GSFC Parts Engineering in the COTS PEMs Era: Problems, Decisions, and Future Development

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Purpose and Outline

Purpose:

To discuss approaches used in the development of PEM screening and qualification guidelines, problems, and future development of parts engineering at GSFC.

Outline:

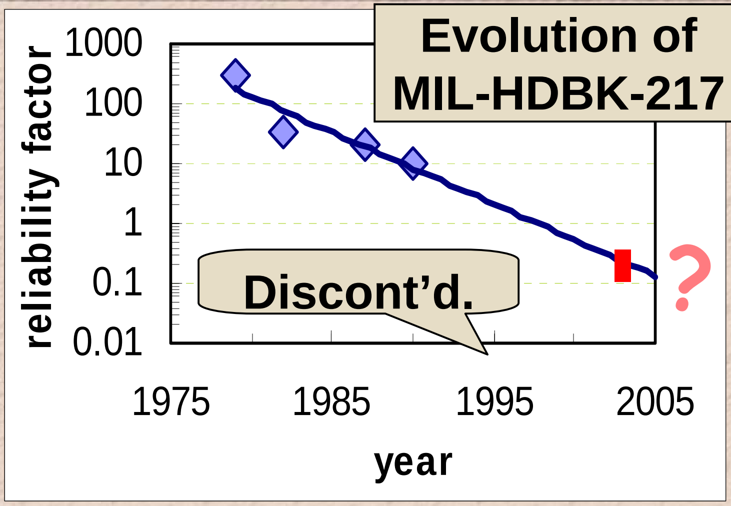
- Classification of COTS PEMs problems.
- Applicability of MIL test standards.
- Development of GSFC PEM-INST guidelines.
- Trends in parts engineering for COTS PEMs.
- Near-future plans.

What is the Risk of COTS Parts Application?

Risk Assessment Matrix (NEPAG web site)

Risk:	Low	Medium	High	Unknown
NASA Parts Selection List	Level 1 (>5 yrs)	Level 2 (2-5 yrs)	Level 3 (1-2 yrs)	Commercial
MIL-HDBK-217 reliability factors	0.25	1	2	10 ?

- Reliability factors and risks of COTS PEMs are not substantiated.
- Unknown risk might be better than high risk: we still have hope.
- Risk evaluation and mitigation for specific applications is the purpose of parts engineering.



Two Sources of Reliability Problems with COTS PEMs

1. COTS

Problems related to commercial philosophy of production:

- Minimal outgoing screening.
- Poor traceability.
- Insufficient reliability testing.
- Unknown process controls.
- Proprietary design, materials, and test conditions.
- Early wear out for leading edge technologies.
- Squeezed performance margins.
- ...

2. PEMs

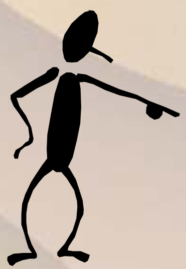
Intrinsic problems related to plastic encapsulation:

- Thermo-mechanical stresses:
  - Cracking.
  - Delaminations.
  - Parametric shifts.
- Moisture effects:
  - Swelling, corrosion.
  - Pop-corning.
  - Parametric degradation.
- Wire bonding:
  - Dry corrosion.
  - Kirkendall voiding.

Can MIL Standards Assure Reliability of COTS PEMs?

- Testing of Mil parts is only one element of the military quality assurance system (QAS), which includes standardized design practices, process controls, consistent technology over years, and the history of hi-rel applications, ...
- Most MIL-STDs were written for old technologies.
- Old golden rule: “One cannot improve reliability by screening out failures in a lot” is applicable to PEMs.
- New package-related problems have to be addressed:
  - Au/Al wire bond degradation.
  - Moisture.
  - Mechanical stresses.
  - Temperature shock during solder reflow.
- Low rated temperatures limit application of stress testing.

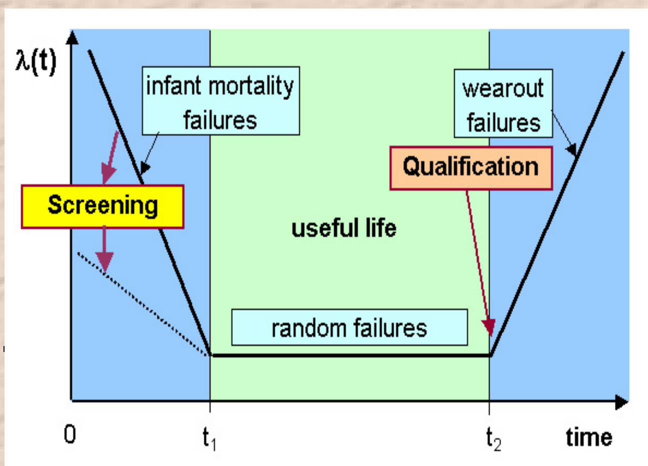
Testing of COTS PEMs per MIL-STDs sometimes is not achievable and may not assure the same level of reliability as for MIL parts.



Typical S&Q Conditions per GSFC EEE-INST-002

So far S&Q remain major tools to assure confidence in PEMs

- <u>Screening:</u>
  - Electrical measurements at 3 temperatures (RT, min. and max. T_{op}).
  - Burn-In (168 hrs at 125 ^{o}C is recommended).
  - Acoustic microscopy (C-SAM required at top side only).



- <u>Qualification:</u>
  - Life test (typically 1000 hrs at 125 ^{o}C).
  - HAST (JESD22-A118, 130 ^{o}C, 96 hrs unbiased).
  - Temperature cycling (typically 200 cycles –55 to +125 ^{o}C per MIL-STD-883, TM 1010, cond. B).

Can We Use 125 ^{o}C for BI?

A quiz for parts engineers:

What limits the temperature of BI?

- Maximum junction temperature?
- Max. operational temperature?
- Glass transition temperature of MC?
- All of the above?
- None of the above?
- Your intuition?

There is no standardized technique to determine $T_{j\,max}$

Mfrs. warn that exceeding T_{op} may cause permanent damage

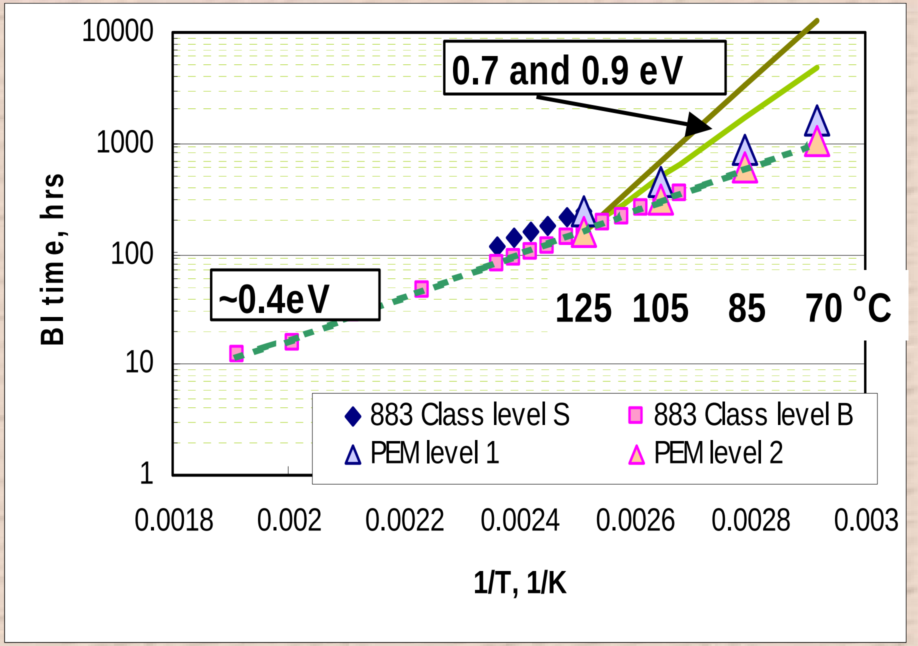
Exceeding Tg does not cause BI failures (IMAPS 2003)

- A methodology to determine BI temperature is needed.
- The significance of T_{jmax} and T_{op} for screening and qualification should be clarified.

How BI Conditions in GSFC Guidelines Were Determined

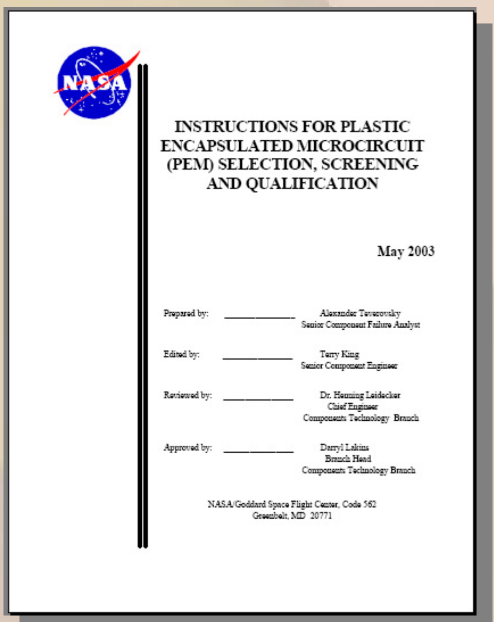
BI conditions were chosen based on extrapolation of the MIL-STD-883, TM1015, regression to low temperatures:

160 hrs/125°C
300 hrs/105°C
590 hrs/85°C
1040 hrs/70°C



- The activation energy, E_a, used in MIL-STD-883 is ~0.4 eV.
- No literature data on activation energies of infant mortality failures were found.
- At E_a = 0.7 or 0.9 eV, the duration of BI at 85 °C would be unreasonably large: 70 to 140 days.

GSFC Guidelines for PEMs Parts Engineering



INSTRUCTIONS FOR PLASTIC ENCAPSULATED MICROCIRCUIT (PEM) SELECTION, SCREENING AND QUALIFICATION

May 2003

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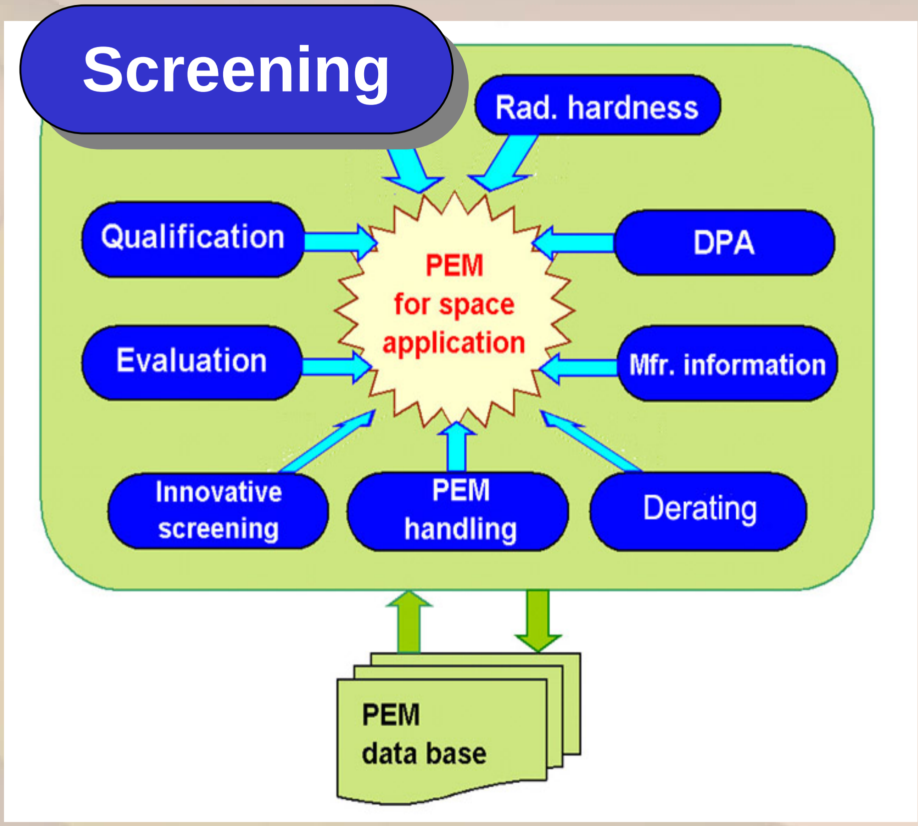
- The first version of the GSFC guideline for COTS PEMs: “INSTRUCTIONS FOR PLASTIC ENCAPSULATED MICROCIRCUIT (PEM) SELECTION, SCREENING AND QUALIFICATION”, was developed in August 2002.
- The latest version (May 2003) was included in the GSFC parts document, EEE-INST-002, which is posted on the NEPP Web site: http://nepp.nasa.gov/index_nasa.cfm/725/.
- Improvement of guidelines is ongoing. Next version is expected in Aug. 2004.

Elements of COTS PEM QAS



- GSFC EEE-INST for PEMs introduces a system of QA tools for parts engineering.
- Commonly used elements are screening, qualification, radiation hardness testing, and DPA.
- Other elements will gain importance as the QA system evolves further.
- Currently the task is to optimize QAS and remove non-value-added tests.

How good is the QAS? Often we do not know how effective the testing is. Mission success does not always mean "thanks to QAS …" it might be also "in spite of …"

A Feedback System to Improve S&Q

Analysis of literature data

Projects are generating a lot of data.
How to learn from our testing experiences?

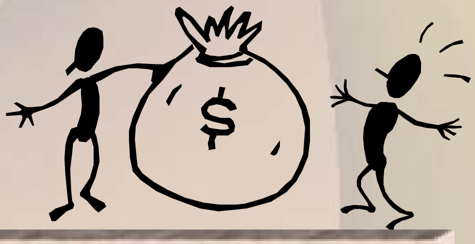
QAS → Accumulation and analysis of project data → LL

Additional evaluation and testing

Why is additional evaluation and testing necessary?

- Most project test data are wasted; obtaining statistics of failures is not easy. (Projects are often not concerned about failures <PDA)
- Test results might be deceptive. (Rejects might be due to poor electrical measurements and/or damage during testing.)
- FA results might be insufficient. (FA might be performed only to assure that there is no risk for the mission.)

Why S&Q Is So Costly



- Reliability assurance does cost money...
- …especially when trying to evaluate general device reliability for a wide range of possible application conditions (similar to MIL parts).
- A methodology to develop application-specific screening and reliability evaluation is necessary.
- Performing radiation and qualification testing on screened samples only increases the cost. Is it always necessary?
- Are BI and C-SAM always value-added tests for screening?
- Is HAST needed for space applications?

- We are still learning, and cost efficiency might be improved by optimizing test plans for specific applications.
- Investments in R&D for better understanding and qualification of new parts might save money during S&Q.

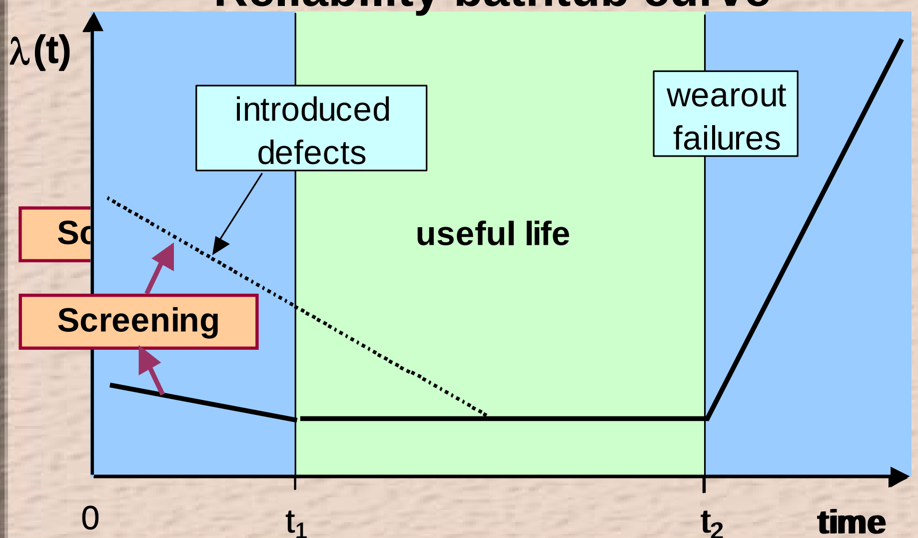
Problems with Screening

- BI and C-SAM can introduce defects:
  - Voltage spikes in power lines during BI, intermittent contacts due to poor sockets, and increased sensitivity to latch-up at HT might cause EOS and damage the parts.
  - Handling: EOS/ESD damage is 0.1% to 1% per insertion/operation [S. Martin, TI, ’97].
  - Repeated insertion of parts into sockets damages the leads.
  - C-SAM might contaminate parts and deform the leads.
- C-SAM and BI might reduce solderability of the leads.
- Hot-carrier degradation is not activated by temperature and might not be screened out by BI.
- BI can affect results of radiation testing and consume resources for “early wear-out” devices.
- MIL-STD 883, TM1015: “… intent of BI to stress ICs at or above maximum rated operating conditions…”. However, all Mfrs warn that these stresses may cause permanent damage to the parts.

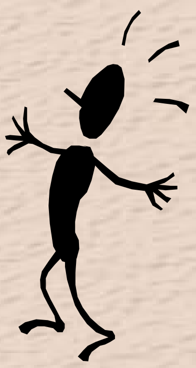
Is Screening Always Useful?

- Screening is the only element of QAS that can affect lot reliability. It can affect it both ways (positively or negatively).
- Multiple data indicate that improper handling and testing can introduce more defects than are screened out.
- PEMs manufacturers do care about IM failures → Yield → $; → Reputation

Reliability bathtub curve



What if the bathtub does not hold water?

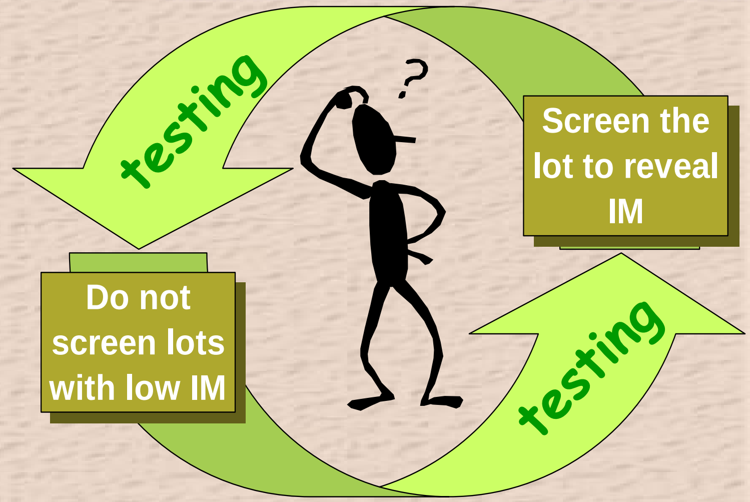


… then screening might add some…

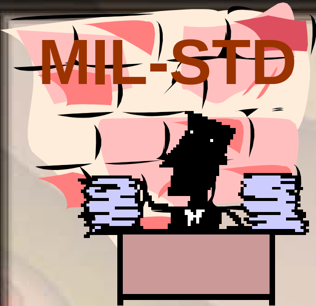
Catch-22 in Screening

[K. Hester, et al., Boeing, '01]: Analysis of 638,000 PEMs of 181 part types:

- Screening does not add value and might negatively impact reliability of high-quality components.
- However, for low-quality components, screening should be maintained.



- To break the circle, make BI and CSAM optional, depending on results of extended qualification.
- Perform qualification on unscreened samples with interim measurements and let the parametric/functional failures to go through. This will identify possible failure modes, evaluate the risk of failures, show whether the screening is necessary, and reduce overall S&Q costs.



Evolution of Parts Engineering

We are here

QAS has become open to criticism and improvement

Rule-based (MIL parts) — Phase I, II, .. — **Knowledge-based (COTS PEMs)**

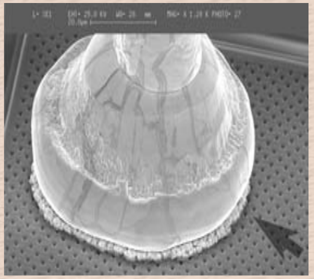
Manufactured, selected, tested, and qualified to strict specifications covered by MIL standards (MIL QAS)	Selected, evaluated, and screened to applications by a PE plan based on guideline recommendations.
Government maintains the standards and is responsible for reliability provided all criteria are satisfied.	PEs are responsible for reliability evaluation and mitigation of risks associated with use of COTS PEMs.
PEs have to know the rules and specifications and use binary logic: pass/fail, accept/reject.	PEs have to know design, testing, manufacturing, reliability physics,… and be able to evaluate risks in specific applications.
Derating is often a historically developed set of rules and one of the means to achieve better reliability	Justified derating is the major means for increasing reliability of advanced technology COTS PEMs.
Reliability is mostly limited by defects => the importance of infant mortality and screening.	Reliability is limited by intrinsic wear-out mechanisms => qualification is more important than screening.

Near-Future Plans: Screening

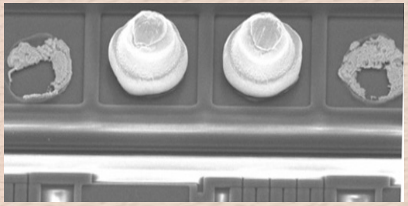
- Analyze screening results performed by GSFC projects to evaluate the effectiveness of different tests.
- Analyze the significance of delaminations and the value of C-SAM examinations for screening.
- Analyze the necessity of TC. Limit the temperature for TC during screening to 125 ^{o}C or Tg of MC.
- Require that all failure modes during EM are determined and reported: No “go/no-go” tests!
- The problem of BI conditions for COTS PEMs requires coordinated efforts of military and aerospace communities.

Important Part of Qualification: Evaluation of Wire Bonding

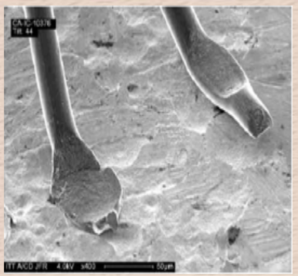
Examples of recently revealed problems



Failures in parts manufactured in 1999 were observed during board-level testing in 2002 (FA: contamination-induced WB degradation).

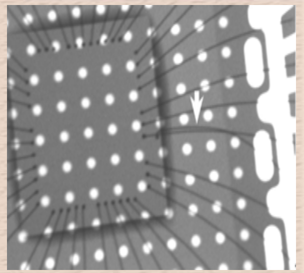


COTS FPGA failed DPA due to poor wire bonding (2003).

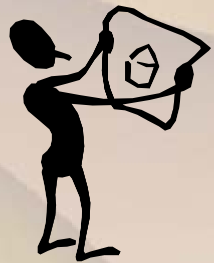


A detector failed in 2002, three years after manufacturing due to degraded WB (Al wire to Au post).

A lifted wire in an ASIC packaged in PQFP was revealed during failure analysis (2003).

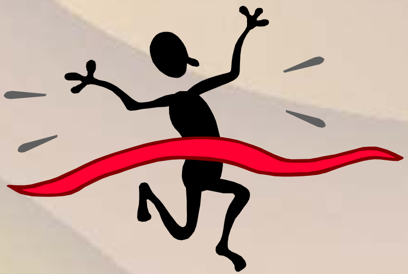


- Substantial portion of reliability issues are now at packaging level.
- Degradation and failures in poor quality wire bonds might happen with time even at relatively benign storage conditions.
- Development of a non-destructive technique for WB qualification in PEMs is important.



Near-Future Plans: Qualification

- Analyze results of qualification testing performed on COTS PEMs by GSFC projects.
- Perform follow-up analysis of repeatable failures revealed during qualification testing.
- Analyze the effectiveness of qualification testing performed on non-screened parts.
- Analyze HAST conditions, and develop alternative moisture testing.
- Develop a nondestructive technique and accelerated test method for rapid assessment of wire bond quality.



Conclusion

- A shift from the rule-based to a knowledge-based parts engineering for COTS PEMs is inevitable.
- This requires better understanding of the effectiveness of S&Q testing and development of new, more flexible approaches for QA to keep abreast of rapid changes in commercial technology used for space projects.
- GSFC COTS PEMs parts engineering is:
  - Developing towards a knowledge-based methodology.
  - Based on a feedback system, which includes analysis of project S&Q test results data and follow-up investigations.
  - Open for constructive criticism and improvements.