National Aeronautics and Space Administration

A structure for lessons learned capture with several lessons from EEE parts and printed circuit boards

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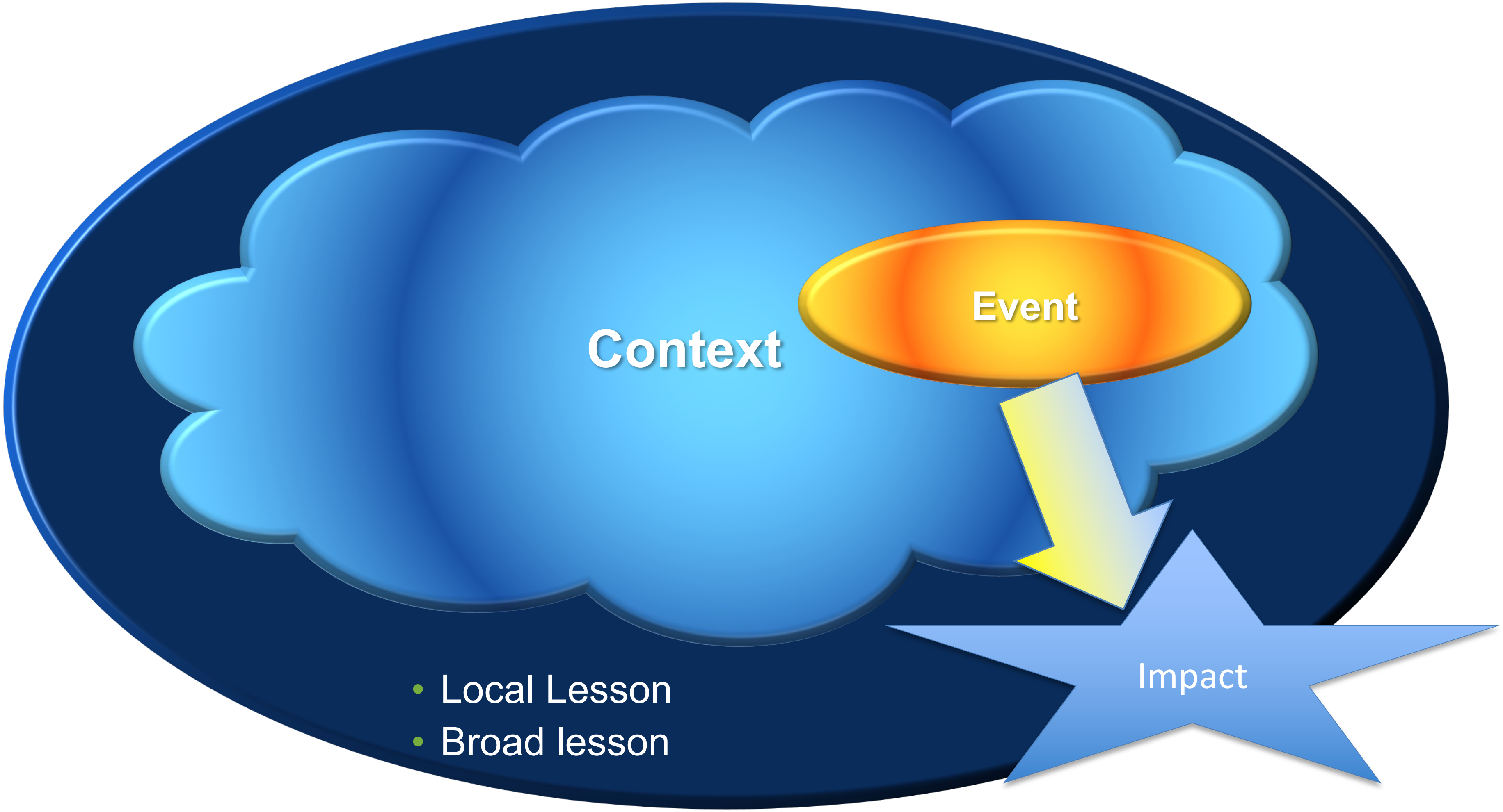
Anatomy of a Lesson



- Local Lesson
- Broad lesson

Lessons Learned Structure

- Given the [CONTEXT or SCENARIO] that existed
  UNDESIRED EVENT occurred
  With [IMPACT]
  Intermediate and/or root causes were determined to be [ ]
  Corrective actions were
  Local lessons learned were
  Broad lessons learned were

  CONTEXT or SCENARIO: A <u>factual</u> situation that existed to give rise to or enable the event of interest
    - the spacecraft was on a crane over the weekend

  UNDESIRED EVENT: The incident of interest that occurred
    - the spacecraft fell

  IMPACT: What was the significance or consequence
    - the spacecraft was destroyed and now requires major repairs

  KEY INTERMEDIATE CAUSE:
    - the cable was frayed

  ROOT CAUSE
    - COVID had caused all crane inspections to be deferred 3 months

  CORRECTIVE ACTIONS:

  LOCAL LESSON LEARNED:

  BROAD LESSONS LEARNED:

*[CAPITALIZED] terms will be called *fillable* items

Key Rules to follow

- The CONTEXT must have existed at the time of the event and should be indisputable
  - The context should not have any conditional aspects
- The causes should come from a logic flow that starts at proximate cause, steps through intermediate cause(s), and works down to root cause(s) if sufficient data exist. A fault tree or event and causal factor are good ways to step through this logic.

Considerations

- In general lessons should be based on root cause
- In some cases, lessons may be derived from proximate or immediate causes, but that point should be made clear and due diligence is required that the lesson is not actually from an assumed root cause that might have led to the intermediate or proximate cause
- Critical thinking should go into a separation of local lessons vs broad lessons.
- Often ”lessons learned” are captured that assume the requirements imposed had to be good, and thus the problem had to be with the product or developer, and not the requirements imposed.

SAC-D DC/DC converter on-orbit failures

- SAC-D launched in June of 2011 on a 3-year mission.
- The project selected COTS DC/DC converters to achieve performance unavailable from other similar converters
- Project screened the hybrids to Level 1 requirements, MIL-PRF-38534, Class K.
- About a year into operations, the first converter failed on-orbit.
- Approximately four years after launch, one of the remaining critical converters failed, ending the mission.
- The assessment shortly after the failure indicated that there were some features in DPA samples that would be considered rejectable, and the failures were attributed to workmanship in the parts.
- Years later, GSFC SMA reviewed the data and noted that the DPA discrepancies are simply a violation of the MIL SPEC and do not indicate a credible linkage to multiple on-orbit failures over the one-year to four-year duration.

SAC-D converters cont'd

- Review of the part's data sheet indicates a tolerance to 500g constant acceleration of the parts.
- However, MIL-PRF-38534 demands a 3000g constant acceleration test, which was ultimately performed on all of the parts as a screen, regardless of the limits in the parts' data sheet.
- Hybrid DC/DC converters have large magnetics connected to an alumina substrate that is subject to wear under excessive mechanical stress, so this is the most likely explanation for premature wear of the parts.
- It should be noted that there was no relevance of a 3000g constant acceleration test for the usage of these parts.
- The test was originally designed as a means to test bond wires for leaded transistors, and since extrapolated to cover hybrids.

SAC-D lessons learned

Given the use of commercial DC/DC converters with strict application of MIL-PRF-38534

The converters were egregiously overtested to prompt failures on-orbit

Resulting in end of mission

PROXIMATE CAUSE: failure of converters on-orbit

KEY INTERMEDIATE CAUSE: parts with a 500g constant acceleration limit were tested to 3000g constant acceleration without any mission need for such a test level

ROOT CAUSE: GSFC demanded testing levels with no consideration of mission needs or part limitations

BROAD LESSONS LEARNED:

- Testing (screening) parts to stress levels well above the application and close to or above the specification limits for an extended period of time may substantially reduce the lifetime of the parts with minimal benefit (application overstress)
- Testing (screening) parts to stress levels well above the datasheet limits may substantially reduce the lifetime of the parts, whether there is a perceived benefit or not (datasheet overstress)
- Prior to performing either application or datasheet overstress to parts for screening purposes, the risk of overstress to the parts in the project context should be evaluated and captured.

"You cannot screen-in reliability, but you can certainly screen it out"

GOES-R hermetic transistors (BJTs)

- Late in development of the GOES-R satellite, an in-circuit failure of a JANS2N3637 bipolar junction transistor (BJT) in a TO-39 package was encountered that was traced to corrosion in one of the bondwires.
  - Failure analysis and residual gas analysis (RGA) of the failed part revealed the presence of moisture and atmospheric ingress.
- Within a few weeks of this event a similar failure was encountered involving a JANS2N2222a BJT in a TO-18 package on the Insight project, experienced by the same prime contractor.
  - This part showed elevated moisture in the internal cavity. It appears that some parts in the lot had elevated hydrogen that may have then been involved in a chemical reaction prompted by handling of the part and weakness in the seal.
- Both of these parts problems prompted the project to replace dozens of parts without any proof or indication that the replacement parts were from better lots than the original lots, at the cost of multiple millions of dollars and a significant launch delay.
- In both cases on the same project, the reliance on part hermeticity and RGA combined with fine and gross leak testing cost the project an enormous amount of money, months of schedule usage, and elevated the risks to the project substantially due to the excessive amounts of rework, without any certainty in the improvement of the lots.
- The "partial hermeticity" in each case likely trapped moisture and contaminants to cause ideal conditions for corrosion.

GOES-R BJTs lessons learned

Given the absolute reliance on hermetic, JANS parts to assure reliability and limited effectiveness in the inherent processes to prevent corrosion in ambient, but controlled conditions

Two JANS bipolar junction transistors (BJTs) experienced failures in testing

Resulting in excessive use of resources and a significant slip in launch date to replace parts without any assurance that replacement parts were better than those installed.

PROXIMATE CAUSE: Two separate failures during testing in two projects involving the same prime contractor

KEY INTERMEDIATE CAUSE: corrosion causing open circuits

ROOT CAUSE: The complete reliance on processes that are neither necessary nor sufficient for part reliability, and the further create secondary risk when used.

LOCAL CORRECTIVE ACTION AT THE TIME:

- replaced dozens of parts throughout the GOES-R spacecraft without proof that replacement parts were better than parts they were replacing

BROAD CORRECTIVE ACTION:

- GIDEP issued

BROAD LESSONS LEARNED:

- The reliance on hermetic parts can drive up both technical and programmatic risk by (1) trapping contaminants in the parts during the manufacturing process, (2) allowing contaminants to enter the parts for those that are on the fine edge of being hermetic, and (3) providing false confidence that the use of such parts provides substantial protection against part failure due to corrosion
- The sample size for RGA testing under MIL-PRF-19500 only provides a top-level indicator that parts in the lot are free from significant elevated moisture or contaminants. Furthermore, there is no practical increased sample size that would provide enough statistical basis
- Before replacing parts always verify with certainty that the replacement parts are better than the existing parts
- The use of JANS parts is neither necessary or sufficient for assuring integrity or reliability of parts through I&T

LandSat-8/TIRS capacitor latent defect

- Starting approximately 10 months after launch of LandSat-8 an anomalous trend was noted in the –EV MCE (mechanism control electronics) current on the TIRS A side electronics.
- Over time the –EV MCE current began to grow at an exponential rate and an anomaly investigation commenced.
- A lengthy investigation could not confirm root cause, however it was suspected at the time that a conductive anodic filament (CAF) in the bare printed circuit board created a short path within the A side electronics.
  - Note that CAF requires moisture as a carrier
- To prepare for possible loss of MCE, tests were conducted to understand SSM drift without positive feedback control.
- Following the recommendations from the A side ARB investigation, TIRS was swapped to the B side electronics to collect optimal science for the 2015 growing season.
- Approximately 5 months after resuming nominal operations on the TIRS B side, indications of an anomalous current have been observed in the +EV MCE current.
- GSFC SMA learned of the anomaly and requested the anomaly report for review.
- Behavior of the on-orbit leakage currents on TIRS bore a striking resemblance to a different capacitor anomaly.

LandSat-8/TIRS capacitor (cont'd)

- Boards were brought out of storage and not long after power-up, the board being tested on the ground started to exhibit the leakage current reflective of the on-orbit behavior.
- Many attempts were made to power cycle the boards, induce recovery, or otherwise affect the profile, with mixed results.
- A thermal camera was placed over the board to watch for hot spots, revealing glowing spots on multiple capacitors.
- Ultimately, it was revealed that there was a manufacturing flaw in the lot of capacitors (Level 1, 55681) that was only apparent after installation.
- A thorough review and reachback exercise identified that the problem had existed over 10 years and had caused problems in multiple prior missions during I&T, and caused the ultimate failure of the EVE instrument on the Solar Dynamics Observatory a few years before.
- Furthermore, shortly afterward, two separate commercial missions experienced full mission failure due to the same flaw.
- Two other recent failures of a similar nature are in review from a DoD mission, suspected to be caused by the same manufacturing flaw.

TIRS capacitor lessons learned

Given the use of Level 1 MIL-SPEC capacitors subject to a manufacturing flaw that escaped the associated MIL-PRF-55681 processes

TIRS instrument switched to safe mode, ultimately on primary and redundant side

Resulting in excessive resources to resolve the problem and a revised operations to remove the closed–loop pointing capability of the instrument

PROXIMATE CAUSE: Several MLCCs lost significant resistance on orbit

KEY INTERMEDIATE CAUSE: Cracks occurred internal to the parts

KEY INTERMEDIATE CAUSE: longstanding manufacturing flaw within the part

ROOT CAUSE: The complete reliance on processes that are neither necessary nor sufficient for part reliability, and that further create secondary risk when used.

LOCAL CORRECTIVE ACTIONS APPLIED:

- functionality was removed from TIRS
- reachout occurred to other affected projects

BROAD CORRECTIVE ACTION:

- GIDEP was issued

BROAD LESSONS LEARNED:

- Over-reliance on testing approaches that are neither necessary or sufficient for success can lead to enormous and broad problems
- Manufacturers are best tuned to identify processes needed to assure reliability of components based on their own manufacturing processes, experiential observations, and usage, but when selling MIL-SPEC parts, manufacturers' priorities are on meeting the MIL-SPEC requirements in lieu of their own processes (The manufacturer was aware of the problem but the affected parts always met the MIL-SPEC requirements of 55681 and the manufacturer had thought that actual failures required handsoldering, which they had recommended against.)

Glory printed circuit board challenges

- An advanced processor was selected for the Glory mission that promised a significant improvement in capability over the standard processors that had been used on most NASA robotic missions.
- The processor had been qualified through standard environmental ranges and was also slated in parallel for ESA's GAIA mission.
- For the qualification boards, the vendor had the boards manufactured to commercial specs that were not known to NASA, but that were aligned with the high-density technology on the board, and thus less restrictive than the board manufacturing specifications that GSFC had been employing.
- Neither the vendor nor GSFC were aware of the incompatibility between the spec GSFC was imposing at the time and the design of the board.
- After multiple tries to produce a board for which the printed circuit board coupons would meet the spec, the vendor realized that design changes were required.

Glory PCB challenges

- The design changes that improved the chances to produce conforming coupons actually reduced the integrity of the design so that when coupons would pass, the board wouldn't function.
- Given the challenges encountered, GSFC then increased the challenge for producing flight boards by introducing requirements for the boards to pass Interconnect Stress Testing (IST), which exacerbated the problem.
  - IST testing is an extreme test that can be helpful to identify failure modes and mechanisms that may appear under extreme conditions, but it does not provide conditions relevant to mission success for most mission environments.
- The processor was one of the first boards in a major GSFC mission to include reconfigurable FPGAs, a feature of which is high pin density.
- The high pin density was fundamentally incompatible with GSFC's required board specification, prompting endless attempts to produce conforming boards and redesigns to include risky features that may not have otherwise been needed.

Glory PCB challenges cont'd

- After months of attempts and late into development, GSFC ended up switching to the older processor technology to avert the problem, assuming the vendor and the associated processor were problematic.
- In parallel, the same processors were provided for ESA's GAIA mission, but for GAIA, the procurement was commercial, only requiring qualification to appropriate temperature ranges and no requirement to meet a particular board specification.
  - One of the few cases where a project benefited directly from export control restrictions
- The collection of eight flight processors and several engineering units met all qualification requirements, were integrated into the spacecraft, and have worked flawlessly, long past the original 5-year mission life.

Glory PCB lessons learned

Given the use of PCB specifications that were incompatible with the qualification, design, and usage environment of the mission

The Glory project could not gain confidence in the commercial product being procured

Resulting in excessive resources to resolve the problem and a costly replacement to the tried-and-true older technology

PROXIMATE CAUSE: Inability to produce boards that were both compliant to GSFC's specifications (per coupon analysis) and function reliably

KEY INTERMEDIATE CAUSE: Specifications were incompatible with new technology (high pin-density reconfigurable FPGAs)

KEY INTERMEDIATE CAUSE: Attempts to use specifications incompatible with the board design and irrelevant to operation (use of Interconnect Stress Test as an acceptance process)

ROOT CAUSE: Blind and overly strict adherence to older specifications that are not compatible with current technologies

LOCAL CORRECTIVE ACTIONS APPLIED (not recommended):

- multiple board respins
- attempts to use more strict and less relevant testing
- replacement of the product

BROAD CORRECTIVE ACTION:

- reevaluation of printed circuit board requirements, especially when high-density interconnect (HDI) technology is used
- institution of printed circuit board coupon risk assessment process

BROAD LESSONS LEARNED:

- Be cognizant of the relevant domain of application of the specifications being employed, especially if there is a significant challenge in meeting the specs for a qualified design.
- Be aware that changes in technology may surpass the application domain of specs that may be in play
- Always be prepared to challenge the specifications that are being imposed when an experienced developer is having difficulty with compliance.

Summary

A structure was presented for lessons learned capture, linking to root cause analysis. These lessons involved one or more of the following:

- Situations where we have failed to look at our own requirements that we've counted on for years as causing the problem
- Situations where we have failed to verify the applicability of the requirements we impose to the specific products to which we are applying them
- Situations where we have misdiagnosed a problem based on suspicion rather than the specific facts
- Situations where we have missed opportunities to prevent future problems by quickly chalking up failures to being one-offs.
  - Even with clear warning signs

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Recent parts failures pertinent to GOES-R and RGA (IGA) testing

MMS High-voltage optocouplers

- The MMS mission involved four spacecraft, each with a very large suite of instruments.
- There were numerous high voltage instruments on the spacecraft, requiring high voltage, switching, power supplies.
- The switching is enabled by collections of high voltage optocouplers.
- Operating above about 6 kV, the nearest solution for several of the applications was the HV801 optocoupler, which is rated to 8 kV.
- There are no MIL-SPEC parts or MIL-SPECs to address this application, so choices were very limited.
- Most unfortunately, there is no derating guidance.

MMS HVOC – context for risk

- The project, SMA (including the current author), and parts engineering, all failed to either address or account for the inherent contexts for risks in the parts:
  - high voltage operation, outside of the realm of any standard practices for assuring parts,
  - use of low volume, hand-manufactured parts,
  - the use of parts in quantities of hundreds that have normally been used and procured in very low volume, and
  - the use of parts in extremely stressing conditions that lack derating guidelines.
- All of these risk factors were realized, which resulted in effectively a full parts qualification program for the HV801's and several redesigns and remanufactures to assure them for the MMS design and environment.
- This had the effect of reducing the amount of environmental testing time for several of the spacecraft from the original plan, and from the GSFC standard practices, as well as the need to account for the risks in using the parts on orbit.
- Fortunately, the design had extensive fault-tolerance designed in, and the four spacecraft enabled proof of the design in testing of the first spacecraft.

MMS HVOC lessons learned

Given the use of HVOCs (1) at levels far above previous usage levels, (2) that are low-volume, hand-produced parts, (3) produced in quantities of hundreds compared to past use of a few, (4) in very stressful conditions with minimal derating and without any derating guidelines

Extensive failures and anomalies were experienced in I&T, and there was no known method to clearly distinguish the threshold of part screening artifacts required to assure reliability, thus driving a full qualification program, multiple part remanufactures, and numerous added tests and multiple levels of assembly

Resulting in excessive use of resources and the need to reduce the environmental test plan for the mission

PROXIMATE CAUSE: numerous screening failures and board-level anomalies and failures of HVOCs

KEY INTERMEDIATE CAUSE: parts were used well outside of past experience level and manufacturing rate without any derating guidance

ROOT CAUSE: GSFC used parts extensively in multiple critical applications without understanding the context for risk as they were used in the mission because testing followed thorough GSFC practices and the spacecraft followed sound design practices, this was confined to a programmatic problem and technical risk was appropriately mitigated

MMS HVOC lessons learned (cont'd)

LOCAL CORRECTIVE ACTIONS AT THE TIME:

- created and applied several screening approaches
- provided new manufacturing directions
- performed additional large-scale system-level tests

BROAD CORRECTIVE ACTIONS APPLIED:

- incorporated warning into GSFC SMA Watchlist about considerations and risk when using HVOCs
- educating community about context for risk in COTS parts

LOCAL LESSONS LEARNED:

- there are many manufacturing features in HVOCs that must be considered to assure parts will be reliable
- partial discharge testing can provide useful indicators for the integrity of HVOCs.

BROAD LESSONS LEARNED:

- When using parts that have specific context for risk that have not been thoroughly addressed in prior use, ensure there are resources and possibly a full qualification period available before the parts are needed for installation into flight hardware
- Be sure that the necessary derating to meet mission requirements is well-characterized prior to selecting parts, or that the risks are addressed through fault-tolerant circuits.
- Ensure that the risks of using low-volume parts, especially when hand-produced at manufacturing rates greatly exceeding past experiences, are properly understood, characterized, and addressed.

MMS laser hole problem in JANS BJT

- During thermal vacuum testing late in I&T, after hundreds of hours of testing involving the part, a JANS 2N2222 failed due to corrosion internal to the part.
- Failure analysis indicated an aggressive solvent had entered the part through a hole created by an errant laser etching process.
- The part had been leak tested, but the test was ineffective.
- The laser-etched hole permitted corrosive solvents to enter the part and get trapped inside, causing corrosion.
- Variants of the laser etching problem had existed for over 10 years, but this was never addressed because the parts were compliant to the JANS requirements.
  - Sampling never statistically significant enough to catch it

MMS BJT laser hole lessons learned

Given the absolute reliance on hermetic, JANS parts to assure reliability and limited effectiveness in the inherent processes to prevent corrosion in ambient, but controlled conditions combined with a process issue that escapes the JANS protections

A JANS BJT failed late in thermal vacuum testing

Resulting in excessive use of resources to resolve and correct the problem, and perform regression testing.

PROXIMATE CAUSE: JANS2N2222 BJT failed in thermal vac

KEY INTERMEDIATE CAUSE: corrosion causing open circuit

ROOT CAUSE: The complete reliance on processes that are neither necessary nor sufficient for part reliability, and the further create secondary risk when used.

LOCAL CORRECTIVE ACTIONS AT THE TIME:

- part was replaced
- regression testing was performed

BROAD CORRECTIVE ACTION:

- GIDEP was issued

BROAD LESSONS LEARNED:

- The reliance on hermetic parts can drive up both technical and programmatic risk by (1) trapping contaminants in the parts during the manufacturing process, (2) allowing contaminants to enter the parts for those that are on the fine edge of being hermetic, and (3) providing false confidence that the use of such parts provides substantial protection against part failure due to corrosion
- The sample size for RGA testing under MIL-PRF-19500 only provides a top-level indicator that parts in the lot are free from significant elevated moisture or contaminants
- The use of JANS parts is neither necessary or sufficient for assuring integrity or reliability of parts through I&T

JANS 2N2222 failure

- Late in I&T (hundreds of hours of testing on the part)
- Longstanding process control problem after changing laser etching equipment led to deep laser etching hole all the way through the part
- Hermeticity testing not 100% effective, allows "one-way leakers" to get through
- Vendor used tri-chlor variant to clean the boards
- Aggressive solvent entered the part, leading to a slow death
- First failure reported on a related problem was in 2004.
- Many paths required to resolve
  - Laser etching equipment
  - Laser etching process control
  - Leak testing*
  - Solvent use
- Round up parts turned up 13 out of ~ 1M that had passed leak test and had a hole
- Detailed statistical analysis indicated that risk is within normal expected JANS failure likelihoods

Recent events

- Functional failure of a GOES-R Microsemi JANS2N3637 (TO-39 package) LDC 0919A transistor during testing due to corrosion internal to the part
- Functional failure of an Insight program Semicoa JANS2N2222a (TO-18 package) LDC 1011 transistor that was inside of a pressure transducer (assembled by an outside vendor) during testing due to corrosion internal to the part.

Both corrosion-related failures occurred at the same vendor in the same time frame with 5-6 year old parts

2N3637 failure after the fact

- Part that functionally failed passed:
  - Visual inspection
  - Fine and gross leak (CHLD, Flourocarbon)
- Part that functionally failed:
  - Failed functional test with excess leakage current
  - Failed RGA test (~3x the moisture limit)
  - Showed signs of atmospheric ingress (O_2/Ar)
- 10 other parts out of 86 tested from the lot failed RGA due to excess moisture
- 3 parts in addition to the failed part showed signs of atmospheric ingress

2N2222a failure after the fact

- Part that functionally failed had passed
  - Visual inspection
  - Fine and gross leak (CHLD, Kr-85)
- Part that functionally failed
  - Failed RGA (far over the moisture limit)
  - Exhibited elevated H2
- 3 other parts out of ~140 tested from the lot showed out of spec moisture in the RGA test. It was noted that there was a variation in the lid welds, between beaded and flat. The flat welds without strong process controls are more difficult to ensure and verify a robust seal
  - All 4 parts that failed RGA had flat welds
  - LM indicated 60% beaded welds, 40% flat, and we saw a similar breakdown in spare parts from the same LDC at GSFC
  - There is no specification or implied process control for the welds
- It is apparent that the moisture was a by-product of a chemical reaction that was prompted by the elevated H2 in the part

RGA testing

- More commonly referred to now as IGA testing (residual vs internal)
- Per MIL-SPECs, used as primary method for measuring moisture in hermetic devices since 1970’s
- Destructive test (hole produced in part)
- QMS used to measure the chemical breakdown
- Not 100% reliable, for various reasons
- Different results may occur depending on how much time has transpired since manufacture, even under ideal handling conditions. Variations may be random.
- We would typically perform this test after passing fine and gross leak tests and failure would identify
  - One-way leakers
  - Undesired ingress at the factory
  - Something has happened over time, such as internal outgassing
- Because of variability of results (of which handling outside of test house’s control may be a factor), test customers have been known to play “RGA roulette” – send to multiple test houses until a passing result is achieved

Test requirements in MIL-PRF-19500 (Method 1018, Procedure 1)

- "Internal gas content: The moisture content of the sealing environment shall be controlled. The internal moisture content of ceramic and metal packages shall not exceed a value of 5,000 PPM **for the sample** when tested in accordance with test method 1018 of MIL-STD-750 at +100°C … " Furthermore, signs of atmospheric or leak-test fluid ingress, or change in pressure outside of a threshold within the sample are cause for rejection of the lot as well. This testing is a bi-monthly process control, but indications are that it is typically applied to each lot produced.
- **Intent** of the requirement: All parts in lot have moisture below 5000 ppm and are hermetic
- Sample size: 3
- Allowable RGA out of spec conditions within the sample: 0

Sampling statistics for 2N2222a

- From Statistical Solutions LTPD calculator
- MIL-PRF-19500 requirement – “normal for JANS parts”
  - Sample of 3, 0 defects allowed provides
    - 60% confidence that 30.5% or less of the lot is defective
    - 90% confidence that 76.5% or less of the lot is defective
- Testing performed as result of failure
  - Sample of 140, 4 defects allowed provides
    - 60% confidence that 3.74% or less of the lot is defective
    - 90% confidence that 5.71% or less of the lot is defective
    - 99% confidence that 8.29% or less of the lot is defective
- For further reference
  - Sample of 15, 0 defects allowed provides
    - 60% confidence that 6.11% or less of the lot is defective
    - 90% confidence that 15.35% or less of the lot is defective
    - 99% confidence that 30.7% or less of the lot is defective
- To achieve equivalent 90% confidence to 4/140, 41 would need to be tested with no failures.

Sampling statistics for 2N3637

- From Statistical Solutions LTPD calculator
- MIL-PRF-19500 requirement – “normal for JANS parts”
  - Sample of 3, 0 defects allowed provides
    - 60% confidence that 30.5% or less of the lot is defective
    - 90% confidence that 76.5% or less of the lot is defective
- Testing performed as result of failure
  - Sample of 87, 11 defects allowed provides
    - 60% confidence that 14.43% or less of the lot is defective
    - 90% confidence that 19.08% or less of the lot is defective
    - 99% confidence that 24.7% or less of the lot is defective
- To achieve equivalent 90% confidence to 11/87, 16 would need to be tested with no failures.

Statistically, the large sample RGA testing for the 2N2222 tells us

- The 2N2222a LDC lot (1011) is at the very low end of RGA test failure rates for JANS parts per the MIL-PRF-19500 requirements
- JANS parts do not fail often (~10 ppm for BJTs)
- It is unlikely that this lot is of elevated risk based on the RGA results
- While negative RGA results always warrant investigation, statistics for JANS parts tell us that individual RGA nonconformances would not imply imminent part failures on their own
- GIDEP based on RGA results is not warranted

Statistically, the large sample RGA testing for the 2N3637 tells us

- The 2N3637 LDC lot (0919A) is consistent with RGA test failure rates for JANS parts per the MIL-PRF-19500 requirements
- JANS parts do not fail often (~10 ppm for BJTs)
- It is unlikely that this lot is of significant elevated risk based on the RGA results
- While negative RGA results always warrant investigation, statistics for JANS parts tell us that individual RGA nonconformances would not imply imminent part failures on their own
- GIDEP based on RGA results is reasonable but may be a tough sell
- Incidentally, sample of three parts sent to GSFC after the failure all passed RGA, and hence would have been sufficient to approve shipment.

Practically, the large sample RGA results for 2N2222a tell us

- Some parts have elevated moisture and elevated H2.
- We need to try to understand why
- All of the RGA nonconformances correspond to parts that have flat welds
  - We need to understand more about the distribution of welds and vulnerability to one-way leaks (two-way leaks are likely to be caught by fine and gross leak tests)
- Manufacturer counts on leak tests to weed out the leakers and apparently does not control the weld process for weld type

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