
Space Qualification for Extreme Environments Electronics and Packaging

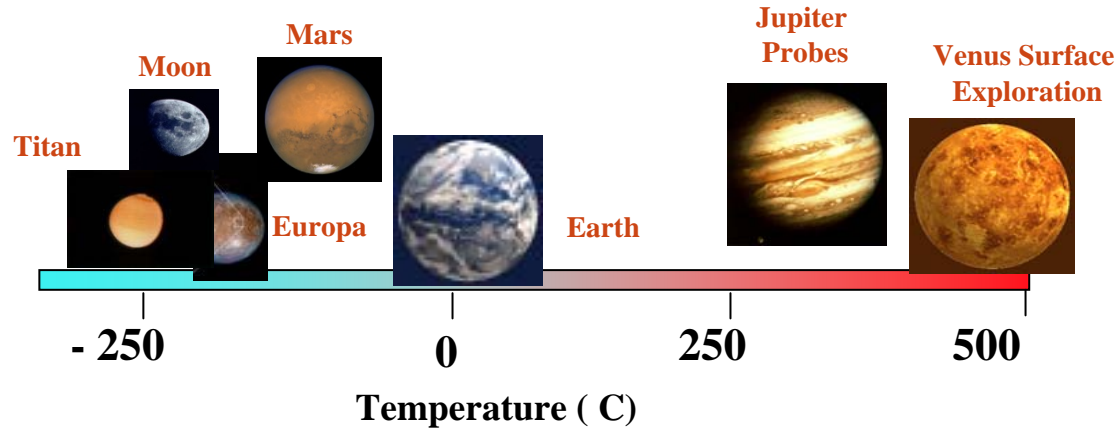
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Outline

- Space extreme environments
- Technology qualification
- Qualification for extreme environments
- Case study
- Summary

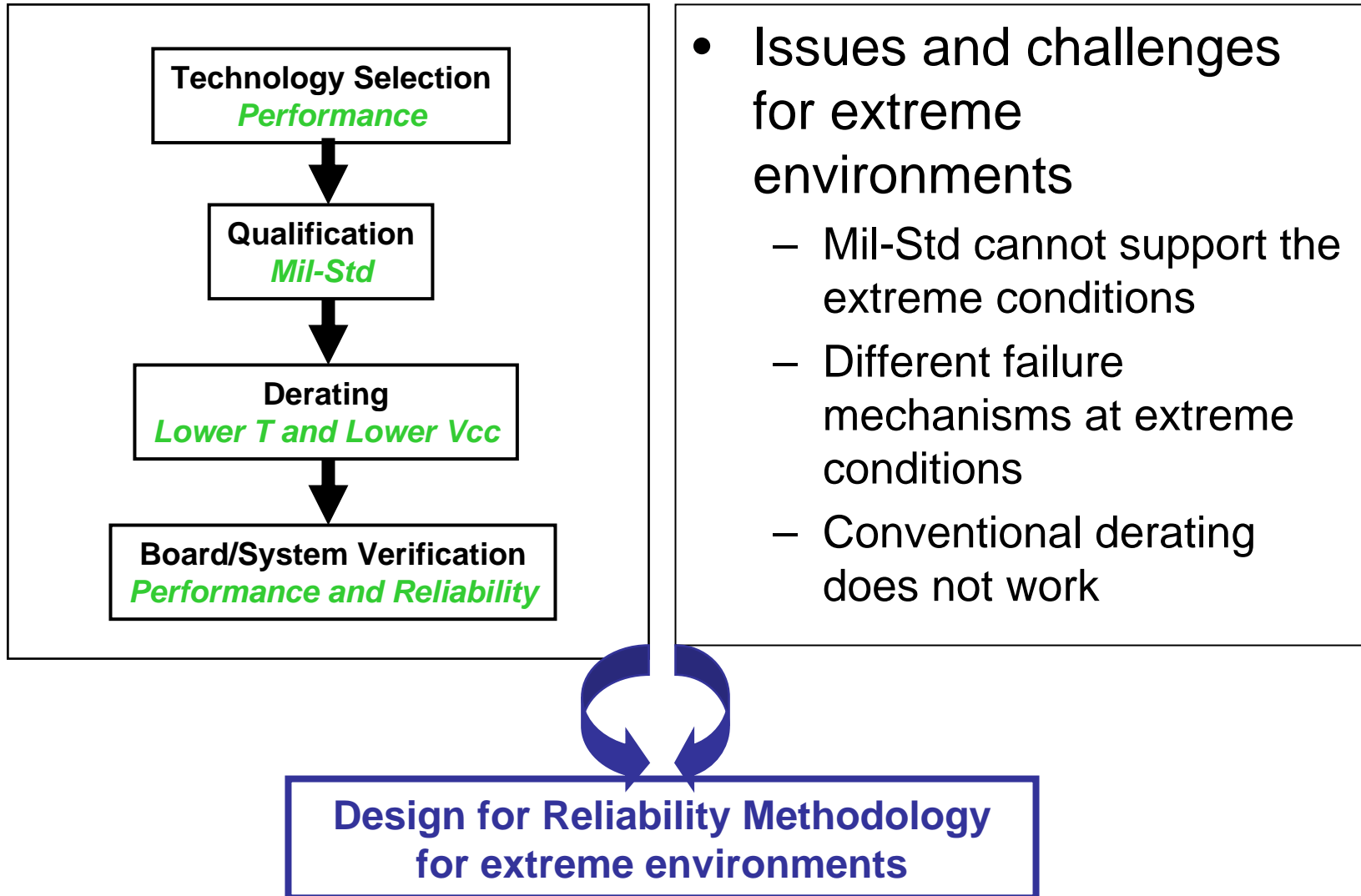
Space Extreme Environments



Mission	T _{low} (°C)	T _{high} (°C)	Press. (bar)	Concerns
Mars Surface Exploration	-128	20	0	Low Temperature and Temperature Cycling
Lunar Surface Missions	-230	120	0	Constant low temperature at Lunar shadow area, thermal shock/cycling elsewhere
Venus <i>In-Situ</i> Exploration		460	90	Sulfuric acid clouds, 97% CO ₂ at the surface
Jupiter Multi-Probes	-140	380	20-1000	High g
Comet Sample Return	- 270	-230	varies	Dust
Titan <i>In-Situ</i>	-180	-140	1.5	2-10% Methane Clouds, Solid/liquid surface
Europa Lander	-160	-120		Combination of radiation and low temperature

All Solar System Exploration *in-situ* missions have to survive in extreme temperatures, pressure, and/or radiation environments.

Technology Qualification



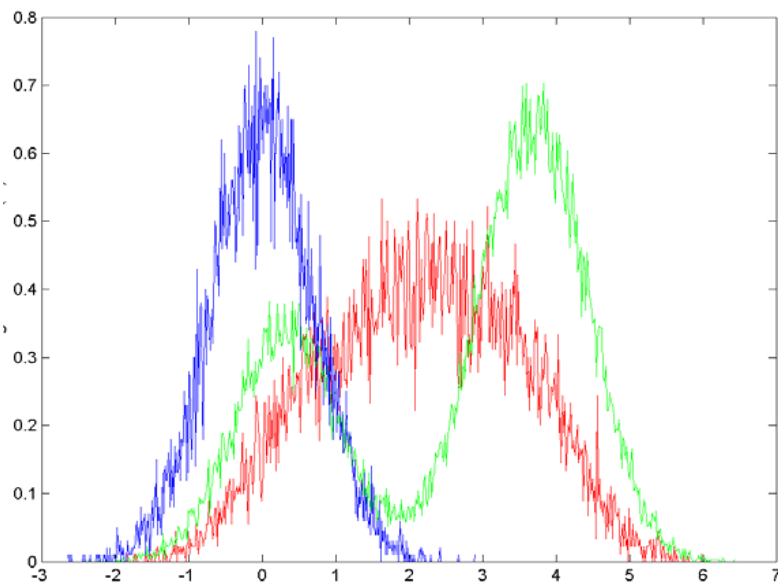
Design for Reliability Methodology

- Design for reliability yields design for reliability guidelines based on reliability model with understanding of failure mechanisms
 - Reliability model
 - Reliability = $f(\text{temperature, power, voltage, current, sample size, confidence level, failure percentage required, failure criterion, failure mode,})$
 - Based on current understanding of device/material reliability and failure mechanisms/modes
 - Design of Experiments
 - Testing matrix includes temperature, voltage, current, power and sample size
 - Focus on major reliability contributors and critical parameters
 - Data Analysis and Failure Analysis
 - Need to be performed after each test run to either verify or revise the reliability model and testing plan
 - Design-for-Reliability Guidelines
 - Only reliable and efficient path to flight insertion for currently available state-of-the-art technologies
 - Screening, qualification, system design

Keys to Design for Reliability Methodology

- Understanding failure mechanisms
 - Technology reliability
 - Physics of failure
 - Device physics
 - Process limitations
- Reliability model
 - Statistical nature of failure
 - Worst-case approach
 - Assume worst case device bias condition
 - Assume worst case operating condition
 - May give a too pessimistic projection
 - A statistical approach
 - Focus on the statistical nature of device degradation and lifetime
 - Focus on actual use/operating condition
 - Yield realistic estimation
- Design for reliability guidelines
 - System design requirements
 - Design in the risk mitigation

Statistical Approach



- 10 bias conditions
- **RED** - 10 transistors at each bias
- **GREEN** - 100 transistors at bias #1, #9 and #10, 10 at other biases
- **BLUE** - 100 transistors at each bias

Circuits	Transistor Failure Criteria	Worst-case Approach	Proposed Approach
Digital	13% I_{dsat}	~ 800 yrs	~ 1000 yrs
Analog	10% g_{max}	~ 0.87 yrs	~ 6.5 yrs

Steady-State Life Test Defined in MIL-STD-883F

- MIL-STD-883F: “the steady-state life test is performed for the purpose of demonstrating the quality or reliability of the devices subjected to the specified conditions over an extended time period and the life tests need to be conducted within rated operating conditions for a sufficiently long test period to assure that results are not characteristics of early failures or infant mortality”.
- Life test defined: 45 parts, 1000 hours, total 45000 device hours at 125°C
 - First, the steady-state life test is to validate the pre-screening testing.
 - Second, the steady-state life test is to indicate a certain device life with a certain levels of reliability and confidence.
 - No failure is allowed in the steady-state life test; however, failures occurred in the test indicate parts failure distribution.

Test Duration and Sample Size

- Minimum test duration
 - The minimum test duration is 1000-hour at 125°C, or equivalent, per MIL-STD-883F.
 - The recommended test duration is the equivalent time to mission life, only if it is possible.
 - Reason: the purposes of the life test is not to demonstrate a device life, but rather to ensure a effective pre-screening test.
- Minimum sample size
 - In addition to the total test time in Chi-square distribution, minimum sample size is determined by the confidence level that the rest of parts in the same wafer lot will last at least the same test duration
 - The minimum sample size for a 90% confidence level that at least 95% of the parts in the same wafer lot will survive life test is 45.
 - The minimum sample size for a 90% confidence level that at least 80% of the parts in the same wafer lot will survive life test is 11.

Qualification for Extreme Environments



- Qualification
 - MIL-STD qualification flow
 - -55°C to $+125^{\circ}\text{C}$
 - Qualification for applications at cryogenic temperatures
 - Constant low temperatures
 - Example: -180°C , -230°C
 - Over a wide temperature range
 - Example: 125°C to -143°C
 - Qualification for applications at high temperatures
 - Example: 480°C



Qualification for Cryogenic Applications

- Design for cryogenic reliability
 - Advantages at LT: faster speed, lower leakage
 - Challenges at LT: variation, functionality, reliability
 - Design for **cryogenic** reliability guidelines
 - *At both device and system level*
 - Including qualification methodology for
 - *screening and long term reliability*
 - » Address potential defects for early failures
 - » Life test to validate pre-screening
 - » Thermal cycling
 - **Long term reliability is the key**

Qualification for High Temperature Reliability

- Design for high temperature reliability
 - Advantages at HT: none
 - Challenges at HT: survivability, reliability
 - Design for **HT** reliability guidelines
 - *At system level only*
 - Including qualification methodology for
 - *screening and short term reliability*
 - Which technology can survive and for how long?
 - surviving/short-term reliability conditions versus system performance requirements
 - How to screen out “infant mortality”?
 - qualification plan to ensure survivability
 - **Survivability and screening are the keys**

A Case Study

A Case Study

- A case study
 - Qualification for a Mars mission
 - Background
 - Mission temperature: $-128^{\circ}\text{C} \sim +85^{\circ}\text{C}$
 - Qualification temperature: $-143^{\circ}\text{C} \sim +125^{\circ}\text{C}$
 - Parts and Packaging
 - Radiation
 - Element evaluation
 - Reliability
 - Commercially available active and passive parts
 - Selection of packaging material combinations
 - » Substrate, die attach, wire bonding, etc.
 - Development of customized op-amp
 - » Design for reliability to address long-term reliability concern at low temperature

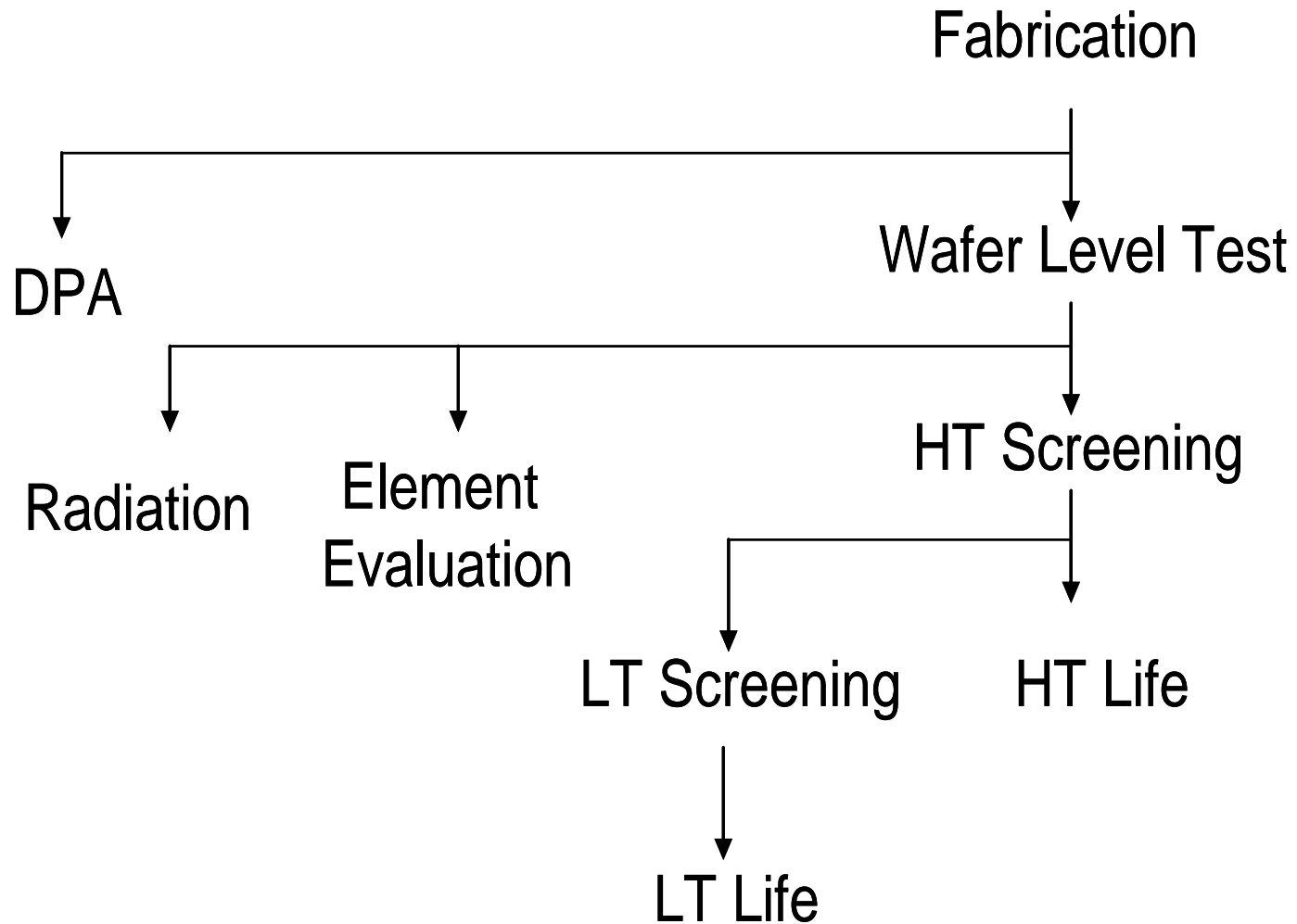
MIL-STD Qualification

- MIL-STD qualification: -55C to +125C
 - MIL-PRF-38535E: A. 3.4.6 and A.3.4.6.1: traceability and lot traveler
 - Wafer level device functional testing
 - MIL-STD-883
 - Method 2010, Condition A: Element Visual
 - Method 1015 for burn-in with pre and post tri-temp burn-in electrical
 - 240 hours at 125C for dynamic burn-in and 96 hours at 125C for static burn-in
 - Tri-temp: -55C, 25C and +125C
 - Method 1005 for steady state life test with tri-temp interim readouts
 - 45 parts, 1000 hours at 125C
 - Tri-temp: -55C, 25C and +125C
 - Thermal cycling

Qualification for a Mars Mission

- Mars application qualification: -143C to +125C
 - Element Evaluation
 - Large sample characterization (LSC): To characterize parts parametric temperature dependence to support WCA and SA
 - Thermal cycling qualification (TCQ): To demonstrate 3x thermal cycling mission life on parts
 - Methodology
 - LSC: Obtain parts parametric population distributions by characterizing a sample of parts at seven temperatures from flight lots, -143°C, -133°C, -128°C, -55°C, 25°C, 85°C, 125°C
 - TCQ: Thermal cycling parts from -130°C to +85°C for 3x cycles of mission life
 - Sample size
 - LSC: total 128 parts tested
 - » 22 samples for active devices (90% confidence for 10% PDA)
 - » 8 (90% confidence for 30% PDA) and 11 (90% confidence for 20% PDA) samples for passives
 - TCQ: total 1248 parts under cycling
 - » 147 (99.9% confidence for 5% PDA) and 22 samples (90% confidence for 10% PDA) for each part type
 - Pre-screening
 - Static and dynamic
 - High temperature (+125C) and low temperature (-143C)
 - Address potential defects for early failures in field at high and low temperature
 - Life Test
 - 45 parts 1000-hours steady state life test at -143C with interim readouts
 - Validate burn-in
 - Radiation
 - SEU

Qualification Flow



Qualification Flow – Qualification Parts Screen

Step	Screen	Required	Reject Criteria	Sample Size
1	Wafer Level Functional Test	Test to datasheet @ room temperature only	Any part failing to meet datasheet parametric at the temperatures specified	100%
2	Element Visual	MIL-STD-883, Method 2010, Condition A		100%
3	Serialization	Laser Serialization for traceability		100%

Qualification Flow - Sample Qualification

Step	Screen	Required	Reject Criteria	Sample Size
4	Sample Construction Test	DPA per MIL-STD-883, Method 5009	Any abnormal processing especially with metallization. Thinning, voids, notches, or apparent aberrations will be recorded.	5 pcs
5	Radiation			5-10 pcs
6	Electrical (Element Evaluation)	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	200 pcs
7	Static Burn-in (HT)	MIL-STD-883, Method 1015, 96 hours at +125C		100%
8	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
9	Dynamic Burn-in (HT)	MIL-STD-883, Method 1015, 240 hours at +125C		100%
10	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
11	Life Test (Dynamic, HT)	MIL-STD-883, Method 1005, 1000 hour at 125C.	Any part failing to meet data sheet parametric at the temperatures specified.	45 pcs

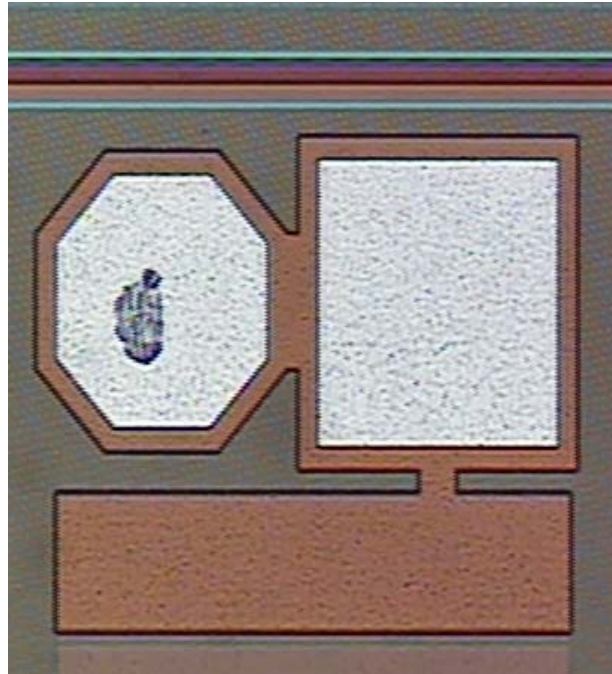
Qualification Flow - Sample Qualification

Step	Screen	Required	Reject Criteria	Sample Size
12	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	45 pcs
13	Static Burn-in (LT)	MIL-STD-883, Method 1015, 96 hours at +125C		100%
14	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
15	Dynamic Burn-in (LT)	MIL-STD-883, Method 1015, 240 hours at +125C		100%
16	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
17	Life Test (Dynamic, LT)	MIL-STD-883, Method 1005, 1000 hour at 125C.	Any part failing to meet data sheet parametric at the temperatures specified.	45 pcs
18	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
19	PDA and FA			
20	Burn-in Condition Determination	Qualification will determine if low temperature burn-in is needed		

Qualification Flow – Flight Parts Screen

Step	Screen	Required	Reject Criteria	Sample Size
21	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%
22	Burn-in	Specifications depends on qualification results		100%
23	Electrical	Test to datasheet @ +125C, +25C, -55C	Any part failing to meet data sheet parametric at the temperatures specified.	100%

Known Good Die (KGD) Approach



- Double bond pads on the device die. One pad is used for temporary packaging for burn-in purpose and the other for actual application wire bonding.

Summary

- Challenges for extreme environments qualification
 - Mil-Std cannot support the extreme conditions
 - Different failure mechanisms at extreme conditions
 - Conventional derating does not work
- Qualification for extreme environments
 - Understanding failure mechanisms
 - Reliability model with statistical nature
 - Design for reliability guidelines
 - Design for reliability for cryogenic applications and high temperature applications

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