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中国航天宇航元器件工程中心
China Aerospace Components Engineering Center

Quality Assurance Method of COTS Optoelectronic Semiconductors in Aerospace Application

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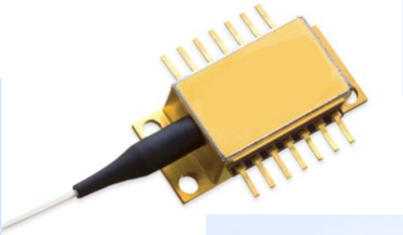
Background Introduction

Background Introduction

The increasing demand of COTS optoelectronic devices by spacecraft laser loads is significant in nowadays.

Because of the harsh space environment, the reliability and stability of optoelectronic devices is very important.

Quickly identifies the reliability weaknesses, confirms whether they are suitable for space applications, and effectively eliminates early failure products and products with batch defects.



2

Research and Analysis

Research and Analysis

01

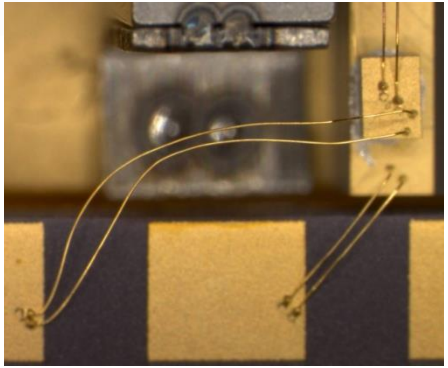
Construction, Process and Materials Defects, and Failure Analysis

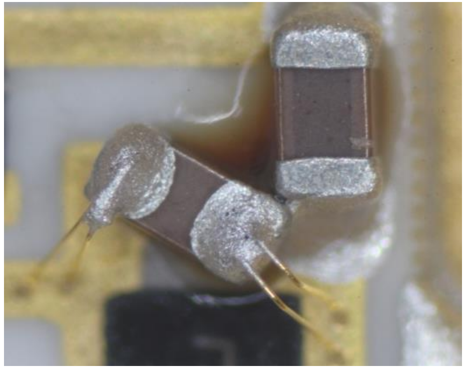
02

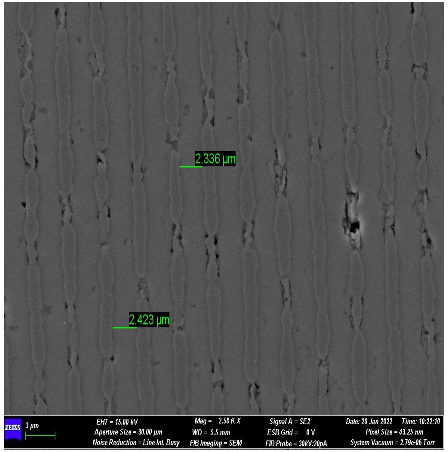
Research on Quality Assurance Standards

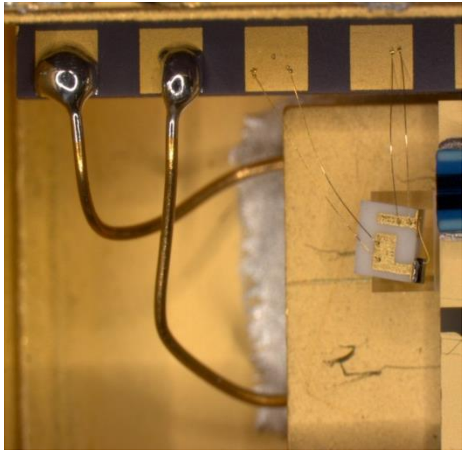
Construction aspects

- ✓ Bonding wire span is too long;
- ✓ Improper insulation spacing control;
- ✓ Nickel electrode capacitor nickel layer thickness doesn’t meet requirements;
- ✓ Crossed output terminals of TEC









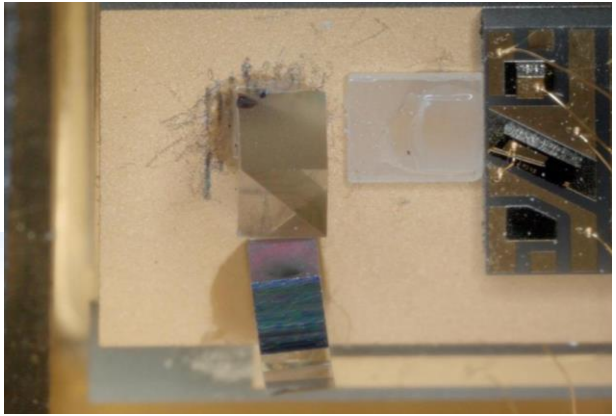
Material aspects

AgSn solder has the risk of tin whisker growth

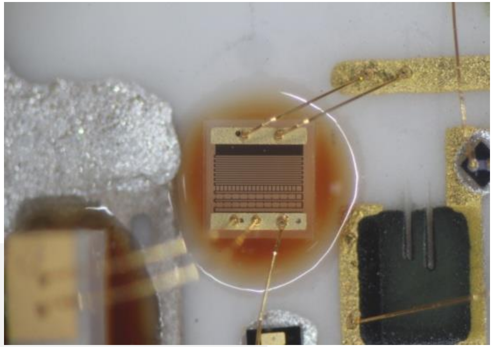
AgSn is a lead-free solder. There is a risk of short circuit due to the growth of tin whiskers during the soldering process.

Long-term reliability of organic adhesives

Under conditions of high temperature, high humidity or mechanical stress, the performance of organic adhesives will deteriorate, resulting in a decrease in the structural stability.



Process aspects

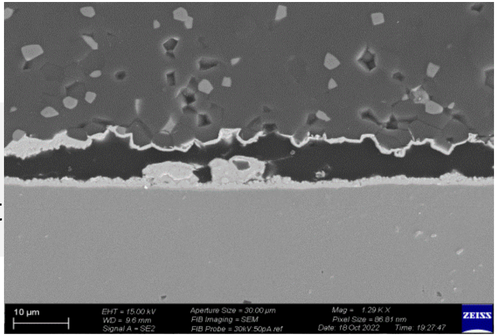


01 Internal silver paste overflow on the pad

02 No gold removal treatment has been performed

03 Other process problems such as:

- PCB board manufacturing processes have multiple quality issues
- Gaps, voids, or lack of angles in the internal component soldering interfaces



Common Failure causes and modes

a) Catastrophic optical damage caused by over-electrical stress.

b) Light source diaphragm burnout and fracture caused by external stress.

c) Laser optical resonator damage caused by over-electrical stress or internal defects.

d) AgCu solder migration along the cracks and corrosion, and large-scale discoloration of the package surface.

e) Thermal expansion coefficient differences between conformal coating and inductors lead to inductor ferrite cracking.

f) Optical fiber breakage caused by abnormal mechanical stress.

Research on Quality Assurance Standards for COTS Semiconductor Devices

NASA-STD-8739.10

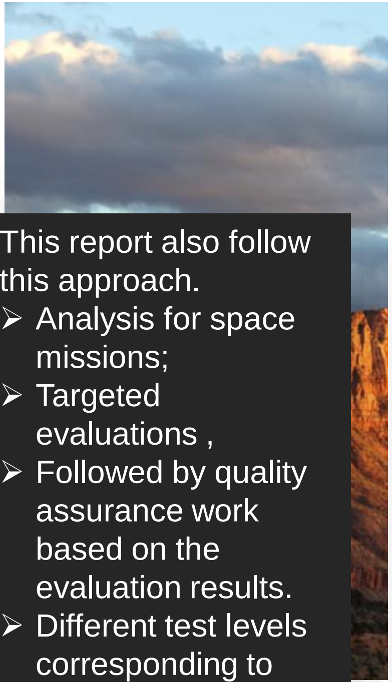
MSFC-STD-3012

NASA GSFC EEE-INST-002

ECSS-Q-ST-60-13C

DLR-RF-PS-006

The connotation of COTS device quality assurance work is to conduct a detailed analysis of space mission requirements and provide **targeted** quality assurance items, requirements, and methods to meet space mission requirements.

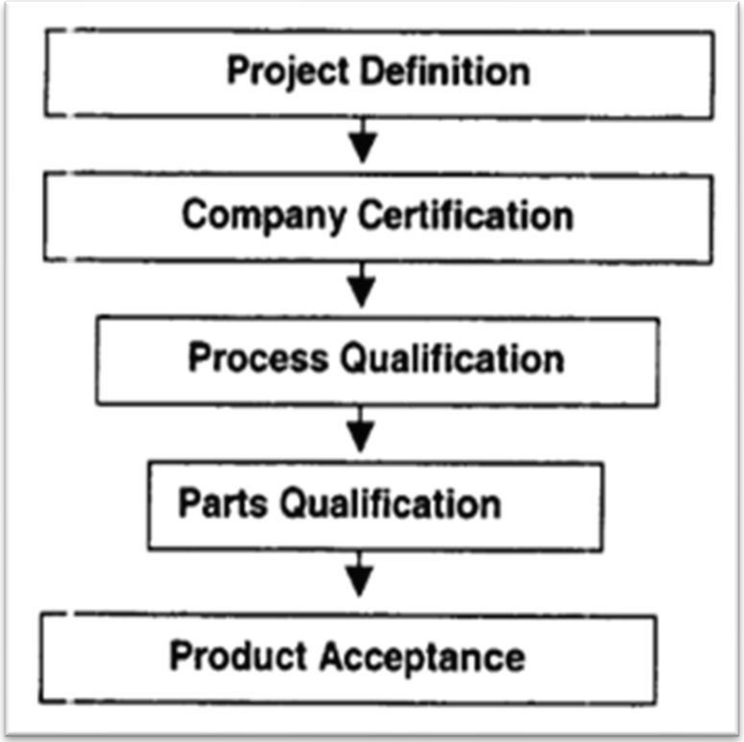


This report also follow this approach.

- Analysis for space missions;
- Targeted evaluations ,
- Followed by quality assurance work based on the evaluation results.
- Different test levels corresponding to different quality assurance test items.

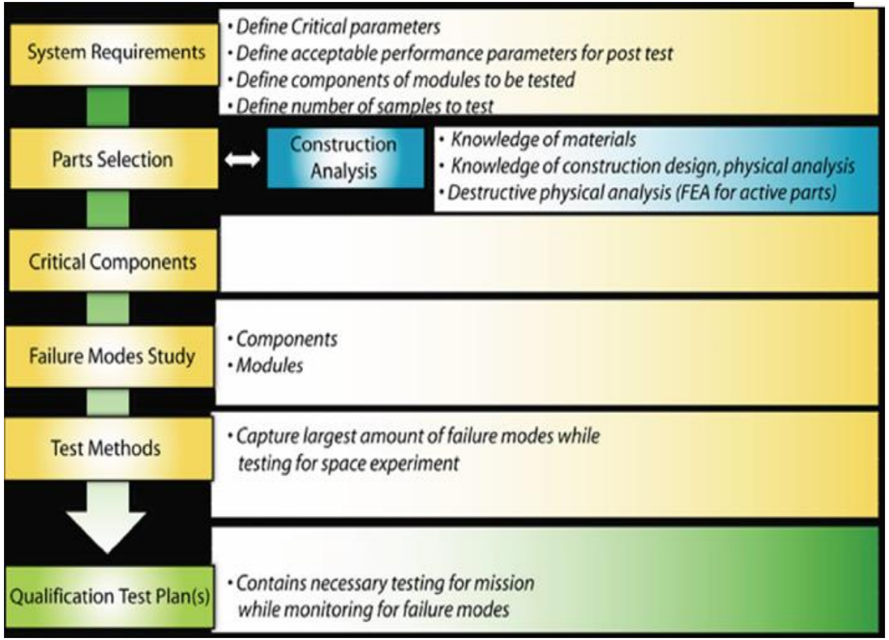
Research on Quality Assurance Standards for Optoelectronic Devices and Modules

- **NASA JPL 2001**, Space Qualification Guidelines of Optoelectronic and Photonic Devices for Optical Communication System: not applicable to COTS product suppliers
- **Others:**
  - **MIL-STD-883**: not targeted at COTS optoelectronic products
  - **GR(Generic Requirements)-468**: for ground equipments, do not meet space levels
  - **AEC-Q102**, Failure Mechanism Based Stress Test Qualication for Optoelectronics Semiconductor in Automotive Application: not entirely applicable to space applications

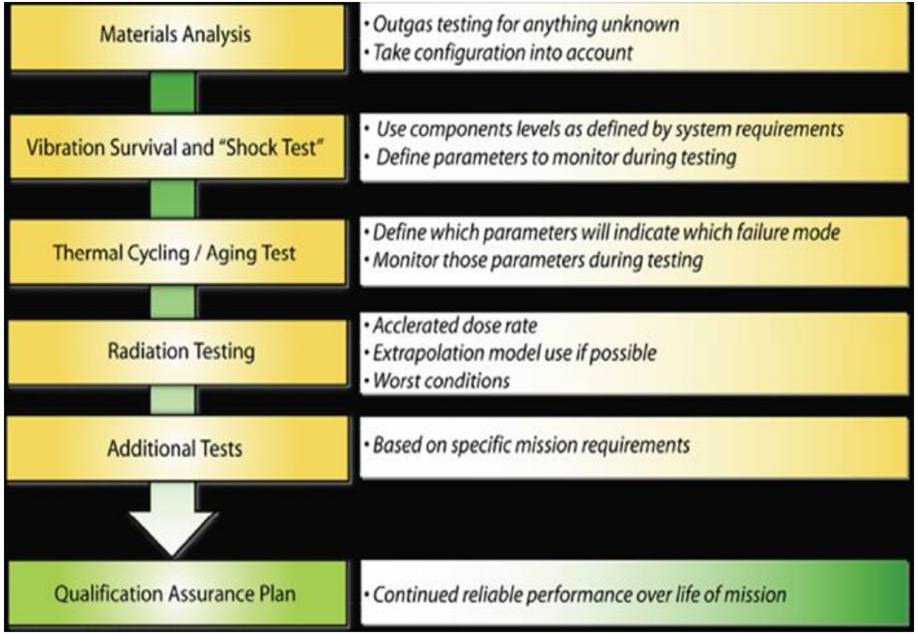


Research on Quality Assurance Standards for Optoelectronic Devices and Modules

- **The Photonics Group of the Applied Engineering & Technology Directorate, Electrical Engineering Division**



COTS optoelectronic devices assurance process



COTS optoelectronic devices qualification process

Summary

Applicability

- NASA- STD- 8739.10 and MSFC- STD- 3012, etc., have been widely used in the international space field. They combine the actual requirements of space missions and the level of COTS devices production, and have strong pertinence and applicability.
- These standards provide effective guidance for the quality assurance of COTS optoelectronics for space applications. There are clear requirements and methods in every link from demand analysis to tests.

Limitation

- It is necessary to further refine and supplement according to practical application of spacecraft.
- For example, for some new COTS optoelectronic devices with new design, new process, and new material, existing standards may not fully cover the requirements.

3

Main Technical Requirements

Scope

01

Applicable Object

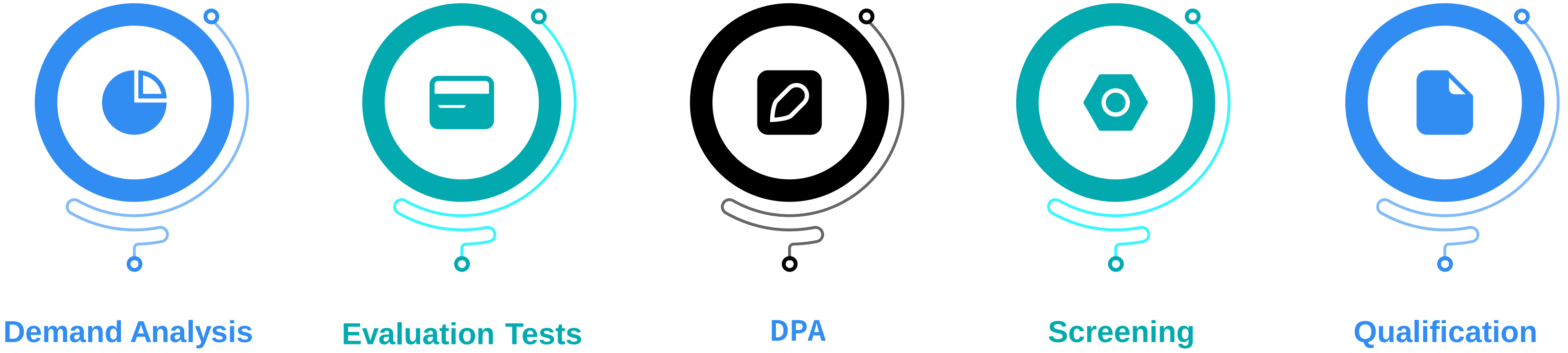
COTS semiconductor optoelectronic devices and modules:
LED, LD, photodiodes, phototransistors, and other semiconductor optoelectronic devices with or without pigtails, as well as laser diode modules, SLD modules, photodiode detector modules, multi-element, array, or focal plane detector modules with or without pigtails.

02

Application Scenario

Provides the quality assurance methods for COTS semiconductor optoelectronic devices and modules used in spacecraft;
Including demand analysis, evaluation testing, destructive physical analysis(DPA), screening testing, and qualification testing.

Quality Assurance Flow



Demand Analysis

Confirmation of User Demand

Focus on the risks by extreme temperatures, temperature cycling, mechanical stress, space radiation, and thermal vacuum environments, and pay attention to previous in-orbit flight experiences.

Quality Information Research of the Supplier

Including but not limited to the technical baseline of the development and production of components or modules, changes in product technical status, and production cessation situations.

Risk Analysis

Risks should be confirmed based on the results of structural analysis, radiation resistance assessment, and life assessment tests. Effective data provided by the supplier may also be directly accepted.

Evaluation Tests

01 Construction analysis

Focus on **special process** such as optical path and coupling process, sealing process and, etc.

02 Characteristic Characterization

- Three-temperature consistency analysis: **±3σ;**
- Characteristic Curve Plotting

03 Radiation Resistance Assessment

- Especially **SEL.**

04 Limit Stress Tests

- **Extreme temperature and mechanical stresses**;
- Dual or triple stress application can be considered.

05 Life Assessment Test

- **Maximum junction** temperature;
- Temporary performance degradation can be ignored;
- **Equivalent life test** time can be calculated through the establishment of an accelerated life model

DPA

Sampling requirement

Considering the actual delivery status of COTS optoelectronic components and modules, as well as the high cost of some modules, specific sampling requirements for DPA should be stipulated.

Testing methods and conditions

Additionally, targeted DPA test methods and conditions should be developed based on the packaging structure characteristics of optoelectronic components and modules.

Test Levels

Level I

- The lowest application risk and the highest quality cost, typically used for satellite platforms

Level II

- Medium application risk and higher quality cost, typically used for satellite platforms, launch vehicles, or critical ground equipment

Level III

- Higher application risk and moderate quality cost, typically used for experimental satellites, non-critical satellites, rockets, and critical ground support equipment

Level IV

- The highest application risk and the lowest quality cost, typically used for non-critical satellites, non-critical ground equipment, and demonstration prototypes

Screening and Qualification Test Requirements

Screening Test Requirements

No.	Test Item	Test Method	Test Level		
			I	II	III
1.	External Visual Inspection	MIL-STD-883, Method 2009	√	√	√
2	Temperature Cycling	MIL-STD-883, Method 1010	√	√	—
3	Serial Numbering	--	√	√	√
4	Mechanical Shock	MIL-STD-883, Method 2001	√	—	—
5	PIND	MIL-STD-883, Method 2020	√	√	√
6	Initial Test Before Burn-in	T_A=+25℃ or room temperature	√	√	√
7	Burn-in	MIL-STD-883, Method 1015	√	√	√
8	Final Test at Room Temperature	TA = +25°C or room temperature,	√	√	√
9	Parameter Change Calculation	Calculate the change in electrical parameters after burn-in test relative to the data from Item 6.	√	—	—
10	PDA Calculation	--	5%	10%	20%
11	Low Temperature Test	Tested at the specified low operating temperature for optical and electrical parameters and functions.	√	√	√
12	High Temperature Test	Tested at the specified maximum operating temperature for optical and electrical parameters and functions.	√	√	√
13	Seal Fine Leak Test Cross Leak Test	 MIL-STD-883, Method 1014 MIL-STD-883,Method 1014	√	√	—
14	X ray	MIL-STD-883, Method 2012	√	—	—
15	External Visual Inspection	MIL-STD-883, Method 2009	√	√	√

Screening and Qualification Test Requirements

Qualification Test Requirements

Test Group		Test Method	Test Level		
			I	II	III
Group 1	Solderability	JESD22-B102	√	√	—
	Marking Durability	MIL-STD-883， Method 2015	√	√	—
Group 2	Lead Bonding Strength	MIL-STD-883， Method 2004	√	√	—
	Fiber Axial Tensile Strength	GR-468， 3.3.1.3	√	√	—
	Seal Fine Leak Test Cross Leak Test	 MIL-STD-883， Method 1014 MIL-STD-883,Method 1014	√	√	—
Group 3	Thermal Shock	MIL-STD-883， Method 1011	√	—	—
	Temperature Cycling	MIL-STD-883， Method 1010	√	√	—
	Seal Fine Leak Test Cross Leak Test	 MIL-STD-883， Method 1014 MIL-STD-883,Method 1014	√	√	—
	Humidity Resistance	MIL-STD-883， Method 1004	√	—	—
	External Visual Inspection	MIL-STD-883， Method 2009	√	√	—
	Final Test	T_A=+25℃or room temperature	√	√	—
	Internal Visual and Construction Inspection	MIL-STD-883， Method 2014	√	—	—
	Bonding Strength	MIL-STD-883， Method 2011	√	—	—
	Die Shear	MIL-STD-883， Method 2019	√	—	—

Screening and Qualification Test Requirements

Qualification Test Requirements--continued

Test Group		Test Method	Test Level		
			I	II	III
Group 4	Mechanical Shock	MIL-STD-883, Method 2002	√	—	—
	Vibration	MIL-STD-883, Method 2007	√	—	—
	External Visual Inspection	MIL-STD-883, Method 2009	√	—	—
	Final Test	T_A=+25℃or room temperature	√	—	—
	Internal Visual and Construction Inspection	MIL-STD-883, Method 2014	√	—	—
	Bonding Strength	MIL-STD-883, Method 2011	√	—	—
	Die Shear	MIL-STD-883, Method 2019	√	—	—
Group 5	Initial Test	T_A=+25℃or room temperature	√	√	√
	Steady-State Life Test	MIL-STD-883, Method 1005	√	√	√
	Final Test	T_A=+25℃or room temperature	√	√	√
	Parameter Change Calculation	Calculate the change rate of photoelectric parameters before and after the steady-state life test.	√	√	√
	Internal gas analysis	MIL-STD-883, Method 1018	√	√	√
	Bonding Strength	MIL-STD-883, Method 2011	√	√	√
	Die Shear	MIL-STD-883, Method 2019	√	√	√
Group 6	Low air pressure	MIL-STD-883, Method 1001	√	—	—
Group 7	Electrostatic discharge sensitivity classification	MIL-STD-883, Method 3015	√	√	—
Group 8	Ionizing radiation (total dose) test	MIL-STD-883, Method 1019	√	√	—
	Single event test	ASTM F 1192	√	√	—
	Neutron irradiation	MIL-STD-883, Method 1017	√	√	—

Other Detailed Requirements

Electrical Testing and Parameter Change Rate Requirements

- LED: ΔR ΔVF
- SLD: $\Delta \varphi e$
- LD modules: ΔV_F, ΔP_{OP}
- *PD and modules:* ΔR_e ΔI_{CEO} ΔI_D
- Multi-element, array, or focal plane detector modules: ΔNEP ΔN_{ef} ΔE_N

Burn-in and Life Testing Requirements

- 100%;
- Fully accept the existing reliable data;
- For photonic modules containing TECs, the life test should be conducted at the maximum case temperature of the module, choose ACC or APC mode;
- Board level is OK

4

Summary and Prospect

Summary and Prospect

Summary

- Investigated the relevant standards for COTS and optoelectronic devices and modules;
- Summarized common construction, process, and material defects and failure mechanisms;
- Proposed the quality assurance methods, including demands analysis, evaluation, DPA , screening, and qualification;
- Supported users in taking corresponding protective measures and provide guidance for future selection.

Prospect

- Demand analysis: the production line evaluation can be further carried out, understanding of supplier quality information;
- Evaluation: the evaluation of construction, design, process defects and aerospace adaptability should be strengthened in order to assess the device risk more comprehensively;
- DPA, screening and qualification tests: it is necessary to constantly interate, further free minds, and propose more low-cost, fast response detection and test technical requirements.

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Thank you!

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