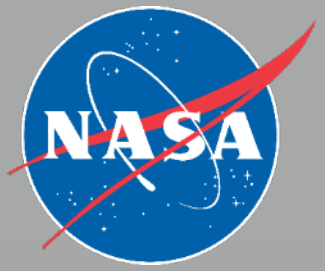
National Aeronautics and Space Administration



Electrical, Electronic and Electromechanical (EEE) Parts for Spaceflight Applications

A NASA Electronic Parts and Packaging Historical Perspective

Michael J. Sampson
NEPAG Manager
michael.j.sampson@nasa.gov

This work was sponsored by NASA Office of Safety & Mission Assurance

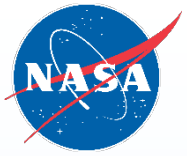
To be presented by Michael Sampson at NEPP Electronics Technology Workshop, Goddard Space Flight Center on June 17, 2019

Acronyms (1 / 2)

Abbreviation	Definition		Abbreviation	Definition
AF	Air Force		IC	Integrated Circuit
BGA	Ball Grid Array		IEEE	Institute of Electrical and Electronics Engineers
BN	Bayesian Network		JAN	Joint Army-Navy
BoK	Body of Knowledge		JPL	Jet Propulsion Laboratory
CMOS	Complementary Metal Oxide Semiconductor		JSC	Johnson Space Center
COTS	Commercial Off the Shelf		LaRC	Langley Research Center
CPU	Central Processing Unit		LGA	Land Grid Array
DDR	Double Data Rate		MAPLD	Military and Aerospace Programmable Logic Devices (Workshop)
DLA	Defense Logistics Agency		MBMA	Model-Based Mission Assurance
DMEA	Defense Microelectronics Activity		MIL	Military
DoD	Department of Defense		MRAM	Magnetic Random Access Memory
DoE	Department of Energy		MSFC	Marshall Space Flight Center
EEE	Electrical, Electronic, and Electromechanical		NASA	National Aeronautics and Space Administration
ELDRS	Enhanced Low Dose Rate Sensitivity		NEPAG	NASA Electronic Parts Assurance Group
ESA	Europeans Space Agency		NEPP	NASA Electronic Parts and Packaging (Program)
ESTEC	European Space Research and Technology Centre		NESC	NASA Engineering and Safety Center
ETW	Electronics Technology Workshop		NODIS	NASA Online Directives Information System
FBC	Faster, Better, Cheaper		NPR	NASA Procedural Requirement
FPGA	Field Programmable Gate Array		NPSL	NASA Parts Selection List
GaN	Gallium Nitride		NRO	National Reconnaissance Office
GIDEP	Government Industry Data Exchange Program		NSREC	Nuclear and Space Radiation Effects Conference
GPU	Graphics Processing Unit		OCE	Office of the Chief Engineer
GRC	Glenn Research Center		OGA	Other Government Agency
GSFC	Goddard Space Flight Center		OSMA	Office of Safety and Mission Assurance
GSN	Goal Structuring Notation		PA	Parts Analysis
GWG	Government Working Group		PIC	Photonic Integrated Circuit
HDBK	Handbook		PIND	Particle Impact Noise Detection
HQ	Headquarters		POC	Point of Contact

Acronyms (2 / 2)

Abbreviation	Definition		Abbreviation	Definition
PoF	Physics of Failure		SMC	Space and Missile Systems Center
PPL	Preferred Parts List		SOA	Safe Operating Area
QML	Qualified Manufacturers List		SoC	System on a Chip
QPL	Qualified Products List		SRAM	Static Random Access Memory
RF	Radio Frequency		SSAI	Science Systems and Applications, Inc.
RH	Radiation Hardened		STD	Standard
RHA	Radiation Hardness Assurance		STMD	Space Technology Mission Directorate
RoHS	Restrictions on the use Of certain Hazardous Substances		STT	Spin Transfer Torque
SAPP	Space Asset Protection Program		SysML	System Modeling Language
SCD	Source Control Drawing		TID	Total Ionizing Dose
SDRAM	Synchronous Dynamic Random Access Memory		TSV	Thru-Silicon Via
SEE	Single-Event Effects		USA	United States of America
SEM	Scanning Electron Microscope		USAF	United States Air Force
SiC	Silicon Carbide		USSR	Union of Soviet Socialist Republics
SMA	Safety and Mission Assurance			



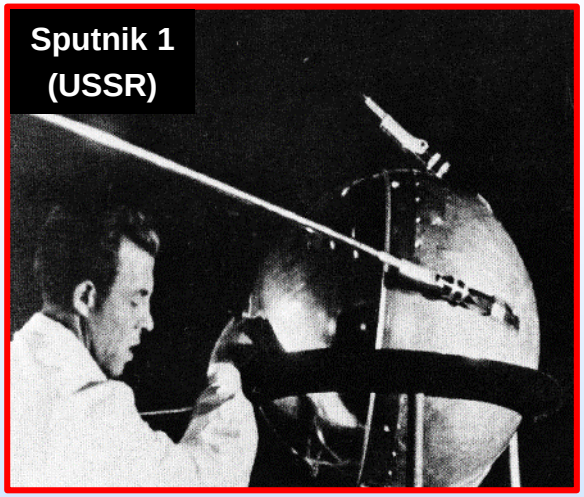
History Doesn't Repeat Itself But it Rhymes!

The 1950s
Beginning of the Space Age

- **1957 October**:
  USSR launch and deployment of ***Sputnik 1***
  Unofficially marks beginning of the space age.
    - Beginning of intense spaceflight rivalry between the USA and USSR

- **1958 January:**
  USA launch and deployment of ***Explorer 1***
  After a series of failures

- Design and manufacturing defects in EEE parts were suspects in premature system failures
- EEE parts were typically commercial and standard military quality, aggressively tested (upscreened)



https://www.nasa.gov/multimedia/imagegallery/image_feature_924.html

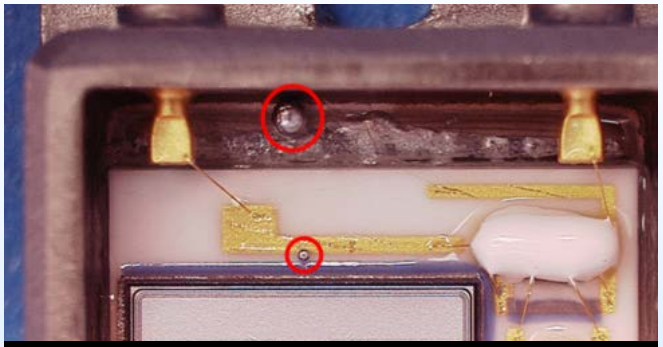
https://www.nasa.gov/mission_pages/explorer/explorer-overview.html

The 1960s

The First Specifications & Products Specifically for Spaceflight Use

- Application specific features:

Electricals and environmentals from -55^{0}C to 125^{0}C or wider	
Hermetic packaging	Resistance to flammability and outgassing
Strict visual inspection	High vibration and shock levels
Conservative derating	Radiation tolerance



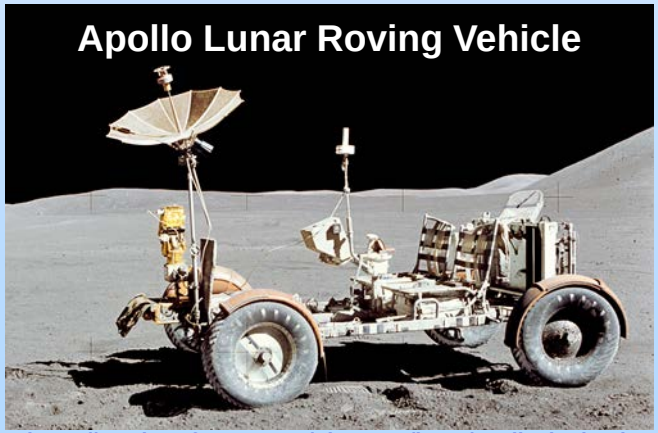
Solder Balls
NASA GSFC PA Lab Report J12121

- **1962:** NASA MSFC developed the 85MO microcircuit requirements
- **1962:** Preferred Parts Lists PPL-100 (MSFC), PPL-1 (GSFC)
- **1968:** NASA developed MIL-STD-976
  Certification Requirements for JAN (Joint Army-Navy) Microcircuits
- **1968:** MIL-STD-883 Test Method Standard for Microcircuits
- **1969:** MIL-M-38510 (microcircuits)
  - *Established Class Levels A and B.*
  - *NASA MSFC certified the first compliant lines*
- **1969:** MSFC published first visual inspection std for transistors and diodes
- **1969:** MIL-STD-883 test method 2018 Particle Impact Noise Detection (PIND)
  - *Solder balls were a serious threat in the early days*

The 1970s

EEE Parts Standardization for Space Begins

- **1970:** MSFC promoted development of the tantalum cased wet slug capacitor, CLR79, to replace the silver-cased CLR65 which tended to short circuit
- **1970:** MIL-STD-883 TM 2020 for scanning electron microscope (SEM) inspection
- **1970:** JPL Preferred Parts List published
- **1972:** NASA hybrid line certification program was established
- **1972:** Class S* was added to MIL-S-19500
- **1973:** USAF-SD published MIL-M-0038510 for Class S* microcircuits
- **1975:** Class A in MIL-M-38510 was changed to Class S* so USAF-SD could cancel M0038510
- **1976:** MIL-STD-975, the NASA Standard Parts List was published
- **1978:** Novel test methods were developed to reduce the risk of low voltage failures in plastic film capacitors
- **1978:** MIL-HDBK-978, NASA Parts Application Handbook was published, in five volumes

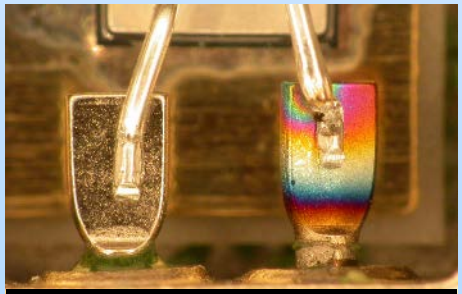


https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_lrv.html

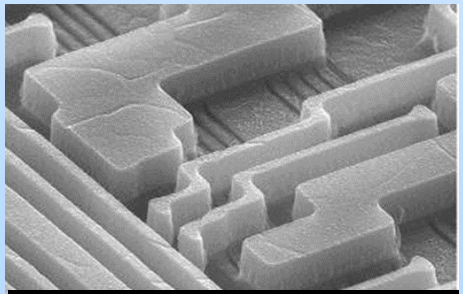
***Class S indicates space grade**

The 1980s
Decade of Transformative Space-Focused Documentation Influenced by NASA

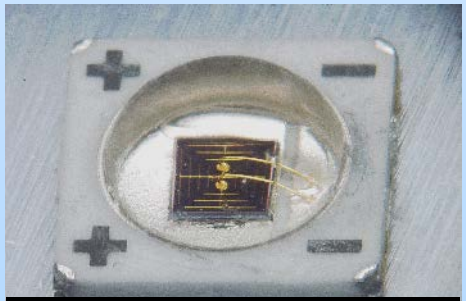
- MIL-STD-1546 — Parts, Materials, And Processes Control Program For Space And Launch Vehicles – USAF-SD
- MIL-STD-1547 — Military Standard For Space And Launch Vehicles – USAF-SD
- MIL-STD-1580 — DoD Test Method Standard: Destructive Physical Analysis (DPA) for EEE Parts – USAF-SD
- MIL-STD-1772 — Certification Requirements For Hybrid Microcircuit Facilities And Lines
- Class S* Capacitors
  - MIL-C-87217 (metallized film-CHS)
  - MIL-C-87164 (mica- CMS)
  - MIL-C-123 (ceramic-CKS)



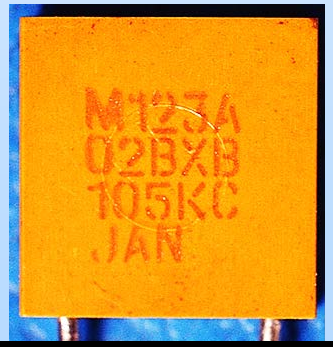
Power Rectifier
NASA GSFC PA Lab Q60698



Microcircuit
NASA GSFC PA Lab J16093



Optocoupler
NASA GSFC PA Lab J16233

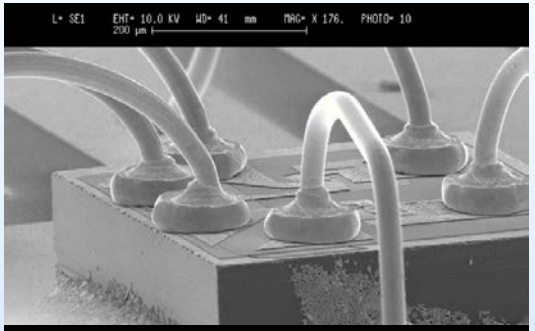


Ceramic Capacitor
NASA GSFC PA Lab J14094

***Class S indicates space grade**

NASA EEE Parts Concerns (1987)
From a NASA Status Report

- Inadequate availability of Class S* and B military parts
  - Vendor-screened parts or SCDs almost mandatory for most programs
- High dropout rates observed during “rescreening” of vendor-screened devices (i.e., vendor “883 compliant”)
- “Off-Shore” Manufacturing Risks
  - Quality control of processes and lines unknown
  - Changes in critical quality factors and production methods can occur without knowledge of the user



Microcircuit
NASA GSFC PA Lab Q50006

- Manufacturers show little interest in providing EEE parts to NASA quality levels due to fragmented procurements and low quantity buys
- Increased frequency of “particle” issues due to poor contamination controls at some suppliers
- Low priority of funds for conference travel and specialized training preclude keeping pace with changes and advancements in parts industry
- NASA Centers extremely thin in expertise in many areas

***Class S indicates space grade**

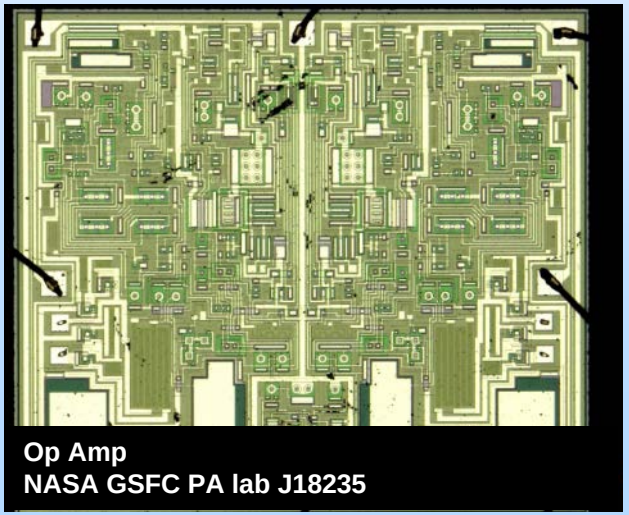
The Early 1990s

Transformation from QPL to QML for Military Hybrids and Microcircuits

QML-38534-1 (1989) & QML-38535-1 (1990)

- A revolutionary change intended to
  - Reduce manufacturing costs
  - Encourage qualification of a wider span of microcircuit technologies and types
  - Speed that qualification
  - Accommodate offshore supply chain elements
  - Encourage the standardization of new technologies
  - Generally facilitate participation in a vibrant QML program for Class K* hybrids and Class V* microcircuits

Hybrid Microcircuit
NASA GSFC PA lab J12147

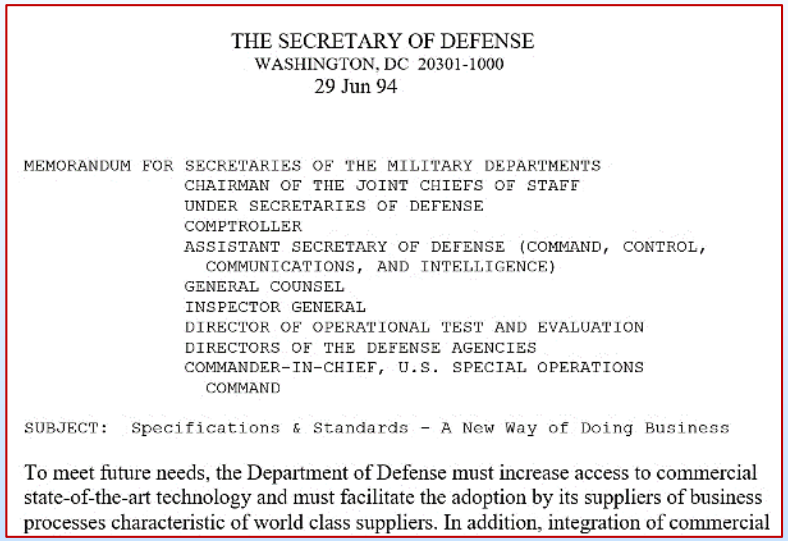


Op Amp
NASA GSFC PA lab J18235

***Class K and V indicate space grade**

But Then There Was …

- **1992:** Faster, Better, Cheaper (FBC) for NASA
  - Initiative of Daniel Goldin/NASA Administrator
  - Inside Agency Comment -- “Pick 2”
- **1994:** Acquisition Reform for the Military
  - The “Perry Memo” – William Perry/Secretary of Defense
    - Also driven by Faster, Better, Cheaper although not stated as such
    - Directed the greater use of commercial and performance specs
    - Military Specifications canceled or converted to Performance Specifications “unless no practical alternative exists to meet the user's needs”
    - “If it is not practicable to use a performance specification, a non-government standard shall be used.”
    - Waivers required for the use of Military Specifications and Standards
    - Attempted purge of all “how to” content, content often based on more than 30 years of painful experience
    - Memo encouraged formation of “partnerships with industry associations to develop non-government standards for replacement of military standards where practicable.”



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

FBC and Acquisition Reform Shook the Industry

Impacts on NASA's EEE Parts Management Approach

- EEE parts management responsibility delegated to each NASA Center. The following Center-Specific Parts Selection Documents persist
  - GSFC 311-INST-001 (now EEE-INST-002) also used by LaRC and GRC
  - MSFC MSFC-STD-3012
  - JSC SSP 30312, Space Station document
  - JPL JPL-D-20348

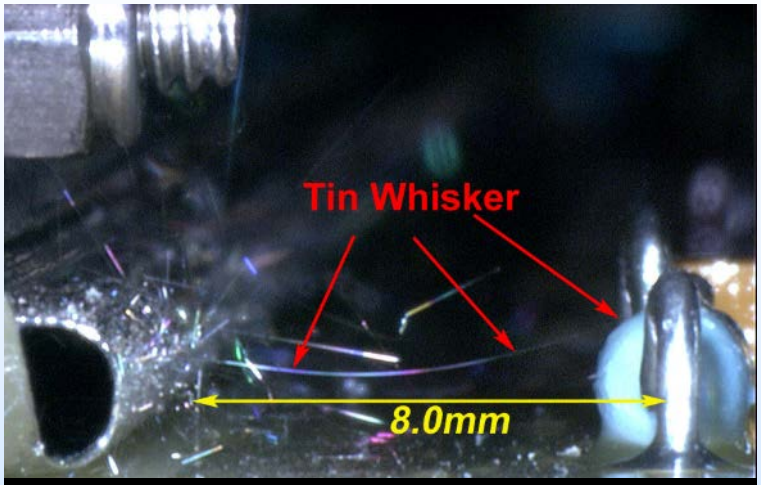
- **1995:** Cancelation of MIL-HDBK-978 NASA Parts Application Handbook

- **1997:** Predecessor of NEPP released the on-line NASA Parts Selection List (NPSL) to capture important content from MIL-STD-975 before it was lost
  - The NPSL captures "standard" EEE parts lessons learned
  - Not intended to be contractually imposed

- **1998:** Cancelation of MIL-STD-975 NASA Standard EEE Parts List

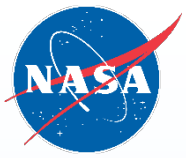
2000s
Global Supply Chain Issues

- RoHS –Restrictions On the use of certain Hazardous Substances (European Union) Forces Others to Develop
  - Pb-free Electronics Risk Control Plans
  - Tin Whisker Mitigation
  - Prohibited Materials Analyses
- Counterfeit Parts Control Plans
- Non-Hermetic Microcircuit Packaging
- COTS, Automotive Grade Parts for Space?
- ELDRS and other Radiation Effects Concerns
- Obsolescence Management
- Challenges Looking Ahead
  - Commercial vs. Government Space
  - Copper Bond Wires
  - Free flow of communication with International Partners
  - Complexity of semiconductor technologies at the nanometer scale



Tin Whiskers on Tin-Plated Printed Circuit Card Guides Space Shuttle Endeavour (~2006)

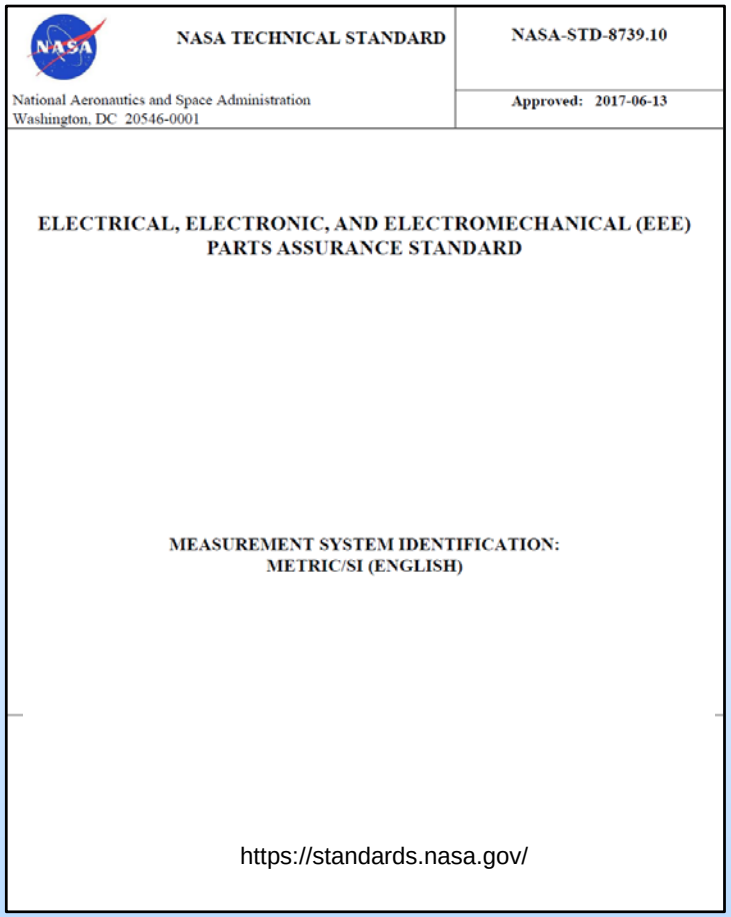
Evolution of NASA Parts Management



YEAR	Activity	Lead Center	HQ Oversight	Comments
1950s and 1960s	Assurance and Reliability requirements evolve at the individual Center Level	N/A	?	
1975	NASA Standard Parts Program	MSFC	Engineering	Responsible for MIL-STD-975, NASA Standard EEE Parts List
1984	Program moved to GSFC	GSFC	Assurance	Focus realigned to assurance
1987	MSFC Annual Report	GSFC	Assurance	List of Concerns still valid today
1992	Packaging effort begins	GSFC	Assurance	Recognition of the growing challenges
1995	NASA Parts Project Office transition to the NASA Parts and Packaging Program	GSFC	Assurance	Impact of Acquisition Reform and Faster Better Cheaper
1996	Program now called NASA EEE Parts Advanced Interconnect and Radiation Program (EEE/AI/RAD	GSFC and JPL	Engineering	Focus on new and emerging technologies
1998	NASA Electronic Parts and Packaging Program (NEPP)	GSFC	Engineering	Post Acquisition Reform realignment. Included radiation hardness assurance (RHA)
2000	NASA EEE Parts Assurance Group (NEPAG) formed	GSFC	Assurance	Focus supply chain, standardization and EEE part failure investigation
2003	NEPAG becomes part of the NASA Electronic Parts and Packaging Program (NEPP)	GSFC	Assurance	Combined NEPP focus on advanced technologies and RHA with NEPAG's focus on current technologies and standardization
2017	NEPP continues as an OSMA Delegated Program	GSFC	Assurance	NEPP Focuses on assurance of EEE parts from TRL 4 to 9
2018-19	**Consolidation as the NASA OSMA Delegated Program**	**GSFC**	**Assurance**	**EEE Parts Consolidation emphasizes NASA standardization under NPR8739.10**

NASA EEE Parts – Evolving Structure in 2019

- NASA EEE parts consolidation:
  - Primary agency test and analysis activities will be at the Goddard Space Flight Center (lead Center) and the Jet Propulsion Laboratory
  - Agency EEE Parts Manager leads
- NEPP Program remains the same:
  - Owns the EEE parts assurance processes and related technical efforts
  - NEPP Program management evolution
- New NASA-wide document activities
  - NASA-STD-8739.10 released
  - EEE-INST-002 update in process
  - Update of NPR 8705.4 Risk Classification for NASA Payloads


NASA TECHNICAL STANDARD

NASA-STD-8739.10

National Aeronautics and Space Administration
Washington, DC 20546-0001

Approved: 2017-06-13

ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL (EEE) PARTS ASSURANCE STANDARD

MEASUREMENT SYSTEM IDENTIFICATION: METRIC/SI (ENGLISH)

https://standards.nasa.gov/

- A new organization, the Government Working Group (GWG) was stood up in 2017 to focus on standardization of space level requirements, both government and Industry

Acknowledgement

Much of the content of this presentation prior to 1990 was borrowed from Mr. Leon Hamiter's paper,

THE HISTORY OF SPACE QUALITY EEE PARTS IN THE UNITED STATES,

Presented at the ESA Electronic Components Conference, ESTEC, Noordwijk, The Netherlands, 12 - 16 November 1990, ESA SP-313 (March 1991)

Leon was a major figure in the development of assurance test and process requirements for space grade parts and was responsible for the creation of MIL-STD-975. Leon served 23 years at NASA MSFC

THANK YOU,

LEON (and JAY)