Echoes of the Past,
Glimpses of the Future
Ongoing Trends in Assurance of
EEE Parts for Spaceflight

Components for Military & Space Electronics
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Aero</td>
<td>Aerospace</td>
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<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
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<tr>
<td>BME</td>
<td>Base Metal Electrode</td>
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<tr>
<td>BOK</td>
<td>Body of Knowledge</td>
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<tr>
<td>CBRAM</td>
<td>Conductive Bridging Random Access Memory</td>
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<tr>
<td>CCMC</td>
<td>Community Coordinated Modeling Center</td>
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<tr>
<td>CDH</td>
<td>Central DuPage Hospital Proton Facility, Chicago Illinois</td>
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<td>CMOS</td>
<td>Complementary Metal Oxide Semiconductor</td>
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<tr>
<td>CNT</td>
<td>Carbon Nanotube</td>
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<tr>
<td>COP</td>
<td>Community of Practice</td>
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<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
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<tr>
<td>CRÈME</td>
<td>Cosmic Ray Effects on Micro Electronics</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DLA/DSCC</td>
<td>Defense Logistics Agency Land and Maritime</td>
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<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
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<tr>
<td>ELDRS</td>
<td>Enhanced Low Dose Rate Sensitivity</td>
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<td>EP</td>
<td>Enhanced Plastic</td>
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<td>EPARTS</td>
<td>NASA Electronic Parts Database</td>
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<td>ESA</td>
<td>European Space Agency</td>
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<td>FPGA</td>
<td>Field Programmable Gate Array</td>
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<tr>
<td>FY</td>
<td>Fiscal Year</td>
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<tr>
<td>GaN</td>
<td>Gallium Nitride</td>
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<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>HUPTI</td>
<td>Hampton University Proton Therapy Institute</td>
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<tr>
<td>IBM</td>
<td>International Business Machines</td>
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<td>IPC</td>
<td>International Post Corporation</td>
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<tr>
<td>IUCF</td>
<td>Indiana University Cyclotron Facility</td>
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<td>JEDEC</td>
<td>Joint Electron Device Engineering Council</td>
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<td>JPL</td>
<td>Jet Propulsion Laboratories</td>
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<td>LaRC</td>
<td>Langley Research Center</td>
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<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
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<tr>
<td>LLUMC</td>
<td>James M. Slater Proton Treatment and Research Center at Loma Linda University Medical Center</td>
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<tr>
<td>MGH</td>
<td>Massachusetts General Hospital</td>
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<tr>
<td>MIL</td>
<td>Military</td>
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<tr>
<td>MLCC</td>
<td>Multi-Layer Ceramic Capacitor</td>
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<td>MOSFETS</td>
<td>Metal Oxide Semiconductor Field Effect Transistors</td>
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<tr>
<td>MRAM</td>
<td>Magnetoresistive Random Access Memory</td>
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<tr>
<td>MRQW</td>
<td>Microelectronics Reliability and Qualification Working Meeting</td>
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<td>MSFC</td>
<td>Marshall Space Flight Center</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NAVY</td>
<td>Naval Service Warfare Center, Crane, Indiana</td>
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<td>NEPAG</td>
<td>NASA Electronic Parts Assurance Group</td>
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<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
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<td>NPSL</td>
<td>NASA Parts Selection List</td>
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<tr>
<td>PBGA</td>
<td>Plastic Ball Grid Array</td>
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<tr>
<td>POC</td>
<td>Point of Contact</td>
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<tr>
<td>POL</td>
<td>Point of Load</td>
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<tr>
<td>ProCure</td>
<td>ProCure Center, Warrenville, Illinois</td>
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<tr>
<td>RERAM</td>
<td>Resistive Random Access Memory</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<td>RHA</td>
<td>Radiation Hardness Assurance</td>
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<tr>
<td>SAS</td>
<td>Supplier Assessment System</td>
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<tr>
<td>SEE</td>
<td>Single Event Effect</td>
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<tr>
<td>SEU</td>
<td>Single Event Upset</td>
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<tr>
<td>SIC</td>
<td>Silicon Carbide</td>
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<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
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<tr>
<td>SOC</td>
<td>Systems on a Chip</td>
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<td>SOTA</td>
<td>State of the Art</td>
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<tr>
<td>SPOON</td>
<td>Space Parts on Orbit Now</td>
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<tr>
<td>SSDs</td>
<td>Solid State Disks</td>
</tr>
<tr>
<td>TI</td>
<td>Texas Instruments</td>
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<tr>
<td>TMR</td>
<td>Triple Modular Redundancy</td>
</tr>
<tr>
<td>TRIUMF</td>
<td>Tri-University Meson Facility</td>
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<tr>
<td>VCS</td>
<td>Voluntary Consensus Standard</td>
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<tr>
<td>VNAND</td>
<td>Vertical NAND</td>
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Overview from a NASA Perspective

• Early Days (Before 1987)
• Mid-life Concerns (1986 to 2003)
• Standardization (1991 to 1995 then 2001 to Present)
• Echoes of the Past
• Today’s Forces for Change
• Glimpses of the Future
  – Specialized Test Facilities to screen against specific problems or normal variation
  – Board and Box Level Screening Practices
  – Robust Systems
    • Redundancy
    • Modeling
    • Self-healing Circuits

Presented by Michael J. Sampson at the 21st Annual CMSE Components for Military & Space Electronics Training and Exhibition 2017, Los Angeles, CA, April 11-13, 2017
Explorer 1 was the first U.S. satellite and the first satellite to carry science instruments. The satellite was launched on Jan. 31, 1958, from Cape Canaveral, Fla. Explorer 1 followed a looping flight path that orbited Earth once every 114 minutes. The satellite went as high as 2,565 kilometers (1,594 miles) and as low as 362 kilometers (225 miles) above Earth.

Credits: NASA

Exciting Times
Then 1986 - CHALLENGER!
1. General Availability Of Class S And Class B Military Parts Is Not Adequate To Complete Most Programs. Use Of Less Desired Vendor Screened Parts Or SCDs Almost Mandatory For Most Programs.

2. Many Vendor Screened Devices (i.e. Vendor 883) Show Unacceptable Dropout Rates When Rescreened To Specifications.


4. Due To Fragmented Procurements And Low Quantity Buys, Manufacturers Show Little Interest In Providing EEE Parts To NASA Quality Levels.

5. Contamination Control At Some Manufacturers' Facilities Is Poor, Resulting In Particle Problems Occurring With Increased Frequency.

6. There Is No Standard NASA Policy On What Reliability Level Of Parts Should Be Used For Various Criticality Systems

7. Low Priority-of Funds For Conference Travel And Specialized Training Preclude Keeping Pace With Changes And Advancements In Parts Industry.

8. Lack" Of Emphasis On Replacement Of Retired Parts Specialists Has Centers Extremely Thin In Expertise In Many Areas.


10. Vast Number Of MSFC Programs Has EEE Parts Specialists Spread Extremely Thin. "Hot Items“ Get Attention.

Black text: echoes with the present
Blue text: echoes of the past
From SPWG April 2002

NASA EEE Parts Assurance Group

Use of COTS is Unavoidable, So …?

• Functionality, availability and size are the unavoidable drivers towards COTS

• How can the risk of COTS be controlled economically?
  - Do we need to do such extensive screening?
  - Which tests are the most value-added/essential?
  - How dependable/relevant to our needs is manufacturer data?
  - Must we test/characterize every lot from every manufacturer?

• Traceability
  - How much lot-to-lot variation is there?
  - How much intra-lot variation is there?
  - Do we need to establish our own traceability system?

• Radiation, is there any way to avoid costly lot specific testing and evaluation?

2003
Lessons Learned from Columbia and Challenger Made NASA More Risk Conscious and Careful

Overview (From a 2003 Presentation)

• Today’s Major Challenge for EEE Parts Assurance - Commercial-Off-The-Shelf (COTS)
• Standardization - Uses and Benefits
• NASA’s History with EEE Parts Standardization
• “New” Options for EEE Part Standardization
  – AQEC
  – By Manufacturer
  – By Higher Level Assembly

• Conclusions

From JAXA Microelectronics Workshop (MEWS) 2003
Today’s Drivers for Change (2003)

1) Cost-Constrained Missions
2) Tight Schedules
3) Aggressive Science and Technology Goals

• COTS Frequently Seen as a Solution to All Three
• COTS Can be the ONLY Solution Where Essential Technology Capability is the Driver

But, the Hidden Costs and Complications of a COTS-Based Solution Can Surprise the Unwary

(MEWS 2003)
Conclusions MEWS 2003

- Standardization Continues As a Key Strategy in NASA’s Approach to EEE Parts Assurance
- Increasing Use of COTS Parts Makes Traditional, Parts-focused Standardization Much More Difficult
- Three Strategies for Standardization Approaches That Could Accommodate COTS Have Been Suggested
- COTS Compatible Standardization Is Likely to Require a NASA Culture Change to Achieve Success Through Any of the Three Suggested Options
- It Seems Unlikely That Any of the Three Options Will Achieve the Assurance of Reliability Enjoyed With MIL Parts

(MEWS 2003)
Today - A Tipping Point?

- Commercial launch vehicles for International Space Station (ISS) re-supply
- Commercial launch vehicles for human-rated missions to the ISS and ... beyond
- Cubesats and Smallsats – what rules for EEE parts selection, qualification and application make sense?
- Cost is the dominant driver
- Anticipate greater use of commercial, non-hermetic parts
- Well-established processes to achieve assurance of system reliability require major updating
- The Space Launch System (SLS)
Space Launch System (SLS) and Orion

https://www.nasa.gov/exploration/systems/sls/multimedia/images.html
Commercial Space

• Commercial Space is expanding rapidly with more and more getting involved all the time

• NASA’s future will include commercial systems to:
  • Launch NASA experiments and astronauts
  • Provide crew-rated systems to service the International Space Station and explore our solar system. Moon, Mars?
  • Provide innovative solutions to improve performance and reduce costs
NASA’s Changing Landscape

• With NASA’s New Era Of Commercial Providers And Small Space Missions (I.E. Cubesats, Etc…) Other Approaches Are Being Considered To Find More Cost-effective Approaches To Meeting Mission Requirements.

• A Few Of The Considerations For This Emerging Space Include, But Are Not Limited To:
  – Increased Reliance On Fault Tolerance, Architectural Approaches, And Even Constellation Spacecraft Sparing,
  – Leverage On The Improved Defect Reliability Of High Yield COTS, Automotive, Industrial, And Medical Grades Of Electronics,
  – Use Of Higher-assembly Level Testing,
  – Reliance On New Tools For Model-based Mission Assurance (MBMA), Circuit Simulation And Verification, As Well As Physics Of Failure (PoF), And,
  – Improved Communication On Considerations, Lessons Learned And Guidelines.
NEPP’s Focus Areas for 2017

• Automotive Parts (COTS/PEMs) Evaluations Continue
  – Could they be the Future Standard Part?
• Radiation Assessments of Complex Parts
  – Field Programmable Gate Arrays, Processors, etc.
• 2.5D and 3D Packaging –
  – Development of a Body of Knowledge (BoK) Report
  – Government/Industry Discussions about Assurance
    Testing/Screening Methods and Qualification
• Standardization Support, Focused on MIL Parts
  – However, NASA Perspective is being Expanded
• Investigating Innovative Approaches to Qualification and
  Screening for non-MIL Parts, Board-level, Box-level etc.
• Reliability Modeling
AS USUAL, it is all about SWaP = SIZE WEIGHT AND POWER but also COST and RELIABILITY
Lessons Learned on COTS for Space

• In an ideal world (and given limitations of full state space coverage), you’d want to:
  – Test at the device level to provide input for fault tolerant design. And,
  – Test at the system level to validate design approaches
    • Possibly uncover additional fault modes (statistics of test coverage).

• Lots of folks are trying to do the 2nd and mistakenly calling it qualification when it’s really “system validation” (with inherent risk)…
Lessons Learned on COTS for Space (2)

• Understanding the criticality of the application is the key to performing adequate testing and validation for risk management
  – However, even “good” ground testing and designs can be surprised due to random/Markov nature of SEEs and challenges related to “completeness” nature of ground beam testing (coverage of targets and operating states)

• Improving data sharing between not only NASA projects, but the greater aerospace industry leads to improved failure mode knowledge
  – Required as input for designers and for efficient determination of additional data needed
  – MSL learned from Juno in a critical functionality area
    • What might have happened without it?
Glimpses of the Future

• Small Sats, Microsats and Cubesats (≤ NASA Class D)
  – Rapidly evolving roles: GEO, Swarms, Formations
  – “Deep Space”: not yet but when ..?
• Low cost, fast turnaround, miniaturized
• Commercial Off The Shelf (COTS) parts use is steadily increasing
• Testing (screening and qualification) is difficult
Glimpses of the Future – Near Term

• Exploitation of the third dimension to permit continued increase in circuit density (2.5/3D)
  – Difficult testing challenges ahead
• Adoption of auto grade COTS as standard flight parts, within assurance constraints
  – Cost for upscreening, modeling or other approaches
• Greater reliance on design and architecture to mitigate risk from unscreened/under screened parts
  – Redundancy, particularly of critical systems
  – Self-healing parts, components and systems
• Increasing use of specialized test houses that have the capability in people and equipment to handle, test and evaluate COTS, from ultra small passives to extremely complex and dense PEMs
• Alternatives to testing/screening at the part level
  – Board and box-level present perceptivity and stress level challenges
SOT 23 Package and a Penny

SOT23-3 to SOT23-8

Hard to See – Hard to Handle!

Picture by Jay Brusse, AS&D, Inc. for NASA GSFC
Glimpses of the Future – Further Term

• Die-size, spacecraft on a chip (StarChip) for laser-powered, inter-star, scientific exploration
  – Project Breakthrough Starshot
  – Destination Alpha Centauri (flight time ~ 20 years)
  – Driving force: Yuri Milner
  – Executive Director: Pete Worden ex-NASA
  – Advisers: Freeman Dyson, Stephen Hawking

• Parts and components utilizing Quantum mechanics enable faster computing, more sensitive and accurate sensors, clocks unbreakable encryption
  – Once a dwindling number of challenges are overcome, part and function options will rapidly increase
The Future of EEE Parts Management/Engineering?

- Modules and subassemblies
- Quantum mechanics
- Satellites-on-a-chip
- Spintronics
- Etc., etc
- Things we have never heard of
The FUTURE

Prediction is Very Difficult, Especially if it is About the Future

Niels Bohr