National Aeronautics and Space Administration

Reliability of COTS parts

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What is the fundamental message, and what isn't it?

- When developing a mission, we need to choose the best parts for the job – they may be MIL-SPEC, they may be COTS, they may be custom
  - When properly selected, MIL-SPEC and COTS parts can have a basis for reliability
  - Sometimes there are no parts available or even existing to do the job for the mission that have a basis for reliability
    - In that case, design practices and system fault tolerance must account for the shortcomings
- There are many limitations for MIL-SPEC parts and those limitations are growing as technology and manufacturing evolve
- **COTS (with no caveats) covers an infinite trade space and critical thinking, sound judgment, and understanding of the concepts of quality and reliability are essential to find the right subset of the trade space**
- This is not a message to blindly use COTS parts
- This is not a message that COTS parts are always the best solution
  - The best solution comes out of a part-by-part determination that considers performance, reliability, availability of parts, usage constraints, and cost

Addressing radiation is no different or even more expansive when making broader use of COTS parts

NESC COTS study

- Originally formed to support the Commercial Crew Program and its heavy use of COTS
- Turned to focus on the overall problem of selection, evaluation, screening, qualification, and usage in robotic and human-rated space systems
- Phase 1 introduced several new ways of looking at COTS and key terminologies to help the agency understand ways to use COTS successfully
- Phase 2 has extensively dispelled myths and established a framework for new approaches to use COTS parts reliably
  - Reliable usage centers around the concept introduced in the Phase 1 study, the Industry Leading Parts Manufacturer (ILPM), and the specific selection of Established parts

This presentation was largely motivated and informed by the NESC COTS study, but it goes well beyond the findings and message of the study

COTS parts

- Parts for which the part manufacturer solely establishes and controls the specifications for performance, configuration and reliability, including design, materials, processes, and testing without additional requirements imposed by users and external organizations. It is typically available for sale through commercial distributors to the public with little or no lead time.
- Manufacturers design for reliability and employ continuous improvement processes and advanced manufacturing techniques
- Manufacturers perform their own qualification tests based on how the parts are manufactured and how they are intended to be used
- Reliability is established by volume
  - Reliability is essential to stay in business, so it is self-controlled and *stable*
  - Low volume parts have questionable and uncertain reliability, and thus must be assured by additional means
- Vendor screening and testing processes assure uniformity and that each part performs as intended, while avoiding damaging or degrading parts through additional handling, use of unknown test equipment, and overtesting
  - Parts not going through vendor screening and testing processes have uncertain linkage back to the historical usage needed to form a basis for reliability
- **High-volume parts from reputable vendors that go through 100% vendor screening covering all datasheet parameters have the best opportunity for reliable usage, when used well within rated limits (<u>including radiation*</u>) because testing is most closely linked to actual manufacture and usage.**

*Radiation is a system-level phenomenon that is not sufficiently addressed at the piece-part level

MIL-SPEC parts

- Originated in DoD out of the need for tight uniformity and interchangeability of parts across the world
- Quality specifications were defined to cover the most extreme range of conditions
- The government controls the drawings, requirements, and specifications of such parts.
- Reliability is often declared based on accelerated testing combined with many stringent requirements and other forms of extreme tests
- Some specs/requirements included based on past lessons learned or past indicators of infant mortality
- Originally, MIL-SPECs were the only reasonable approach to procure parts that were necessary to function reliably.
- Thus MIL-SPECs were the best existing source to obtain parts to use in space systems
  - The government monitored parts manufacturing and testing
  - Failure rates from highly-accelerated tests were used to predict reliability and verify that issues were not appearing in manufacturing.
- **MIL-SPEC parts arbitrarily link to reliability because they are assured by quality specifications that may not represent actual usage or manufacture, and might overtest parts by using standard screening practices. Since reliability is a by-product, it is far from guaranteed***

*many MIL-SPEC parts go through extended reliability testing but the testing is not relevant to the actual usage and it does not address the types of failures typically encountered with MIL-SPEC parts

NASA-screened COTS parts

- COTS parts that are screened and/or qualified (level 1 or 2) using MIL-HDBKs via a document such as EEE-INST-002.
- Reliability is equivalent to that of COTS parts except that MIL-SPEC tests are applied to the parts, resulting in extra handling and frequent overtesting relative to the part application and often to its datasheet. Thus this option provides the greatest uncertainty for reliability, especially if the COTS parts are low volume or low quality to start with.

ILPM

ILPM: a COTS manufacturer that produces high quality and reliability parts that do not require additional screening and lot conformance testing, common in today's requirements for using "non-standard" parts in space

- Implements a "Zero Defects" program, as described in AEC-Q004 or a similar source.
- Designs parts for manufacturability, testability, operating life and fielded reliability.
- Manufactures parts on automated, high-volume production lines with minimal human touch labor.
- The manufacturer understands and documents all manufacturing and testing processes and the impacts and sensitivities of each process step on product characteristics and quality.
- The manufacturer's end-product testing includes 100% electrical verification of datasheet parameters.
- The manufacturer implements rules for removing outlier parts and removing abnormal lots; these rules may apply either in-process or with finished parts.
- The manufacturer implements a robust change system that assures all major changes are properly qualified and that customers are notified of major changes
- The manufacturer implements a robust Quality Management System acceptable for spaceflight.

Each organization should maintain its own list of ILPMs

The ILPM concept is not new

- Hakim (C3I and CALCE) published Research Note, *Plastic Encapsulated Microcircuit Reliability Prediction: Why,* in 1997
- Pointed out that "best commercial practice suppliers have already addressed the design, materials, and processing issues of molded packaged microcircuits, and corrosion is no longer a mechanism of concern to the user"
- Proposed test to demonstrate acceptance of a supplier and part capability is: 300 h of biased HAST (120degC/85% RH) with zero failures out of 45 test samples.
- Stated that it can safely be assumed that a supplier whose products pass the proposed HAST test has incorporated the correct designs, materials and processes to eliminate the corrosion mechanism
- Suppliers failing the test will not be acceptable unless they incorporate changes and demonstrate the results.

Established Part

- Produced using processes that have been stable for at least one year so there are enough data to verify the part's reliability;
- Produced in high volume. High volume is defined as a series of parts sharing the same datasheet having a combined sales volume over one million parts during the part's lifetime;
- 100% electrically tested per datasheet specifications, minimally at typical operating conditions and is in production prior to shipping to customers. Additionally, the manufacturer must have completed multi-lot characterization over all operating conditions cited in the part's datasheet, prior to mass production release. Thus, production test limits are set for typical test conditions sufficient to guarantee that the parts will meet all parameters' performance specifications on the datasheet;
- Produced on fully automated production lines utilizing statistical process controls (SPC), and undergoes in-process testing, including wafer probing for microcircuits and semiconductors, and other means as appropriate for other products, e.g., passive parts. These controls and tests are intended to detect out of control processes and eliminate defective parts at various stages of production.

Why have COTS been perpetually deemed “unreliable” or “low-grade”

- The COTS definition is infinite
  - This is exacerbated by an infinite number of definitions
    - COTS is often a “label” used at a manufacturer with a local definition
  - “Reliability” defined by the worst elements in the broad category
- MIL-HDBK-217
  - Arbitrary “failure rates” (PEMs 60-600x MIL-SPEC without any current foundation)
  - Approach (along with similar handbooks) has become engrained across the traditional aerospace contractor community
  - Standard “probability of success” (Ps) requirements have demanded its use
- Issues with the plastic used in PEMs in the 70’s and 80’s.
  - Took time to work through challenges to get the materials and manufacturing right
  - e.g. moisture in the plastics were interacting with aluminum, resulting in corrosion
  - Problem was solved in the late 80’s and PEMs ultimately surpassed hermetic ceramics in part-level reliability (failure rates)
- Myths about COTS vs radiation

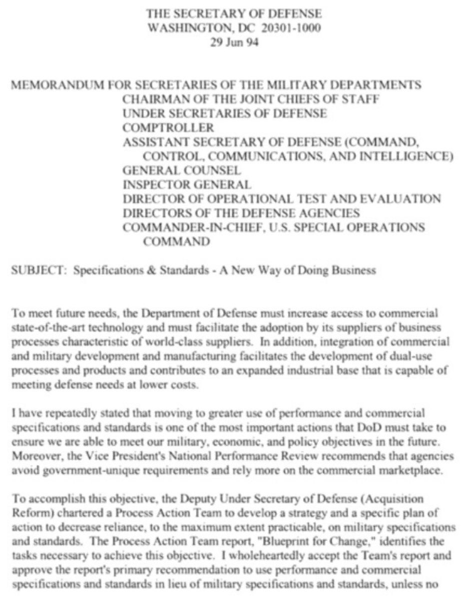
Growth of commercial electronics

- Commercial electronics demand grew and surpassed that of military electronics, driven largely by computers
  - Parts were originally derived from the MIL-SPEC designs, but sans the costly design features (e.g. hermetic ceramics) and tests (e.g., 2Vr conditioning)
  - Parts were prone to occasional failures without the focused protections
- As demand for electronics exploded, the demand for reliability followed shortly, especially in markets such as automotive and medical
  - Industry recognized the outdated and costly practices that were used in the MIL-SPEC system and focused more on improving the designs, pointed protections, and process controls rather than re-adding the obsolete, non-relevant practices
  - By about 1995, commercial electronic parts had largely equaled or surpassed MIL-SPEC parts in reliability and this fact was acknowledged across much of industry and in many elements of parts leadership within the government

The Perry Memorandum (1994)

The ”Perry Memorandum” was released in June 1994, entitled *A New Way of Doing Business,* per direction of Defense Secretary William Perry

- Recognized the cost and availability constraints as well as technological limitations brought about by the MIL-SPEC system.
- Directed the broad use of commercial practices
- Required MIL-STDs to be rewritten as MIL-PRFs (performance based)
- Required waivers to use MIL-STDs
- Required PMs and acquisition decision makers to challenge requirements
- Directed first choice in an order of precedence to be the use of a commercial part*



THE SECRETARY OF DEFENSE
WASHINGTON, DC 20301-1000
29 Jun 94

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
COMPTROLLER
ASSISTANT SECRETARY OF DEFENSE (COMMAND, CONTROL, COMMUNICATIONS, AND INTELLIGENCE)
GENERAL COUNSEL
INSPECTOR GENERAL
DIRECTOR OF OPERATIONAL TEST AND EVALUATION
DIRECTORS OF THE DEFENSE AGENCIES
COMMANDER-IN-CHIEF, U.S. SPECIAL OPERATIONS COMMAND

SUBJECT: Specifications & Standards - A New Way of Doing Business

To meet future needs, the Department of Defense must increase access to commercial state-of-the-art technology and must facilitate the adoption by its suppliers of business processes characteristic of world-class suppliers. In addition, integration of commercial and military development and manufacturing facilitates the development of dual-use processes and products and contributes to an expanded industrial base that is capable of meeting defense needs at lower costs.

I have repeatedly stated that moving to greater use of performance and commercial specifications and standards is one of the most important actions that DoD must take to ensure we are able to meet our military, economic, and policy objectives in the future. Moreover, the Vice President's National Performance Review recommends that agencies avoid government-unique requirements and rely more on the commercial marketplace.

To accomplish this objective, the Deputy Under Secretary of Defense (Acquisition Reform) chartered a Process Action Team to develop a strategy and a specific plan of action to decrease reliance, to the maximum extent practicable, on military specifications and standards. The Process Action Team report, "Blueprint for Change," identifies the tasks necessary to achieve this objective. I wholeheartedly accept the Team's report and approve the report's primary recommendation to use performance and commercial specifications and standards in lieu of military specifications and standards, unless no

*Note that using a commercial part screened to MIL-SPECs does not meet even the spirit of this requirement since a MIL-SPEC part comes off the shelf with such screening

The recognition of commercial part reliability

- The 1994 SHARP* Commercial and Plastic Components in Military Applications workshop, hosted by NSWC Crane, concluded that commercial microcircuits were as (or more) reliable than MIL-SPEC microcircuits but there were two problems to work out:
  - The fact that "COTS" parts were rated (at the time) 0°C – 70°C & "industrial grade" (another form of COTS) parts were rated -40°C – 85°C, while military grade were rated from -55°C – 125°C would require that COTS parts be "uprated" for operation at the full MIL temperature range. This would require detailed discussions with the manufacturer and a range of tests. This led to
    - the perpetual mantra that *COTS parts are not designed for military and space applications***
    - the resulting conclusion that testing would always be required to assure such parts in a military application even after the aforementioned premise disappeared.
  - The notion that the typical availability lifetime for a COTS part was far shorter than a typical weapon system lifetime

* Sustainable Hardware and Affordable Readiness Practices

**It is often suggested that radiation hardness is a critical notable example of how COTS parts are not designed for the space environment, but in fact, (1) COTS has no direct connection to radiation hardness or lack thereof, (2) < 10% of parts counts need be considered for radiation, and (3) most "space grade" MIL-SPEC parts are not radiation hardness assured

The "Designed for Space Applications" Myth

- Most "space grade" (e.g. JANS) parts are not designed for space applications.
  - They are original JEDEC semiconductor designs that have been put through a series of tests deemed in the 60's to be important to survive the military temperature range and an extended ground development period.
  - Most do not have any form of radiation hardness assurance (RHA)
  - Most that do have RHA are no different from their non-RHA counterparts except for lot-specific radiation testing
- The tests representative of space-grade have virtually no relationship to the space environment, but they are representative of problems encountered with part design and manufacture from the mid-20th-century.
- Such tests are often incompatible with modern technology parts and many are designed for parts that have "built-in" derating (i.e. parts that are required to perform for extended periods at multiples of part rating levels).

The relevant question for selecting any part is whether the application range is well within the definition and limitations of the datasheet rated values

About MIL-SPEC ”upscreening” of COTS parts – what did Swift tell us?

- Why would it ever make sense to apply a 30-50-year-old test to a recently designed and manufactured component?
- Can you make a poorly-selected part high quality or high reliability by applying tests to it?
- Why did we not learn this lesson from Swift (2004)? Can we learn it today, 20 years later?
  - “SWIFT BAT parts engineering successfully executed a parts control and test program that assured that all parts met or exceeded Grade 3 [sic] program requirements, including radiation tolerance. There were a few scattered failures during parts testing, but the subsequent failure analyses revealed that the failures were due to mishandling or improper testing at the board or box level.”
  - But yet, “Design engineers elected to select plastic parts, which allowed the use of state-of-the-art devices that provided the advantages of lower power, volume, and weight. However, commercial-grade parts are designed for a very different set of operating conditions than those found in a space application. A full and thorough evaluation is needed for any part type proposed for space flight use like the ones used on the SWIFT BAT project.” ---- is this really the lesson we should have learned?

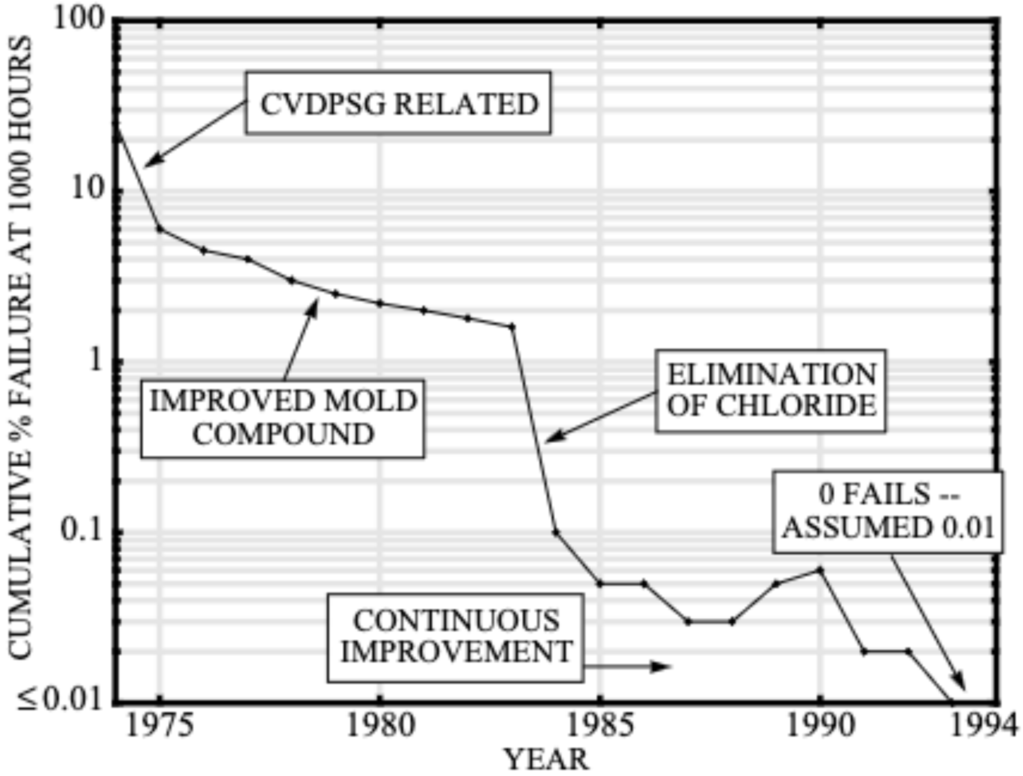
Broad sweeping statements are used even when context is available

Prescription -> Performance per Perry

- The MIL-SPEC QPL (Qualified Product List) transitioned to the QML (Qualified Manufacturer List), which resulted in now having commercial and military products manufactured on the same lines
  - Helped military parts then “catch-up” to reliability of commercial parts
  - Intended largely to phase in commercial practices to military parts
- MIL-PRFs were written from the MIL-STDs, with more encouraging language about manufacturers having the opportunity to perform their own tests to demonstrate that previously mandated standard tests could be removed or changed
- Toward the late 90’s demands for commercial electronics grew in volume and scope and there was no longer a basis for manufacturers to broadly set temperature ranges
- Thus, by around 2000, the “COTS” and ”industrial” labels no longer implied specific temperature ranges except with the very few manufacturers that had well established lines across COTS, industrial, and MIL, strategically keeping them separated
- The ranges then became based on the demand and performance limitations and often commercial parts began to meet or exceed the MIL ranges in many cases.
  - Most importantly – the datasheet and mission requirements are key points of consideration instead of broad labels
  - Despite this transition, the aerospace community has still held onto labels and used them to make broad assertions, resulting in costly decisions

Corrosion in Plastic Encapsulated Microcircuits Evolution

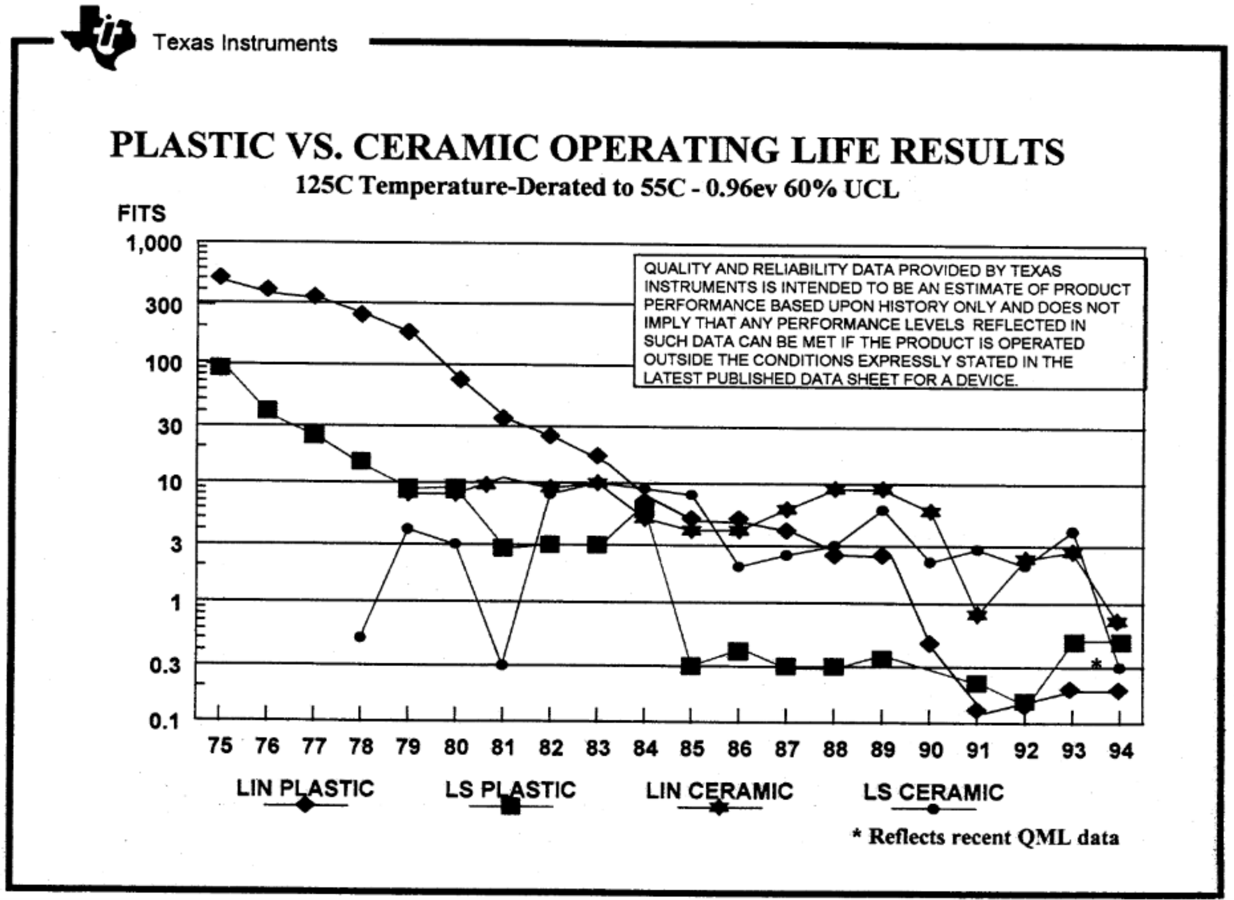
IMPROVEMENTS IN THB 85°C/85% RH PERFORMANCE IN PLASTIC-PACKAGED (PDIPs) CMOS LOGIC ICs



Schultz & Gottesfeld, 1994 (NEPP)

Corrosion problems in plastic parts were almost entirely eliminated by 1994 through standard commercial practices

TI PEMs reliability evolution



QUALITY AND RELIABILITY DATA PROVIDED BY TEXAS INSTRUMENTS IS INTENDED TO BE AN ESTIMATE OF PRODUCT PERFORMANCE BASED UPON HISTORY ONLY AND DOES NOT IMPLY THAT ANY PERFORMANCE LEVELS REFLECTED IN SUCH DATA CAN BE MET IF THE PRODUCT IS OPERATED OUTSIDE THE CONDITIONS EXPRESSLY STATED IN THE LATEST PUBLISHED DATA SHEET FOR A DEVICE.

* Reflects recent QML data

Presented by TI at 4th Annual Commercial and Plastic Components in Military Applications Workshop, Nov 1995

Plastic became more reliable than hermetic ceramic in 1984

QPL -> QML

- When the MIL-STDs transitioned to MIL-PRFs, there were three major changes in the documents
  - Removal of many of the requirements to perform continuous reliability testing of parts
  - More encouraging language for manufacturers to justify removing or changing tests shown to be non-value-added
  - The Standard Evaluation Circuit concept (representative of actual part) was introduced to evaluate the capability of alternative methods for manufacturing and test and to monitor product performance.
- A few manufacturers embraced the new opportunity, but most did not take advantage, likely because there was little financial basis to do so.
- Not long after the introduction of QML, some issues with FPGAs at the time prompted MIL parts leadership to reinstate MIL-SPEC testing
- Effectively, the MIL-PRFs became the new MIL-SPECs as written, and QML did not solve the problems around parts cost, availability, and innovation as they were intended
- Furthermore, there was little follow-up as per the original plan to evaluate the effectiveness of meeting the original intent of changing to QML
  - The problems that existed that prompted the Perry Memo continued, and continued to expand
- Recommendations for an order of precedence starting with commercial parts, followed by QML parts, then MIL-SPEC parts were not heeded

The damages resulting from 217

- The inappropriate use of MIL-HDBK-217 all but assured that there would be no escape from the MIL-SPEC system for parts
  - Incorrectly defining commercial parts failure rates as ten times greater than than the highest-grade MIL parts is unwarranted for current commercial parts and not supported by actual in-service space systems experience
- Long after its demise, the convenience it provided to crank out highly desirable mission reliability numbers would never be overcome
  - Numerous software tools were developed that exacerbated the problem
- The broad adoption, particularly across the space community, formed an indelible backdrop for assurance practices, particularly associated with parts.
- Even for those that understood the fallacies and its underlying assumptions and limitations, a prevailing sense that it promotes good practices would maintain its cultural force
- Somehow this cultural acceptance instilled within the space community the misguided notion that reliability of a complex system could be estimated and assured through levels of testing and government prescription and intervention for the electronic parts within
  - **Even though the document itself stated otherwise**

The self-fulfilling prophecy of MIL-STD testing

- The findings across the community that commercial parts were as or more reliable than their MIL-SPEC counterparts were quickly buried and forgotten.
- The broad assertion that testing is needed for using all commercial parts in military applications that was originally based on generic temperature ranges that have since gone away has transitioned to the mantra that testing is needed to remove infant mortals and assure reliability. Current commercial practices employing appropriate in-process screens and statistical process controls obviate that assertion.
- The MIL-STD tests that were designed around the MIL-SPEC parts became the perceived right answer to test commercial parts that have departed greatly from the original MIL-SPEC designs
- While many MIL-STD tests are of value to be applied to current parts, many are incompatible and result in occasional or frequent failures or nonconformances. The part manufacturers can best establish the relevance of such tests.
- Thus, applying incompatible tests can cause broad test discrepancies and even assertions that parts that are working reliably in stressful applications are high risk, as indicated in the following NASA lesson learned: https://llis.nasa.gov/lesson/23502 based on the misperception that the collection of decades' old tests are representative of space applications.
- Such results that involve many "test discrepancies" and "failures" provide the misguided perception that the parts are at fault and that the screening is effective. Instead, these tests have been misapplied to commercial parts.

In fact, it is not the space application that many commercial parts are not designed for; it is the testing regimes that were deemed "necessary for space".

Lot Control vs High Volume Statistical Process Controls

- Lot control is an approach for manufacturing parts that is centered around individual lots and that depends heavily on end of line testing, focused and extensive quality requirements, and traceability. Each lot is effectively a new build, thus providing little assurance of performance in another lot. Therefore, lot traceability is essential. Reliability can only be established indirectly as a by-product of the extensive quality requirements and a proven part design since there would not be sufficient data to establish reliability directly. Occasionally, there are manufacturing problems in lots that are not addressed in the quality specifications, which often result in field failures. This is the approach in the MIL-SPEC system because of the limited volume of usage.
- High-volume, statistically-process-controlled (SPC) manufacturing involves continuous production and in-line testing to assure uniformity across all production lots without a focus on individual lot characteristics. Combined with field feedback and process control metrics such as DPPM, DPPB, CpK, or AQL, reliability can be assured directly.

Intelligent use of COTS parts

- Always use parts within the limits of their datasheets
  - Respect the datasheet!
- AEC-qualified parts (not just “for automotive use”) from leading manufacturers, produced under IATF 16949 will maximize reliability
- Use familiar parts when possible
- Avoid an approach that prompts you to use more parts as often happens with capacitors
- Conservative derating is good practice, but excessive and forced derating may result in need for many extra parts, a mass or space problem, or a weaker design with less margins.
- Use parts that the manufacturer declares to be for reliable use
- Use parts that have been established for over a year and in high volume production
- Buy parts from authorized distributors
  - There is no purpose in MIL-SPEC distributor restrictions when buying COTS parts
- There are many great options for “enhanced space” COTS parts for microcircuits and discretes
- Avoid requiring the tightest performance and tolerances from passive parts
- Strive for flexible resistance values (ranges) in current sensing applications
- Be sure that parts only offered with pure tin have matte tin finish, when available.
  - Give preference to manufacturers that use JEDEC tin whisker acceptance testing or similar approach
- Often increased performance and modern design and manufacturing drive increased reliability
- In some cases, you can only use what’s available against the guidance – accordingly assess and acknowledge the risk and explore reasonable mitigations

Common approaches for addressing radiation

- Avoidance: dormancy of sensitive electronic elements in high stress regions such as SAA or Van Allen Belts
- RHBD: Proven rad-hard by design approach, applied to circuits and/or parts
- Traditional parts-centric: Use of RHA* parts with radiation-tolerant design to accommodate high stress region operation
- Modern parts-centric: Use of familiar sensitive** parts along with proven circuit designs in comparable environment, normally combined with select strategic parts testing outside of specific projects to characterize variability or parts changes in general
- Radiation-tolerant design: Use radiation-tolerant circuit design techniques including features such as MOSFET protection and overcurrent detection with reset capability, resettable processors, EDAC, derating beyond EEE-INST-002 recommendations, etc.
- Risk-based approach combining past on-orbit experiences in similar stressing environments.
- System fault-tolerance (including redundancy): This may include new, unproven approaches, with backup proven systems.

* RHA = radiation-hardness assured, with lot-specific testing and accompanying paperwork. Radiation hardness or tolerance of individual parts is not sufficient for performance in severe radiation environments, as evident from SMAP. While sometimes termed "risk avoidance," this approach does not avoid risk

**Sensitive parts include actives such as memory, processors, CMOS devices, MOSFETs, etc.

Will use of COTS cause a radiation nightmare?

- It certainly can if you're in a radiation environment and you pretend it's not there, but that has **nothing** to do with COTS.
- Typically, about 90% of the overall part count even for large missions are not radiation-hardness-assured (because they don't need to be).
  - The majority of places where COTS are really needed are for non-susceptible parts, such as most passives
- The problem is no different from that of using a 5962-XXX microcircuit or a JANS2NXXXX BJT (neither of which is radiation hardness assured). Most "space-grade" parts are not radiation hardness assured
- For reference, an IRHM58160 is a COTS part (and it is radiation hardness assured).
- No matter whether you use COTS, MIL-SPEC or "special drawing" parts, radiation should be addressed in the same way
- As we transition to newer technologies and higher performance, we will have to think about radiation mitigation in different ways because parts with RHA will almost always be multiple generations behind
  - However, some of the new technology parts will be less susceptible to radiation by the nature of their designs (thinner gate oxides, etc)

Intelligent use of COTS is of insignificant difference from our current parts assurance practices from a radiation standpoint

Radiation and on-orbit non-RHA performance data sources

- Test data:
  - Traditional: radhome.gsfc.nasa.gov, transitioned to https://nepp.nasa.gov/pages/pubs.cfm
  - New: esarad.esa.int
  - New: pmpedia.space
- On-orbit experiences (“fact of” - some info available)
  - Spacecube data (LEO on-orbit – extensive non-RHA and COTS – 10+ yr)
  - Aerocube data (LEO on-orbit – 100% non-RHA COTS – 10+ yr) (Aerospace Corporation)
  - Swift data (585km x 604km, 20.6 deg - extensive COTS ~ 19 yrs)
  - Ascent (GEO cubesat – launched 12/2021) (AFRL)
  - Biosentinel (deep space cubesat – launched with Artemis)
  - Newspace – extensive, limited data availability

Can we slow down the use of COTS?

- The use of COTS is already here, no matter what requirements we impose
  - The only question is whether we want to put a spacecraft on-orbit or not
- COTS parts are not brought forward into our projects because someone wants to save a few dollars or a few weeks or eke a little bit of extra unnecessary performance.
- COTS parts are needed in order to fly mature technologies from the last 25 years
- COTS parts are needed to make systems more reliable
- COTS parts are needed because they are available
- COTS parts are needed because they do not involve excessive costs for non-value-added activities

The use vs non-use of COTS in our systems is a simple prohibition question. There is no way to stop them – you simply need to place the right boundaries to properly use them without damaging them or inflating costs unnecessarily. The tighter boundary you place on them, the more likely you will encourage poor choices and bad practices

Some recent history of COTS EEEE parts in space

- 2004: Swift mission flies 40% COTS EEEE parts (with level 3 upscreening)
- 2013-2017: Multiple Spacecube variants with up to 99% COTS EEEE parts (no upscreening)
- Numerous Ames missions, 100% COTS EEEE parts (no upscreening)
- Ingenuity: 99% COTS EEEE parts with focused screening
- SpaceX: Mostly COTS EEEE parts
- SSTL: Mostly COTS EEEE parts(several decades)
- AFRL's Ascent: 100% COTS EEEE parts (GEO)
- Newspace: almost 100% COTS EEEE parts and components

31 Aerocubes with 100% COTS with no RHA or rad-tolerant design (resets only) over about 20 years development time and many ten years plus on-orbit with one failure in ground test, four circuit failures due to SEL (2 matching pair), and one discrepant RTC

Part Evolution

CDR35BX474AKUS
0.47uF, 50V
TTI: 100MOQ/$2.60ea

G311P838AFX475K2R1
4.7uF, 50V
TTI: 50MOQ/$278ea

GRT21BC71H475KE13L
4.7uF, 50V
Digikey: 1MOQ/$0.27ea

SpaceCube Time-on-orbit

As of Oct 2021 (STP-H6 was turned off Dec 9, 2021 to make room for the next instrument)

Project	Version	Part Req	BOM Count	Operation Months	FPGA Quantity	COTS %	COTS Months
RNS	v1.0	2+	3700	0.0833333	4	1%	3.08333
MISSE-7	v1.0	N/A	3100	90	4	2%	5580
SMART	v1.5	N/A	1000	0.0333333	1	95%	31.6667
STP-H4 CIB	v1.0	N/A	1500	30	2	1%	450
STP-H4 ISE2.0	v2.0-EM	N/A	1250	30	3	98%	36750
STP-H5 CIB	v1.0	N/A	1500	46.933333	2	1%	704
STP-H5 ISEM	v2.0 Mini	N/A	1000	46.933333	1	26%	12202.7
STP-H5 Raven	v2.0-EM	N/A	1500	46.933333	3	99%	69696
RRM3	v2.0	N/A	1429	36.666667	2	65%	34057.8
STP-H6 CIB	v1.0	N/A	1500	31.833333	2	1%	477.5
STP-H6 GPS	v2.0	N/A	1157	31.833333	2	65%	23940.3
Restore-L Lidar	v2.0	3	2000		2	0%	N/A
STPSat6	v2.0 Mini	N/A	1500		1	98%	N/A

Totals	Units Flown	11
	Commercial FPGAs	26
	Commercial FPGA Device-Years	83
	Part Years	57213
	COTS Parts Years	15324

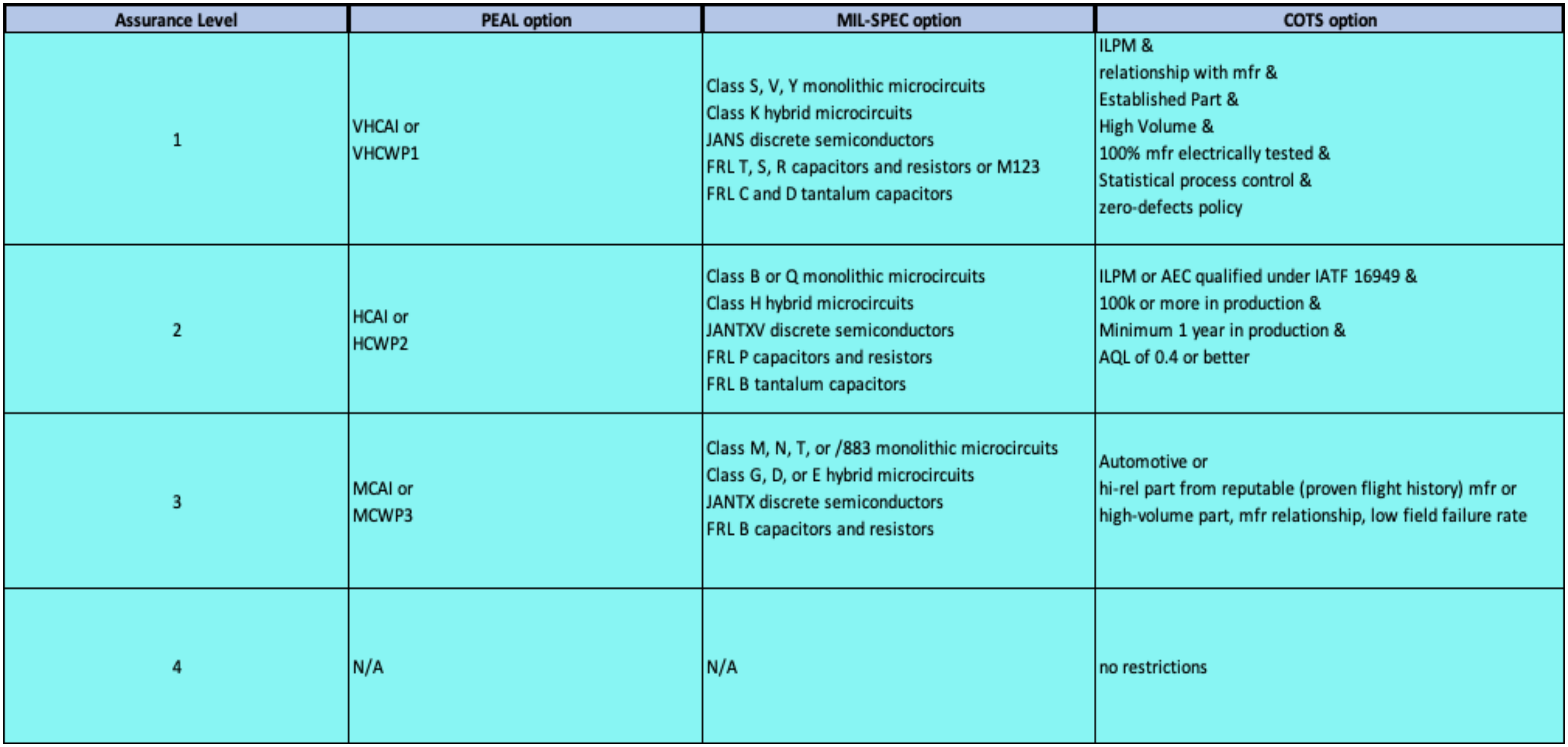
Also to note: We flew many COTS components on some of these projects:

- ISE2.0, SMART, and ISEM all flew COTS cameras that were ruggedized. SMART flew COTS SATA drives.
- Raven flew a $5 USB interface card to an IR sensor
- STP-H5 and -H6 have CHREC Space Processors (CSPs) that were 95% COTS components. See references for more info on CSP results (no failures to date)
- NavCube Commercial vendor populated PWBs

Post-NESC COTS report parts assurance

- Nearly two decades after the development of EEE-INST-002, with minimal updates since, a new approach for parts assurance is needed
- The primary outdated element of 002 is the handling of COTS EEEE parts
  - Manufacturing capabilities have changed (and improved) drastically since the practices of EEE-INST-002 were initiated
  - The differences in the screening processes vs the design and manufacture of the parts have become drastic in many cases
- The NESC COTS study has revealed many avenues for reliable use of COTS parts without relying on such screening methodologies
- Some strategic work is needed to fully institutionalize the broad use of COTS across all mission classes, but the tools are available to pilot a new approach, while a capability is developed in parallel
  - The need for a wider door for COTS entry is here today, but we'll need to step through it carefully and gradually

Transition to “three-option” parts assurance



Assurance Level	PEAL option	MIL-SPEC option	COTS option
1	VHCAI or VHCWP1	Class S, V, Y monolithic microcircuits Class K hybrid microcircuits JANS discrete semiconductors FRL T, S, R capacitors and resistors or M123 FRL C and D tantalum capacitors	ILPM & relationship with mfr & Established Part & High Volume & 100% mfr electrically tested & Statistical process control & zero-defects policy
2	HCAI or HCWP2	Class B or Q monolithic microcircuits Class H hybrid microcircuits JANTXV discrete semiconductors FRL P capacitors and resistors FRL B tantalum capacitors	ILPM or AEC qualified under IATF 16949 & 100k or more in production & Minimum 1 year in production & AQL of 0.4 or better
3	MCAI or MCWP3	Class M, N, T, or /883 monolithic microcircuits Class G, D, or E hybrid microcircuits JANTX discrete semiconductors FRL B capacitors and resistors	Automotive or hi-rel part from reputable (proven flight history) mfr or high-volume part, mfr relationship, low field failure rate
4	N/A	N/A	no restrictions

New technology does not mean less reliable or radiation sensitive

- Which has greater reliability?
  - a space-proven non-RHA part using TMR
  - An RHA part without TMR
- Which has greater reliability?
  - One RHA MOSFET with 40 nm gate oxide in an SMD-2 package
  - Three non-RHA MOSFETs with 5 nm gate oxide in DPAK

P/N	IRHNA57160	STD100N10F7
VDSS	100V	100V
ID	75A	80A
RDS(on)	12 mΩ	8 mΩ
Package	SMD-2 (~232 mm^2)	DPAK (~60 mm^2)
Weight	3.3 g	0.33 g

Where has the current radiation approach bitten us?

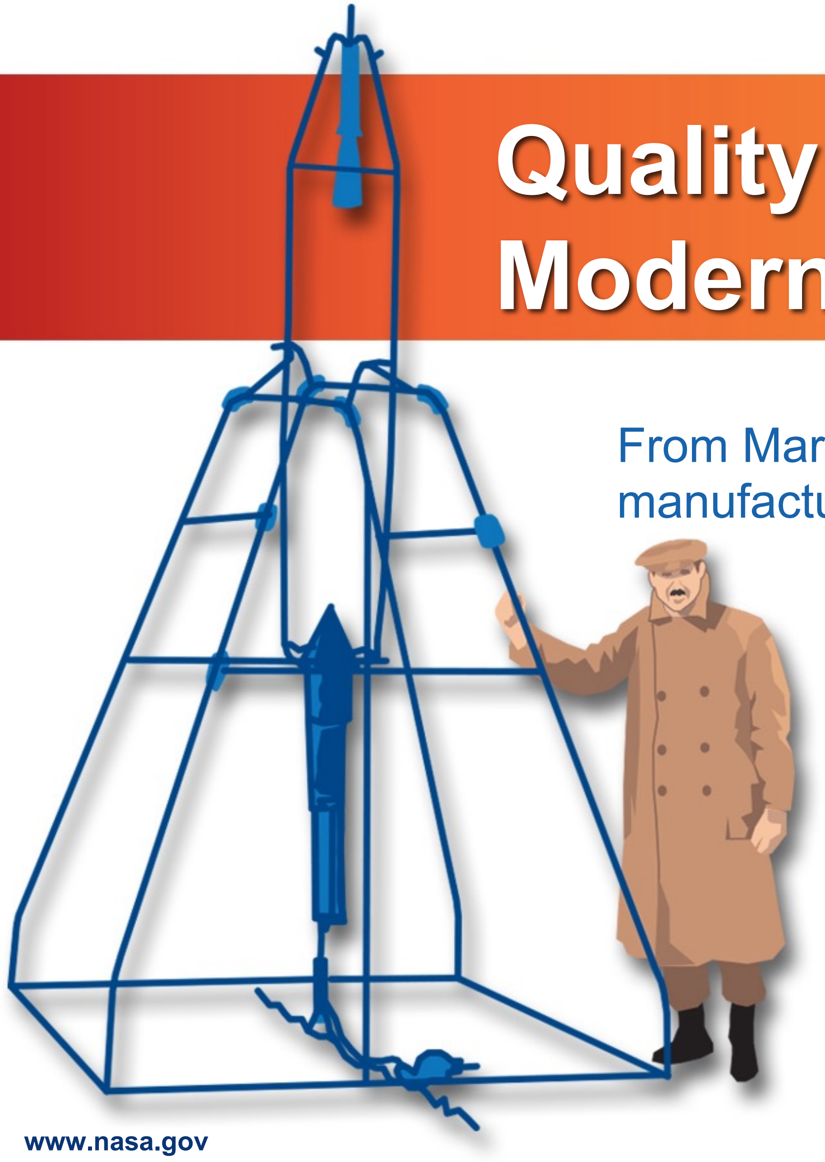
- Chandra: piece-part level radiation assessment of detectors did not account for the orientation effect in the system, which attenuated in one direction, amplified in the other.
- Hubble SM-1: a susceptible “space-grade” optocoupler lacked necessary circuit protection (filter); subsequently HST largely goes dormant in SAA
- SMAP: JANSR (radhard, “level 1”, space-grade) MOSFET experienced combined circuit effects when switching, with SEEs in the SAA, causing regular exceedance of rated voltage, ultimately causing gate rupture, and thus taking out the radar.
- Many missions have been forced to change out components with lesser components or at the expense of extreme programmatic hits based on finely prescribed piece-part radiation requirements

Parts Evaluation & Assessment Lab (PEAL)

- Reinstitution of a major institutional capability that assured reliable parts usage in the early days of NASA
- Driven by the reality of dominance of COTS in the market, the necessity to exploit commercial capabilities, and gain the confidence needed to fly parts in low-risk tolerance missions.
- NASA employees and in-house contractors
  - Select and procure parts for characterization
    - Consider unfamiliar parts used and proposed on new and recent missions as top priority
    - Gather input from scientists, component designers, instrument developers
    - **Primary focus should be on part technologies, though specific "part number" assessments should also be performed to properly evolve from current approaches and to monitor trends in specific part design changes over time**
  - Determine screening and lot acceptance tests (LAT) to be employed for future project usage
    - or determination that manufacturer screening/LAT or statistical process controls as designed are sufficient
  - Establish tactical and strategic radiation assessments
  - Perform reliability testing and analyses
  - Determine required post-procurement actions (if any) for each part
  - Maintain parts selection list
    - Part-number-specific assessments over time can be used to characterize evolving trends for some individual part designs to understand risks of obsolescence and the motivations for changes in part design and manufacture
- This is a strategic, Agency-level activity that provides structure for parts selection and acceptance for future missions, not a part acceptance laboratory for missions in development

National Aeronautics and Space Administration

Quality and Reliability in Modern Manufacturing



From Mark Porter’s (JPL) training on high volume manufacturing

SAFETY and MISSION ASSURANCE DIRECTORATE Code 300

Major Historical Trends
Reliability Engineering for Automotive Applications

- As EEE parts started being integrated into automotive systems, reliability became a critical focus. Automotive applications require components that can withstand extended temperature ranges, vibration, and exposure to various environmental conditions. The automotive industry developed its own set of reliability standards, such as AEC-Q100, to address the unique challenges and ensure consistent performance throughout a vehicle's lifetime.

Major Historical Trends
Quality Control and Standardization for Commercial Devices

- As EEE parts became widely used in commercial devices, such as smartphones, laptops, and home appliances, manufacturers prioritized quality control and standardization. International standards like ISO 9000 were adopted to ensure consistent manufacturing processes and product reliability. Additionally, companies started investing heavily in testing and quality assurance to meet consumer expectations for durable and reliable electronic products.

Major Historical Trends
Reliability Challenges in Mass Production

- The shift to automotive and commercial applications introduced new challenges related to mass production. Scaling up production while maintaining consistent quality and reliability became a significant concern. Manufacturers had to implement advanced manufacturing processes, automated testing, statistical analysis, and process controls to identify and address potential reliability issues early in the production lifecycle.

Major Historical Trends
Accelerated Life Testing and Predictive Modeling

- As the volume of EEE parts used in automotive and commercial applications increased, accelerated life testing and predictive modeling became vital tools to assess reliability. Manufacturers used accelerated testing to simulate the effects of long-term usage in a shorter time frame, enabling them to predict failure rates and design components with higher reliability.

Major Historical Trends
Emphasis on Long-Term Reliability for Consumer Electronics

- In the consumer electronics market, there has been an increasing focus on long-term reliability. Consumers expect electronic devices to last for several years without significant performance degradation or failures. As a result, leading EEE part manufacturers invest in better materials, design practices, and manufacturing techniques to ensure prolonged product lifespans.

Major Historical Trends Summary

- As EEE parts shifted from military and space to automotive and commercial applications, the industry adapted to meet the specific reliability requirements of each sector. Space applications demand a high level of reliability due to mission-critical operations and the inability to repair or replace failed hardware. Automotive and commercial applications demand a high level of reliability due to the severe consumer and safety consequences of failures and because of the high volumes of product in service. As such, advancements in manufacturing processes, quality control, data gathering, continuous improvement, and reliability engineering have made EEE parts more reliable than ever, even in high-volume commercial applications.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability

- Improvements in silicon wafer fabrication processes have played a crucial role in reducing failure rates and increasing the lifespan of electronic devices. These advancements have been driven by innovations in semiconductor manufacturing techniques and materials science.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability
Smaller Feature Sizes

- One of the most significant advancements in silicon wafer fabrication is the ability to create smaller feature sizes on the semiconductor chips. As the feature sizes shrink, the distance that signals need to travel within the chip decreases. This reduces signal delay, power consumption, and heat generation, leading to improved reliability and energy efficiency.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability Increased Integration

- Advancements in fabrication processes have allowed for higher levels of integration on a single chip. More components can be packed onto a single silicon die, reducing the need for complex interconnects between chips. Fewer interconnects mean fewer points of failure, enhancing overall reliability.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability

Enhanced Yield Rates

- Improved fabrication processes have resulted in higher yield rates during chip manufacturing. Yield refers to the percentage of functional chips obtained from a wafer. Higher yield rates mean more working chips from each wafer, reducing production costs and increasing the supply of reliable components.

Silicon Wafer Fabrication Process Improvements
Impacts on Reliability
Better Material Quality

- Process improvements have led to the production of silicon wafers with better material quality. The reduction of impurities and defects in the wafers ensures that the chips built on them are more reliable and less prone to premature failures.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability Precision and Uniformity

- Advanced fabrication techniques enable greater precision and uniformity in the manufacturing process. This results in chips with a consistent yield, consistent electrical properties, and consistent performance characteristics, improving the overall reliability of devices that use these components.

Silicon Wafer Fabrication Process Improvements
Impacts on Reliability
Reduced Defect Densities

- Innovations in manufacturing have significantly reduced defect densities on silicon wafers. Defects can negatively impact chip functionality and long-term reliability. Lower defect densities mean fewer chances of encountering defects that could lead to failures during the device's operational life.

Silicon Wafer Fabrication Process Improvements
Impacts on Reliability
Better Process Control

- Modern fabrication processes incorporate advanced process control methodologies, such as statistical process control (SPC) and in-line monitoring. These techniques ensure that the manufacturing process remains stable and predictable, minimizing the occurrence of random defects and variations that can compromise reliability.

Silicon Wafer Fabrication Process Improvements Impacts on Reliability

Advanced Packaging Techniques

- In addition to wafer fabrication, packaging techniques have also evolved to improve the reliability of electronic components. Advanced packaging technologies, such as wafer-level packaging and 3D packaging, offer better thermal dissipation, reduced interconnect lengths, and improved protection against environmental factors.

Summary

- The combination of supply chain issues and evolution along with the need to fly current technology drive the need for broad use of COTS
- The evolution of technology and manufacturing processes has created an insurmountable differential between design/manufacture of parts and most MIL-SPEC-based upscreening processes
- Successful history of usage combined with the findings of the NESC COTS Phase 2 study demonstrate a readiness to step forward with an expanded use of COTS
  - There are many considerations and COTS encompasses an infinite trade space, so thoughtful implementation with proper engineering judgment is necessary
  - No cookbook will apply, so thoughtful engineering is needed
- While radiation considerations demand thoughtful space implementation of current technologies, this has nothing to do with COTS.
- A long-term broad COTS usage approach in NASA will require a capability such as PEAL since there will never be guidance to cover all situations

How should automotive and hi-rel COTS be selected?

- Respect the datasheet
- Characterized by extensive in-production and/or post-production screening or electrical testing as evidenced by one or more of the following
  - Description in the datasheet as designed for reliable usage with credible description why
  - Manufacturer-provided documentation, such as
    - Production Part Approval Process (PPAP) document
    - Quality Manual
    - Website detailed technical information provided
  - Parts are qualified to the pertinent AEC Q-category specification (Q100, Q101, Q200)
  - Production is managed under IATF 16949 quality management system (QMS)

We start at the top (NPR 8705.4)

Electronics, Electrical, and Electromechanical (EEE) Parts	**Objectives:** **Select EEE parts at an appropriate level for functions tied directly to mission success commensurate with safety, performance and environmental requirements.** **Accepted Standard:** **NASA-STD-8739.10, Electrical, Electronic, and Electromechanical (EEE) Parts Assurance Standard or OSMA endorsed NEPP interim standards**			
	Class A: ~~Level 1 parts, equivalent Source Control Drawings (SCD) or requirements per Center Parts Management Plan.~~ Assurance Level 1 parts, equivalent Source Control Drawings (SCD), requirements per Center Parts Management Plan, or documented proven developer practices that have demonstrated results, consistent with the lowest level of risk tolerance, to achieve necessary performance.	Class B:: ~~Class A criteria or Level 2 parts, equivalent SCD or requirements per Center Parts Management Plan.~~ Assurance Level 2 parts, equivalent SCD , requirements per Center Parts Management Plan, or documented proven developer practices that have demonstrated results, consistent with a low level of risk tolerance, to achieve necessary performance.	Class C: ~~Class B criteria or Level 3 parts, equivalent SCD or requirements per Center Parts Management Plan.~~ Assurance Level 3 parts, equivalent SCD , requirements per Center Parts Management Plan, or documented proven developer practices that have demonstrated results, consistent with a moderate level of risk tolerance, to achieve necessary performance.	Class D: ~~Class C criteria or Level 4 parts, equivalent SCD or requirements per Center Parts Management Plan.~~ Assurance Level 4 parts.
	EEE Parts Notes: The intent is always to select the most appropriate assurance level parts to meet mission needs and requirements. There is nothing to disallow or discourage the use of parts aligned with higher classification levels with no additional testing when they are available. However, it is highly discouraged to require higher assurance level parts as standard or across the board. It is also discouraged to screen and/or qualify parts to achieve compliance above the current recommended assurance level.			

NASA-STD-8739.10 overview

- “Parent” agency parts standard
- Provides the end-to-end guidance for parts assurance in the agency at higher level than specific screening and qualification guidance
- Introduces a few new items since EEE-INST-002
  - Level 4: COTS with no additional screening
  - Automotive and vendor hi-rel as level 3 compliant
  - Various updated technical references
- Next version will introduce some updates
  - Level will be “assurance level”, no longer ambiguous interchangeable reference to grade, reliability level, quality level, which are all significantly different
  - Will point down to two paths for parts assurance
    - Traditional: 8739.11 (based on EEE-INST-002)
    - COTS: Three-option parts assurance

Dual Path update to 8739.10

Traditional: NASA-STD-8739.11	Three-option parts assurance (COTS-driven) (aka NASA-STD-8739.22)
Traditional, proven designs	New designs
Older generation technology	Newspace developers
Minimal size, weight, and power constraints	Current generation technology
Long lead times tolerable	High constraints on size, weight, and power
Emphasis on MIL-STD quality definitions	Emphasis on modern manufacturing, high volume, and statistical process controls
Use MIL-SPEC or screen in quality	Use established reliability or strategic part testing results

Approach Categorization (excerpt)

	Scores		
	Risk Factors	Resource Usage	Performance/ Tech infusion
1. COTS by exception, FMRR or lot-specific radiation testi Traditional space	3	10	10
2. COTS inclusive, FMRR or lot-specific radiation testing Traditional space w/expanded COTS	2	7	5
3. COTS inclusive, FMRR or strategic (non-lot-specific) radiation testing	4	4	2
4. COTS inclusive, FMRR, strategic (non-lot-specific) radiation testing with select radiation tolerant design	3	4-5	2
5. COTS inclusive, strategic (non-lot-specific) radiation testing with select rad-tolerant design	3	4-5	2
6. COTS inclusive, full rad-tolerant design, FMRR or strategic rad testing for front-line defenders and NVRAM Newspace conservative	1-2	2-4.	2-5
7. COTS inclusive, no radiation testing or FMRR, select rad-tolerant desig NASA ARC Aerocube	4-6	1-2	1-2
8. COTS inclusive, no consideration of radiation Cheap and fast	10	1	1
9. MIL-SPEC exclusive, no radiation testing, FMRR, or rad-tolerant design For reference only	10	6	10

Low risk modern approach

Medium-high risk Rapid technology infusion

Traditional+COTS

Fast, cheap, high risk

Radiation Venn diagram