Historically, outgassing testing was developed to qualify any plastic and organic materials that in the vacuum of space could outgas volatile materials that could condense on sensitive optical surfaces. The plastic molding compound is a complex and typically proprietary formulation of a specific encapsulating resin and various types of additives, which provide the desired properties for the packaged device. Formulations can include epoxy resin, hardening compounds, accelerators, fillers, flame retardants, couplers, stress relief additives, mold release additives, coloring, and ion–getters among others. If any of the material outgases when exposed to a vacuum and/or heat, it may compromise operation and reliability of sensitive optics or sensors. One way to implement PEMs in space craft is to selectively identify the most reliable devices in a lot (or even multiple lots) of part types. Screening and qualification are generally the method employed to eliminate rejects and mitigate risk of certain types of failure mechanisms. Below in Table 1 are examples of failure mechanisms and modes that exist in PEMs that can be detected with comprehensive screening and qualification. These mechanisms are not just found in PEMs but are the predominant mechanisms that present a challenge to the space parts user.

A commercial database containing a record of 1483 on-orbit commercial and scientific satellite histories for the past twenty years was compiled.. 157 system failures from this population were analyzed for the NEPAG (NASA EEE Parts Assurance Group) Program [7]. Time to failure, using launch date and failure date information, was estimated. Figure 2 shows a box chart of this data by assigned parts level. In this chart, the error bars indicate the range between maximum and minimum values, the box the 25 to 75 percentile range, the line in the box is the 50 percentile or median value and the diamond is the mean. There is a clear relationship between the part level and the time to failure data. It is not intended to imply all the system failures analyzed or even the majority of them resulted from EEE part failure, the database used does not provide the necessary level of detail. What can be said is that EEE part failures undoubtedly contributed to the failures and that systems that had more reliable parts, probably had bigger budgets and greater attention to detail in all aspects and as a result lasted longer without a system failure. Most alarming is Grade 3 where the median time to failure was only 2 months.

This data suggests there is a strong benefit from using higher-grade parts and practices. A report describing this research and providing more details of the analysis and other results related to the failure incidence rates will be published in 2003 [7].

Table 1: Predominant Failure Mechanisms that exist in PEMs [11]

Failure Mechanism	**Definition**
Ionic contamination	Any contaminant which exists as ions and when in solution increases electrical conductivity.
Outgassing	Gaseous emission from a material when exposed to reduced pressure and /or heat.
Popcorning	Expression that is used to describe a phenomenon that causes package cracking in PEMs (typically surface mount packages) during soldering to boards.
ESD	(Electrostatic Discharge). Transfer of charge from one surface to another by static electricity.
EOS	Electrical Overstress
Delamination	A separation between the laminated layers of a base material and/or base material and overlaying coating.
Infant Mortality	Failures in a device population which occur early in the life of the population.
Wire Sweep	Term used to describe the permanent movement or bending over of interconnection wires inside a PEM which can occur during the molding process.
Electromigration	Migration of metal within interconnect lines which occurs when the momentum transfer of electrons is sufficient to move metal ions through the line. Factors such as high current density regions accentuate migration.
Purple Plague	An intermetallic compound between gold and aluminum (AuAl2).
SEL (Single Event Latchup)	A loss of device functionality due to a single event typically the result of a parasitic SCR structure in an IC becoming energized by an ion strike.
SEU (Single Event Upset)	A "soft error", change of logic state, or a bit flip caused by alpha particles or cosmic rays as they pass through a device.
TID	Total Ionizing Dose, accumulation of absorbed ionizing radiation specified at a particular dose rate exposure at 25C.
TDDB	Time Dependent Dielectric Breakdown (typically refers to device oxide wearout)

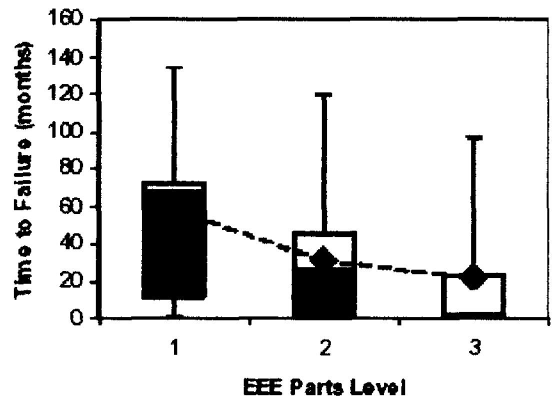

Figure 2. Time To On-Orbit System Failure vs. EEE Part Level [7]

6. MITIGATING THE RISKS OF USING PEMs IN SPACE

Unfortunately, the space environment is not one of the intended applications currently targeted by manufacturers for PEMs. As such, PEMs intended for space applications typically require additional screening and/or qualification testing to be performed by the user. The purpose of this testing is to compliment what the manufacturer has already accomplished.

a. SCREENING TESTS

The terminology "screening" traditionally implies 100% verification testing at the piece-part level. Complimentary sample-based tests such as mechanical inspection may be performed, as well. In some cases it may be possible to perform Environmental Stress Screening (ESS) at the board level. ESS is a process in which a populated printed circuit board is subjected to temperature cycling in a powered state. The intent of ESS is to cull any potential gross workmanship defects that may exist as a result of the fabrication (and to a limited extent design) process. Upon completion of the ESS testing, a visual inspection by a quality assurance engineer is performed [13]. Feedback from this inspection would then be given to the design engineer. The design engineer can then determine if any changes are required. In addition to ESS of the boards, vibration and electrical verification tests could be performed at the box and system level.

Likewise, following a screening flow (which can include burn-in) a final check could be performed on a small subset of parts (destructive test). This extra test is utilized to verify that the screen was adequate to eliminate the weak devices and there was enough life left to be reliable during a mission. The sample of parts (that have gone though a screening flow) would have an additional burn-in performed on them (these devices are not intended to be used on the mission). The ideal result would be that all of the samples pass 100% indicating that the screen was successful at eliminating the weak devices and still left enough life for the mission. The possibilities for screening flows are virtually endless depending on mission requirements. Below is a list of typical screening tests that should be performed prior to a qualification flow.

Electrical Verification

Most PEMs do not meet standard military temperature range (i.e., -55°C to +125°C). This should not be viewed as an immediate cause for concern, but a risk to be mitigated. What is most important is for the PEM in question to meet the appropriate mission temperature profile. In most instances the most severe temperature extremes occur during ground based testing, not during actual flight. However, if no alternative part can serve, it becomes necessary to assure that part can function at the temperature profile required. To assure a part will function reliably in the intended flight application it is recommended that 100% electrical verification at the mission temperature profile extremes be performed.

Visual & Mechanical Inspection

Visual inspection should be performed, on a 100% basis, in accordance to the nearest applicable standard (i.e., military, JEDEC, best commercial practices, etc.). Mechanical inspection should be performed, on a sample basis, in accordance to the same. The intent of these inspections is to ensure device compliance to purchase order requirements.

Radiographic Examination

Radiographic examination (X-ray) should be performed, on a 100% basis, in accordance with MIL-STD-883, Method 2012, "Radiography." Unlike film, real-time X-ray provides high-resolution images in various planes by rotating the devices inside the chamber. This enables the PEMs user to develop a three-dimensional abstraction of the device internal construction. Performance of X-ray should not be viewed in the context of pass/fail criteria attributed to lot rejection. While individual nonconforming parts should be rejected, the true benefit derived from performing the examination is to gain knowledge regarding overall device construction. -Depending on machine characteristics, care may have to be taken to avoid subjecting parts to damaging levels of radiation.

C-SAM

Acoustic microscopy imaging is a powerful tool and there are numerous references that cite the importance of Scanning Acoustic Microscopy utilizing different modes such a "C", (CSAM), in assessing the reliability of PEMs. However, there does not exist today an industry standard for assessing the acceptance or rejection of PEMs based upon C-SAM results. There is evidence that delamination at these surfaces can be a reliability concern [12].

Studies have shown that delamination at the mold compound/die interface can be the primary cause of electrical failure during temperature cycling [12]. Mold compound/die delamination has been shown to initiate at the die corners and produce stress-induced passivation damage over a large area of the die as the delamination spreads. After delamination, shear displacement in the delaminated regions causes wirebond degradation. Also, metal corrosion is accelerated in the delamination regions. C-SAM has been shown to be an important tool for the detection of delamination in three dimensions within a package. C-SAM inspection is nondestructive and package damage can be tracked through successive stages of reliability testing.

Some Space Assembly facilities assume that at least one lead-frame element exhibits 100% delaminated on the top-side in all product and therefore use conformal coating as a mitigation technique. [13]

Materials Characterization

Not all manufacturers and assemblers of PEMs are the same: they use different encapsulants, additives, lead-frames, die passivation materials, assembly processes, and materials. Manufacturers of PEMs must implement qualification procedures tailored to evaluate and monitor the capability of their product to meet desired service life in the expected applications to assure that products made with PEMs are reliable. One of the key materials involved in PEMs is the mold compound. Is is important to qualitatively and quantitatively understand the mold compound used in the PEMs for a Space Application as it could have serious repercussions for moisture sensitivity, adhesion to leadframe materials, mobile ionics, burn-in etc.

A study of glass transition temperature (Tg) of the encapsulating materials was performed using Thermo-Mechanical Analysis (TMA) for each of the five parts and the results showed a wide spread with one value as low as 117°C, see Figure 3. A study of this type is destructive to a device (although tests could be run on parts and not damage the functionality of the device, it is not recommended as a nondestructive method). A recommendation from the work would be to measure Tg for every lot until confidence in a manufacturer's process has been established. Even then, periodic testing for Tg would be advisable [7].

b. QUALIFICATION TESTS

Objectives of qualification testing can be to evaluate the effectiveness of new materials, processes, and design; to supply routine information on the quality of a product; to develop information on the integrity of a device and its structure; and to estimate its expected service life. Qualification tests are destructive by nature. Most tests are not conducted at the application conditions, but incorporate accelerated levels of stress to accelerate failure mechanisms, often at known sites in a device [14]. Unlike the device manufacturer who must balance device reliability and product yield, the space-user is strictly concerned with assuring device survival during integration, test, launch, operation, and (if necessary) storage. In application conditions where the environment is not controlled, the load profiles of temperature, humidity, vibration, contamination,
and radiation, as a function of time, must be predicted based on past experience. Past experience for space applications is not always available. Currently, many companies are building databases to record such data.

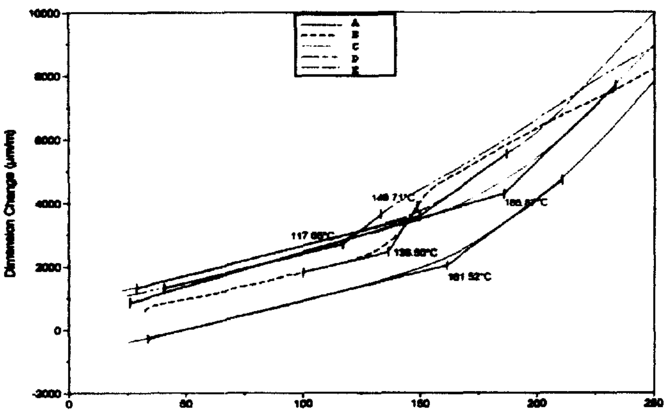

Figure 3. Glass Transition Temperature of Molding Compounds used in For Five Different Manufacturers of PEMs [7]

Destructive Physical Analysis (DPA)

The purpose of conducting DPA is to build a knowledge base of component construction technology. It is hoped that observations and measurements made during DPA will aid in the establishment of uniform pass/fail criteria associated with C-SAM results (delaminations). DPAs can be performed by following the guidelines established in MIL-STD-1580, "Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts," where applicable.

High Temperature Operating Life (HTOL) or Life Test

HTOL is concerned with infant mortality and the long-term reliability of devices to withstand temperature extremes. When performing HTOL, the guidelines established in JEDEC Standard JESD-22-A108, "Bias Life" can be followed. Dynamic bias is preferred, but not mandatory. It is recommended that electrical measurements at the mission temperature extremes (e.g., cold, room, & hot) be performed prior to the start and at the completion of the test. In addition, it is also recommended to take electrical measurements, at room temperature, at the 168-hour and 500-hour marks. These additional measurements avoid wasting precious schedule time. Due to the long time period between purchase cycles, the space user can anticipate performing HTOL on every lot of PEMs. However, to reduce testing costs, parts purchased at the same time may be able to be qualified as a family [13].

Temperature Cycling (T/C)

The purpose of performing T/C is to cull potential coefficient of thermal expansion (CTE) mismatch concerns. T/C testing can induce or exacerbate delamination, aiding corrosion by creating pathways for moisture ingress. When T/C testing is performed, the guidelines established in Joint Electron Device Engineering Council (JEDEC) Standard JESD-22-A104 or Mil-Std-883 method 1010 Cond C, "Temperature Cycling" can be followed. After the completion of T/C testing, final electrical measurements at the mission temperature extremes (e.g., cold, room, & hot) should be performed.

Steady-State Temperature Humidity Bias Life Test (85/85)

85/85 testing is conducted to assure that parts can survive in the uncontrolled moisture laden environment prior to launch; specifically, variances in moisture and temperature during integration, test, transportation and storage of the spacecraft. Once in the vacuum of space, moisture becomes a non-issue; moisture is immediately depleted upon entering the vacuum environment. When 85/85 testing is performed, the guidelines established in JEDEC Standard JESD-22-A101, "Steady-State Temperature Humidity Bias Life Test" should be followed. After completion of testing, final electrical measurements at the mission temperature extremes (e.g., cold, room, & hot) should be performed.

Outgassing

Outgassing testing is used to identify and quantify volatiles being emitted from PEM samples according to an accepted standard such as ASTM E595. The parameters measured for this standard are the total mass loss (TML), collected volatile condensable materials (CVCM), and the water vapor regained (WVR). Since molding formulations are continually changing the outgassing test should be used to monitor and or qualify packages to insure their suitability in critical space applications.

Radiation Hardness Assurance (RHA)

All parts, commercial and/or military must be evaluated for RHA. When required, total dose evaluation is conducted in accordance with MIL-STD-883, Method 5005, "Qualification and Quality Conformance Procedures," Group E, or equivalent. Because PEMs are not required to be decapsulated, conducting a total dose test is not a cause for concern [13]. For PEMs, Single Event Effects (SEE) testing can be of great cause for concern. It is hoped with the advent of higher energy charged ion accelerators that it will be no longer be necessary to decapsulate every PEM to perform SEE testing. In the mean time, the process involves much trial and error.

c. THE DERATING PROCESS

The derating process is a prudent practice to follow, whether or not a device has a military or commercial pedigree. It involves reducing device voltage, current and power by a certain percentage to extend longevity.

Building high reliability spacecraft used to be a relatively straight forward process that involved the selection, purchase, and use of military qualified Class 'S' and/or Class 'B' parts for all of the components. The spacecraft was built according to customer dictated requirements. Historically, the customer would expend considerable resources (e.g., time and money) being personally involved in the manufacturer's design process and overall program management. In today's performance-based paradigm the space customer outlines the mission requirements and holds the manufacturer responsible for meeting the requirements. The only degree of customer oversight is in the area of cost and schedule. The attractiveness and increased use of COTS and PEMs are a direct response toward attempting to meet these constraints.

7. METHODOLOGY AND APPROACH TO QUALIFY PEMS FOR SPACE

Most manufacturers of space flight hardware have very conservative manufacturing practices. When using new packaging technologies, such as PEMs, even more conservatism is warranted. It is considered important to test any PEM to the manufacturer's data sheet first, and then to any special requirements for space applications, particularly if the end use is near the extreme of the manufacturer's specification.

There are a number of reliability related issues with using COTS PEMs for space, independent of the device technology, including traceability, lot conformance, relevance of manufacturer data, screening, change control, radiation hardness and obsolescence. An evaluation taken on by NEPAG and NEPP (NASA Electronic Parts and Packaging Project) is designed to investigate these issues. To minimize the risk to a mission, the following criteria were used to select PEMs for evaluation [7]:

- Technology should be fairly mature,
- Moderate complexity
- Of interest to current NASA projects,
- Reasonably testable,
- Would not require exotic test fixturing
- Parts that successfully passed testing could be used on flight projects
- Robustness of design and process
- Reliability of device vs package type

The subtlety of each step is what makes this plan effective. As stated in the qualification test section the DPA performed can assess the materials used, the overall assembly quality and the glass transition temperature (Tg). It is necessary to measure Tg to determine the correct burn-in temperature. A burn-in temperature of 25°C below the Tg was decided as acceptable due to material properties and variations of the molding compounds. The high thermal expansion above the Tg value raises reliability concerns such as: excessive stress on wire bonds, delamination between encapsulant and lead frame or die paddle, excessive stress on the die, and the release of bromine or red phosphorous (flame retardants) which has been shown to cause corrosion. The 1st electrical test is designed to calculate/compare the vendors AOQL from rejects, while the FIT verification step is designed to compare with the manufacturer reported FIT rates. In the above flow all electrical data is full DC and parametric (no pass/fail from the data sheet) so that any shifts (degradation) can be followed throughout the qualification.

Table 2: Recommended Screening/Qualification Flow for PEMs [7]

Screen/Qual Sequence	Condition
DPA	SEM 2.Tg
Serialization	Laser Serialization or other means for traceability
1st Electricals	Test to data sheet @ +25C, 70C, OC
FITS Verification Sample Static Burn-in	BI @ 125C with readouts @ 168hrs., 500hrs. and 1000hrs
Temp Cycle	Ta = -65C to +150C
X-Ray	Mil-Std-883 method 20-12, Inspect for wire sweep
C-SAM	Inspect for delamination and or cracks
Electricals	Test to data sheet @ +125C, -55C, (with functionality)
Dynamic Burn-in	Circuit per application 168hrs. at +125C, Vcc=max rating
Electricals	Test to data sheet @ +25C, +70C, OC, +125C, -55C
Dynamic Life Test (BI)	Circuit used is per application (at +125C)
End Point Electricals	Test to data sheet @ +25C, +70C, OC, +125C, -55C
Post screening DPA	Die visual inspection/Bonding inspection
Lead solder heat exposure/precondition	Simulates board solder. Per separate flow
Temp Cycle	Qual Ta = -65C to +150C
Post T Cycle Electricals	Interim test every 100 cycles to data sheet @+25C, +70C, OC, +125C, -55C
HAST Qual	140/85%
Post HAST Electricals	Interim test every 168 hrs. to data sheet @+25C, +70C, OC,

	+125C, -55C
Vibration (optional)	Mil-Std-883 method 2007 cond A
Cold Startup (optional)	Per application requirements

8. SUMMARY

COTS devices, including PEMs, have found their way into spacecraft designs and the trend is likely to continue. Advantages of plastic packages over their ceramic counterparts include lighter weight, enhanced functionality, including access to state-of-the-art technology, and increased product availability. Lower operational temperature profiles, traceability, moisture susceptabilty, corrosion, inspectability as well as issues with radiation tolerance have been significant detriments toward greater acceptance of these devices by the space community.]

Developing a successful and reliable mitigation strategy is the challenge facing the space user that wants to take advantage of the benefits PEMs can provide. Each space mission is unique and a universal solution for mitigating risk does not exist. Screenings and qualifications must be tailored to specific mission requirements. These steps address known failure mechanisms for plastic parts and mechanisms that are a potential risk given the right circumstances. The sample sizes used for the various steps are dependent on the sensitivity of the test to screen out rejects. Critical steps are always 100% of the lot tested and not based on sampling. Radiation testing (very important) is not 100% since it is a destructive test and expensive to perform.

Where missions in the past were well specified and utilized Hi-Rel parts, new missions require creative solutions for upscreening and qualifying COTS and PEMs. As space hardware manufacturers become more knowledgeable with using PEMs, other screening and qualification methods will undoubtedly be developed. The goal is to develop more cost effective screening and qualification methods.

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