EEE Parts Selection for Space Missions

Commercial Lunar Payload Services (CLPS) Technical Workshop

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Acronyms

ARC	Ames Research Center	KSC	Kennedy Space Center
COTS	Commercial-Off-The-Shelf	LaRC	Langley Research Center
CLPS	Commercial Lunar Payload Services	MPCV	(Orion) Multi-Purpose Crew Vehicle
DoD	Department of Defense	MEAL	Mission, Environment, Application and Lifetime
DPPM	Defective Parts Per Million	MIL-SPEC	Military Specification
DRD	Data Requirement Deliverable	MSFC	Marshall Space Flight Center
EDCPAP	Engineering Directorate Certified Parts Approval Process	NASA	National Aeronautics and Space Administration
EEE	Electrical, Electronic, Electromechanical	NEPP	NASA Electronic Parts & Packaging (Program)
EEEE	Electrical, Electronic, Electromechanical, Electro-Optical	NPR	NASA Procedural Requirements
FAA	Federal Aviation Administration	NESC	NASA Engineering & Safety Center
FIT	Failure-In-Time	PCP	Parts Control Plan
GFE	Government-Furnished Equipment	PEM	Plastic Encapsulated Microcircuit
GRC	Glenn Research Center	PPAP	Product Performance Approval Process
GSFC	Goddard Space Flight Center	QML	Qualified Manufacturers List
IEEE	Institute of Electrical and Electronics Engineers	SAE	Society of Automotive Engineers
ILPM	Industry Leading Parts Manufacturer	SMA	Safety and Mission Assurance
ISS	International Space Station	SMD	Science Mission Directorate
JPL	Jet Propulsion Laboratory	SPC	Statistical Process Control
JSC	Johnson Space Center	SSP	Space Station Program
KSC	Kennedy Space Center	STD	Standard

NASA Policy and Guidance for EEE Parts Requirements

Document	Title	Purpose
NPR 8705.4A	Risk Classification for NASA Payloads	- Provides assurance principles and practices associated with different risk classes
NASA-STD-8739.10	Electrical, Electronic, and Electromechanical (EEE) Parts Assurance Standard	- Requirements for Space Flight Hardware - Provide EEE Parts Grade Level definitions of Grades 1-4
EEE-INST-002 – (Outgoing)	Instructions for EEE Parts Selection, Screening, Qualification, and Derating	- Provides criteria for selection, screening, qualification on NASA GSFC flight projects but widely used or referenced across the space industry - Incorporates Parts Levels 1, 2 and 3
NASA-STD-8739.11* (Incoming)	Electrical, Electronic, Electromechanical, and Electro-Optical (EEEE) Parts Selection, Testing, and Derating Standard	- Will replace EEE-INST-002 - Adds a Parts Assurance Level 4 commercial option
NESC COTS Assessment Phase 1	Phase I of the NESC Recommendations on Use of Commercial-Off-The-Shelf (COTS) EEE Parts for NASA Missions	- Captures practices on the use of COTS across multiple centers - Provide recommendations that could lead to future guidance
NESC COTS Assessment Phase 2	Phase II of the NESC Recommendations on Use of Commercial-Off-The-Shelf (COTS) EEE Parts for NASA Missions	- Provides recommendation to select Established COTS parts from ILPMs - Proposes elimination or reduction of part-level verification testing in cases where evidence of sufficient quality and reliability exists for COTS parts and part datasheet meets the Mission Environment, Application, and Lifetime (MEAL)

* Working draft available upon request

Traditional EEE Parts Selection for NASA Missions

- NASA-STD-8739.10 and GSFC EEE-INST-002 recommend MIL-SPEC parts as the first choice
  1) different levels of MIL-SPEC parts as baseline parts
  2) detailed MIL-SPEC/NASA screening and qualification requirements on COTS or non-MIL-SPEC parts
- The U.S. Department of Defense (DoD) Qualified Manufacturers List (QML) process, where the government has control and insight of MIL-SPEC parts, results in parts with high (but not perfect) quality and full access to part-level process controls and verification data

Traditional EEE Parts Selection for NASA Missions

Examples of EEE-INST-002 guidance for parts selection and corresponding part-level verification testing:

Table 1 MONOLITHIC INTEGRATED CIRCUIT REQUIREMENTS (Page 1 of 2) 1/

Part Designation	Use As Is	Screen To Requirements in Table 2 2/	Qualify To Requirements in Table 3 2/
Level 1:			
1) Class V or Class S	X		
2) Class Q or Class B		X 3/, 4/, 5/	
3) SCD		X 4/, 5/	X
4) 883-Compliant or Class M 5/		X 4/, 5/, 6/	X
Level 2:			
1) Class V or Class S	X		
2) Class Q or Class B		X 4/	
3) 883-Compliant or Class M 6/		X 4/, 8/	X 9/
4) SCD		X 4/, 8/	X 9/
5) Mfr. Hi-Rel 7/		X 4/, 8/	X 9/
6) Commercial		X 4/, 8/	X 9/
Level 3:			
1) Class V (or S)	X		
2) Class Q (or B)		X 4/	
3) 883-Compliant or Class M 4/, 9/		X 4/	
4) SCD 9/		X 8/	
5) Mfr. Hi-Rel 10/		X 8/	
6) Commercial 10/		X 8/	

Notes follow on next page.

Table 1 PEM REQUIREMENTS 1/

Project Requirement	Screening (per Table 2)	Qualification 2/ (per Table 3)	DPA 3/
Level 1	X	X	X
Level 2	X	X	X
Level 3	X	X	X

Traditional EEE Parts Selection for NASA Missions

Example of 100% screen and sample-based qualification testing for non-QML parts:

Table 2 SCREENING REQUIREMENTS FOR PEMS 1/ (Page 1 of 3)

Screen	Test Method and Conditions	Level 1	Level 2	Level 3
1. External visual, and serialization 2/	Per paragraph 5.3.1. of PEM-INST-001	X	X	X
2. Temperature cycling	MIL-STD-883, Method 1010, Condition B (or to the manufacturer's maximum storage temperature range, whichever is less). Temperature cycles, minimum.	20	20	10
3. Radiography 3/	Per paragraph 5.3.2. of PEM-INST-001	X	X	X
4. C-SAM inspection 4/	Per paragraph 5.3.3. of PEM-INST-001	X	X	X
5. Initial (pre-burn-in) electrical measurements (EM) 5/	Per device specification, at 25 °C At min. and max. rated operational temperatures.	X X	X X	X -
6. Engineering review (Steps 1 to 5) 6/				
7. Static (steady-state) burn-in (BI) test at 125 °C or at max. operating temperature 7/	MIL-STD-883, Method 1015, condition A or B. Hours, minimum depending on the BI temperature.	240 hrs. at 125 °C 445 hrs. at 105 °C 885 hrs. at 85 °C 1,560 hrs. at 70 °C	160 hrs. at 125 °C 300 hrs. at 105 °C 590 hrs. at 85 °C 1,040 hrs. at 70 °C	160 hrs. at 125 °C 300 hrs. at 105 °C 590 hrs. at 85 °C 1,040 hrs. at 70 °C
7a. Post static BI electrical measurements @ 25 °C	Per device specification. Calculate Delta when applicable.	X	X	X
9. Dynamic burn-in test at 125 °C or at max. operating temperature 7/	MIL-STD-883, Method 1015, Cond. D. Hours, minimum.	Same as test step 7.	Same as test step 7.	Same as test step 7.
10. Final parametric and functional tests	Per device specification (at 25 °C, maximum, and minimum rated operating temperatures).	X	X	X
11.Calculate percent defective (Steps 7 to 10) 6/	Maximum acceptable PDA.	5%	10%	10%
12. External visual/packing 2/	Per paragraph 5.3.1 and Section 8 of PEM-INST-001.	X	X	X

Notes on next page.

Section M4
Microcircuits, Plastic Encapsulated

EEE-INST-002
5/03

Table 3 QUALIFICATION REQUIREMENTS FOR PEMS 1/ (Page 1 of 2)

Process	Sub Test	Test Methods & Conditions	QTY (Failures)		
			Level 1	Level 2	Level 3
1. Visual inspection & serialization 2/		Section 5, paragraph 5.3.1 of PEM-INST-001	32	32	17
2. Radiation analysis		TID and SEE	3/	3/	3/
3. Baseline C-SAM	(Parts in subgroup 1 only)	Section 5, paragraph 5.3.1 of PEM-INST-001	22	22	N/A
5. Preconditioning	Moisture soak 4/	JESD22 – A113-B, para. 3.1.5, condition A (168 hours, +85°C, 60% RH).	32	32	17
	SMT devices Reflow simulation (with flux application, cleaning, and drying)	JESD22-A113-B, Table 2 and paragraphs. 3.1.6 through 3.1.9. Peak solder reflow temperature +235 °C.	32	32	17
	Through hole devices Resistance to soldering temperature	JESD22-B106-B.	32	32	17
4. Electrical measurements	Per device specification	Measure at 25 °C, min. & max. rated temperatures.	32(0)	32(0)	17(0)
6. Life testing Subgroup 1	HTOL, 125 °C 5/, 6/	MIL-STD-883, Method 1005, Cond. D Hours, minimum.	22 1,500	22 1,000	10 500
	Electrical measurement (per specification)	Measure at 25 °C, min. & max. rated temperatures.	22(0)	22(0)	10(0)
6a. Temperature cycling Subgroup 1	Temperature cycling 5/, 7/	MIL-STD-883 Method 1010, Cond. B (-55 °C to +125 °C), cycles, minimum.	22 500	22 200	10 100
	Electrical measurement (per specification)	Measure at 25 °C, min. & max. rated temperatures.	22(0)	22(0)	10(0)
	C-SAM 8/	Section 5, paragraph 5.3.3.	22	22	N/A
	DPA or FA	9/	X	X	N/A
7. Highly accelerated stress test (HAST)	Biased HAST 5/	JESD22 - A110, with continuous bias (96 hours, +130 °C, 85% RH).	10	N/A	N/A
Subgroup 2	Unbiased HAST 5/	JESD22-A118, Condition A (96 hours, +130 °C, 85% RH).	N/A	10	7

Notes on next page.

Section M4
Microcircuits, Plastic Encapsulated

EEE-INST-002
5/03

New Updates in NASA-STD-8739.11

Was:
(per EEE-INST-002)

Table 1 PEM REQUIREMENTS 1/

Project Requirement	Screening (per Table 2)	Qualification 2/ (per Table 3)	DPA 3/
Level 1	X	X	X
Level 2	X	X	X
Level 3	X	X	X

Now:

Table 1. PLASTIC ENCAPSULATED MICROCIRCUIT REQUIREMENTS 1/

Assurance Level	Monolithic Microcircuit Type	Specification	Use as Is	Screening	LAT	DPA
Level 1	QML Class P	MIL-PRF-38535				X
	SCD 2/	SCD		X	X	X
Level 2	QML Class P or N	MIL-PRF-38535				X
	Automotive, Commercial, SCD 2/	AEC-Q100, VICD, SCD		X	X	X
Level 3	QML Class P or N	MIL-PRF-38535				X
	Automotive, Commercial, SCD 2/	AEC-Q100, VICD, SCD		X		X
Level 4	QML Class P or N	MIL-PRF-38535	X			
	Automotive, Commercial, SCD 2/	AEC-Q100, VICD, SCD	X			

New Level 4 added →

Notes:

1/ The character "X" designates a requirement. The character "R" designates a recommendation.

2/ SCD shall be generated to the program-specific Parts Procurement Plan that specifies screening and qualification testing.

New Updates in NASA-STD-8739.11

Table 2. PLASTIC ENCAPSULATED MICROCIRCUIT SCREENING 1/ 4/

Test	Test Sequence	Test Methods, Conditions, and Requirements	Level 1 SCD	Level 2 SCD, Automotive, Commercial	Level 3 SCD, Automotive, Commercial
1	Wafer Lot Acceptance	MIL-STD-883, Methods 5010 Appendix II and 5007	X		
2	Nondestructive Bond Pull	MIL-STD-883, Method 2023, 2% PDA	X		
3	Internal Visual	MIL-STD-883, Method 2010	X Cond. A		
4	Temperature Cycling	MIL-STD-883, 1010, Condition B, 10 Cycles min.	X	X	
5	External Visual	MIL-STD-883, 2009 (3 to 10X)	X	R	
6	PIND 2/	MIL-STD-883, 1010, Condition A	X	X	
7	Serialization		X	X	
8	Radiographic	PEM-INST-001 Para 5.3.2	X		
9	Burn-in 3/	MIL-STD-883, 1015, Condition D.	X 240 hr. @125°C	X 160 hr. @125°C	R 96 hr. @125°C
10	Final Electrical Measurements at +25°C, Min. and Max. Operating Temp.	Per applicable device procurement specification	X	X	X
11	Maximum Percent Defective Allowable (PDA)		≤ 5%	≤ 10%	
12	External Visual	MIL-STD-883, 2009 (3 to 10X)	X	X	R

Notes:

1/ The character "X" designates a requirement. The character "R" designates a recommendation.
2/ PIND required for cavity PEM microcircuits.
3/ Limit burn-in temperature to below the maximum junction temperature (Tj) as specified by the manufacturer.
4/ Plug cavity microcircuits vent holes before environmental testing.

Table 3. PLASTIC ENCAPSULATED MICROCIRCUIT LOT ACCEPTANCE TESTS 1/

Inspection Test	Test Methods, Conditions, and Requirements	Quantity (Accept Number) Level 1	Quantity (Accept Number) Level 2
Group 1			
Visual Inspection and Serialization	MIL-STD-883, Method 2009 (3X to 10X)	77	44
Group 2			
Preconditioning Moisture Soak 2/	JESD22- Moisture Sensitivity Level soak shall be in accordance with IPC/JEDEC J-STD-020.	X	X
Reflow		X	
Radiography	MIL-STD-883, Method 2012, Two Views	X	X
Electrical Measurements	Measure and record parameters at 25 °C, min. and max. rated temperatures per device specification.	45 (0)	22 (0)
Life Testing 3/	MIL-STD-883, Method 1005, Test Condition D, HTOL, 125 °C, 1,000 hours minimum Measure and record parameters at 25 °C, min. and max. rated temperatures per device specification.	45 (0)	22 (0)
Group 3			
Baseline SAM	PEM-INST-001, Para. 5.3.3	22 (0)	12 (0)
Temperature Cycling	MIL-STD-883, Method 1010, Condition B; 100 cycles. Measure and record parameters at 25 °C, min. and max. rated temperatures per device specification.	22(0)	12(0)
SAM	PEM-INST-001, Para. 5.3.3	22(0)	12(0)
Group 4		10 (0)	10 (0)
Biased HAST	JESD22-A110, with continuous bias, 96 hours, +130 °C, 85% RH.		
Final Electrical Measurements	Measure and record parameters at 25 °C, min. and max. rated temperatures per device specification.		

NPR 8705.4 Risk Categories for NASA Missions

Mission and Instrument Risk Classification Considerations		
Priority (Relevance to Agency Strategic Plan, National Significance, Significance to the Agency and Strategic Partners)	Very High: High: Medium: Low:	Class A Class B Class C Class D
Primary Mission Lifetime	Long, > 5 Years: Medium, 3 to 5 Years: Short, 1 to 3 Years: Brief, < 1 Year:	Class A Class B Class C Class D
Complexity and Challenges (Interfaces, International Partnerships, Uniqueness of Instruments, Mission Profile, Technologies, Ability to Reservice, Sensitivity to Process Variations)	Very High: High: Medium: Medium to Low:	Class A Class B Class C Class D
Life-Cycle Cost	High : Medium to High Medium : Medium to Low	Class A Class B Class C Class D

NPR 8705.4 EEE Parts Requirements

Risk Category: Class A Level 1 parts, equivalent Source Control Drawings (SCD) or requirements per Center Parts Management Plan.	Risk Category: Class B Class A criteria or Level 2 parts, equivalent SCD or requirements per Center Parts Management Plan.	Risk Category: Class C Class B criteria or Level 3 parts, equivalent SCD or requirements per Center Parts Management Plan.	Risk Category: Class D Class C criteria or Level 4 parts, equivalent SCD or requirements per Center Parts Management Plan.

* References NASA-STD-8739.10 for parts level definition

NASA-STD-8739.10 Table 2 EEE Part Level Description

GRADE / LEVEL	SUMMARY	LEVEL OF IN-PROCESS CONTROLS AND SCREENING	COST / PART	POTENTIAL UPSCREEN COST	TYPICAL USE
1	Space quality class qualified parts or equivalent	Highest	Highest	Low	Space flight
2	Full Military quality class qualified parts or equivalent	High	High	Medium	Space flight or critical ground support equipment
3	Low Military quality class parts and Vendor Hi-Rel or equivalent. Screened automotive grade EEE parts.	Medium	Moderate	High	Space flight experiments, cube-sats noncritical space flight, critical ground support equipment, test demonstrations and ground support systems
4	“Commercial" quality class parts. Qualification data at manufacturer’s discretion. No government process monitors incorporated during manufacturing.	Variable	Lowest	Highest	Cube-sats, noncritical space flight, noncritical ground support equipment, ground support systems, test demonstrations and prototypes. Limited critical GSE.

Examples of NASA COTS Parts Acceptance Approaches

Science Mission Directorate (SMD) Standard Mission Assurance Requirements for Payload Classification D:

8. EEE PARTS

8.1 **GENERAL**

The Developer shall document and implement a Parts Control Plan (PCP) (DRD MA-19). Per NASA-STD-8739.10, Level 4 or Commercial-Off-The-Shelf (COTS) parts may be used without additional screening.

The Developer should address the following for part selection, screening, and usage in the PCP when information is available:

- Prior usage of the part and qualification for the specific application
- Parts manufacturing variability, within lots and from lot-to-lot
- Traceability and pedigree of parts
- Reliability basis for parts
- Parts stress/application conditions

The PCP shall address counterfeit parts in accordance with SAE AS5553.

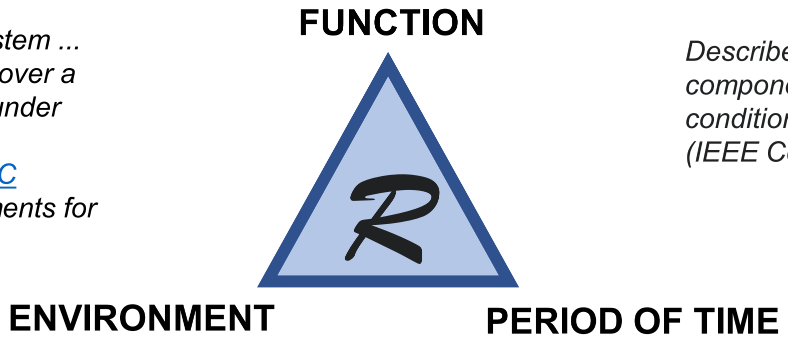
JSC Engineering Directorate Certified Parts Approval Process (EDCPAP):

- Allows for the use of unscreened COTS parts in Government-Furnished Equipment (GFE) on ISS, SSP, MPCV, and Gateway
- Replaces the need for additional MIL-SPEC/NASA screening or qualification through verification that the part manufacturers follow best practices to ensure defect-free parts
- Note: GFE is almost never necessary to the functioning of the launch vehicle

Goal is Established Reliability!

Reliability

The probability that a system ... will function as intended over a specified period of time under specified environmental conditions. (NPR 8705.2C Human-Rating Requirements for Space Systems)



Describes the ability of a system or component to function under stated conditions for a specified period of time. (IEEE Computer Dictionary)

Quality - Robustness - Screening - Qualification - Physics of Failure - Derating

Mission, Environment, Application and Lifetime (MEAL)

NESC COTS Technical Assessment

Recommendations on Use of Commercial-Off-The-Shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) Parts for NASA Missions – Phase II

"Properly selected COTS parts in appropriate applications can offer performance and supply availability advantages compared to MIL-SPEC parts. Their utility and demonstrated reliability results from large volumes and automated production and testing processes. However, careful review and a thorough understanding of their specifications (i.e., datasheet limitations) is needed, and verifying that manufacturer specifications and reliability meet space hardware application needs is necessary."

NESC COTS Report Findings and Recommendations

- New terminologies defined in the reports
  - Phase I defined an Industry Leading Parts Manufacturer (ILPM)
  - Phase II defined an Established COTS part
    - Phase II provided the criteria of an ILPM and an Established COTS part
    - ***Recommend selecting Established COTS parts from ILPMs***
- Phase II report proposes:
  - MIL-SPEC screening and non-radiation-related lot acceptance testing be reduced or eliminated in cases where evidence of sufficient quality and reliability exists for COTS parts
  - The extent of NASA's insight into COTS manufacturers and the amount and nature of the needed evidence will differ by mission and will likely be driven by a mission's resources and associated risk posture

What Is An ILPM?

NESC Phase I report defined an **Industry Leading Parts Manufacturer (ILPM)** as:

> A parts manufacturer with high volume automated production facilities and which can provide documented proof of the technology, process, and product qualification, and its implementation of the best practices for "zero defects" for parts quality, reliability and workmanship.

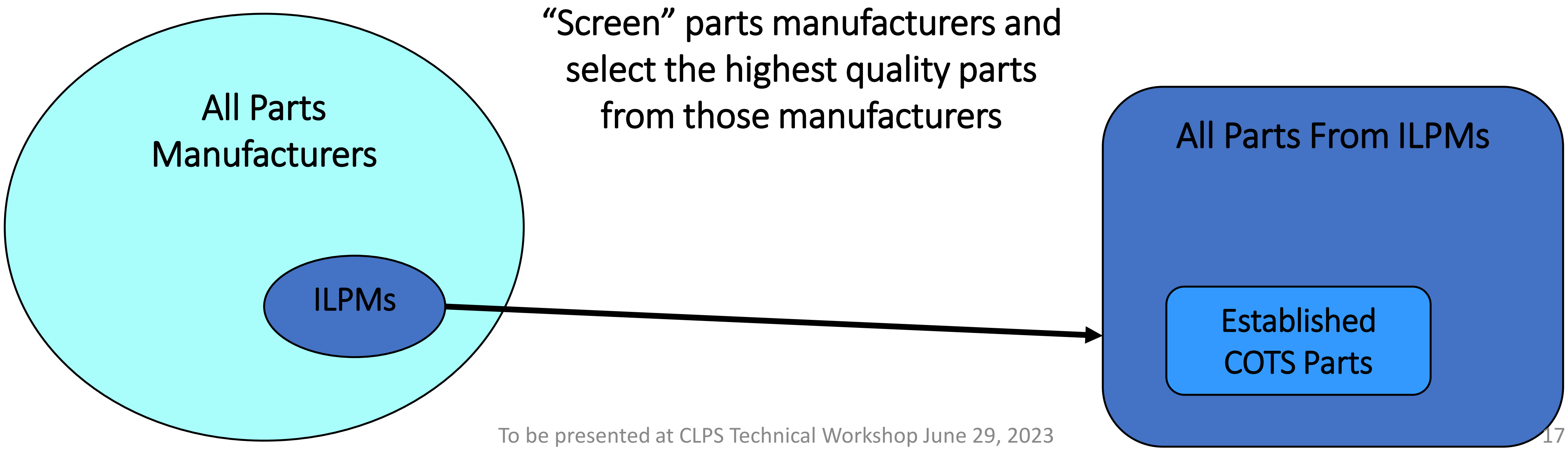
ILPM Criteria

1. Must have at least one Established COTS Part category
2. Willing to share parts quality and reliability data with NASA (DPPM, FIT) and how those statistics are derived
3. Willing to provide NASA documents substantiating parts quality and reliability
4. Willing to work with NASA or prime contractors to maintain a strong customer-manufacturer relationship (preference for on-site visit)

Established COTS Part Defined

Recommendation from NESC Phase II report is for NASA missions to implement the use of an **Established COTS part** from an ILPM

- High volume part produced on fully automated production lines utilizing statistical process control (SPC), with demonstrated stability and 100% electrical testing per datasheet specifications at typical operating conditions in production prior to shipping to customers



An Established COTS Part……

1. Is produced using processes that have been stable for at least **one year** so there are enough data to verify the part’s reliability.
2. Is 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.
3. Is **100% electrically tested** per datasheet specifications at typical operating conditions in production prior to shipping to customers. Additionally, the manufacturer must have completed multi-lot characterization over the entire set of 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.
4. Is produced on **fully automated production lines** utilizing statistical process control (SPC), and undergoes in-process testing, including wafer probing for microcircuits and semiconductors, and other means appropriate for other products (e.g., passive parts). These controls and tests are intended to maintain process tolerances and eliminate defective parts at various stages of production.
5. Has demonstrated **consistent yield** trend appropriate for high volume commercial technologies at that technology node.

What Is/Is Not Provided In the NESC COTS Report

- Intended audience are NASA personnel and commercial practitioners who support NASA spaceflight missions
  - Project managers, parts engineers, parts manufacturers, radiation engineers, avionics engineers, system engineers, circuit design engineers, reliability engineers, SMA personnel, and parts procurement specialists
- Provides guidance in using COTS parts for Class A-D and human-rated missions
  - Does not address the initial and lifecycle cost of using COTS parts
  - Does not distinguish between critical or non-critical systems in recommendations
  - Does not address radiation hardness assurance for COTS parts, references NESC-RP-19-01489 "Guidelines for an Avionics Radiation Hardness Assurance" document for best practices
  - Provides guidance, not implementation details
    - Guidance on part- and board-level verification per mission risk classification
    - Proposed ILPM process is not the same as MIL-SPEC vendor qualification processes
    - Per NESC recommendation, the NASA Electronic Parts and Packaging (NEPP) Program has started a pathfinder study to explore implementing the guidance
- Current practices from DoD and FAA captured in the report were provided by the corresponding agencies regarding their practices, which are independent from the NESC recommendations

Considerations for EEE Parts Selection

- Parts selection should be driven by the project MEAL and mission risk posture
- For Class A/B or human-rated missions with a low tolerance for risk, use existing MIL-SPEC parts when feasible ***but*** do not assume a MIL-SPEC part is equivalent to its commercial counterpart
- The criticality of the parts application along with system redundancy, board/box level testing should be evaluated and a consideration during parts selection and test plan development
  - Identify application-critical parameters and functionality and verify by testing over application range
  - Identify environments that might be problematic for parts in their applications and verify by testing and analysis
- When using COTS parts, use Established COTS parts from ILPMS for which parts quality and reliability can be demonstrated through evidence (e.g., Level 3 PPAP)
- Minimize the additional screening and lot acceptance testing needed post procurement
- Additional COTS parts considerations:
  - COTS parts should be procured only from Original Component Manufacturers (OCMs) or authorized distributors for counterfeit parts avoidance
  - Communicate with the OCMs and/or distributors to ensure procured semiconductor-based devices are from the same wafer lots when needed, for required lot acceptance and/or radiation testing
  - Perform parts obsolescence analysis during parts selection and procurement
  - Implement a tin whisker mitigation plan as recommended by GEIA-STD-0005-2, to cover all pure tin uses
  - Radiation hardness is an additional consideration that requires evaluation at the part level and/or mitigation at the circuit/system level