RAD-HARD NAND Storage For Aerospace and Outer Space Data (AOSD)

Erik A. Nilsen, PhD

Chief Technology Strategist

Flexxon

Storage Requirements in Aerospace Applications

Systems for space exploration

- Rovers
- Telescopes
- Satellites

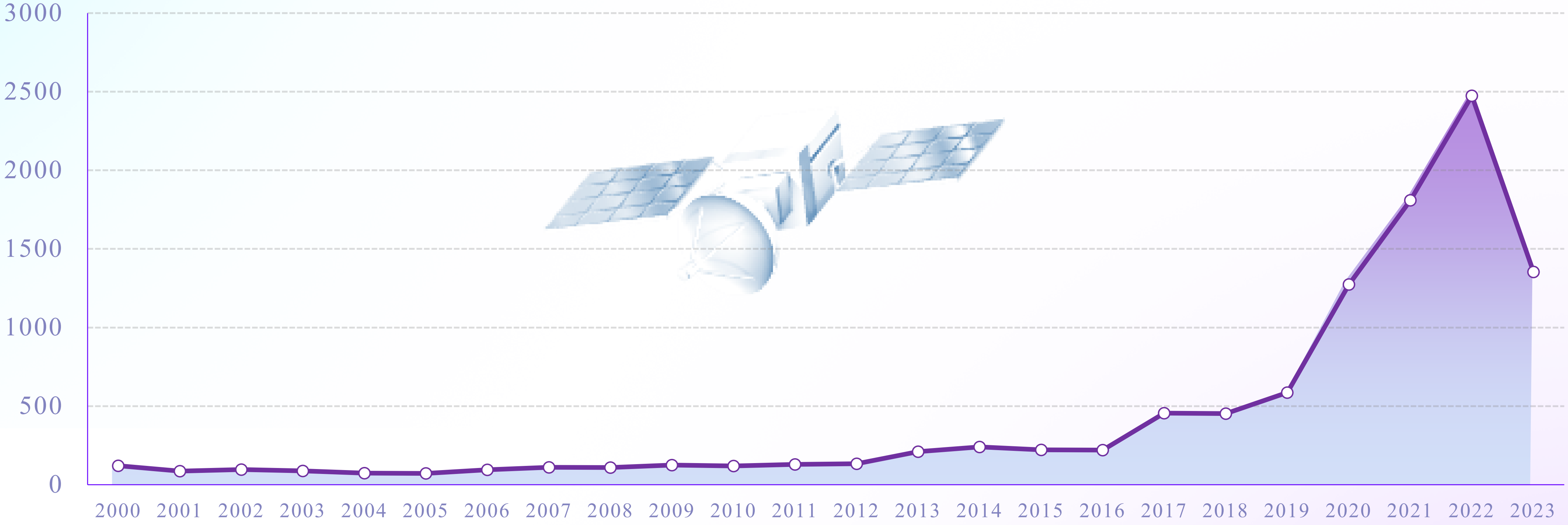
Systems for everyday life

- Weather sensors
- Cell communications
- Commodity GPS
- Defense & intelligence

Space-based terrestrial communications

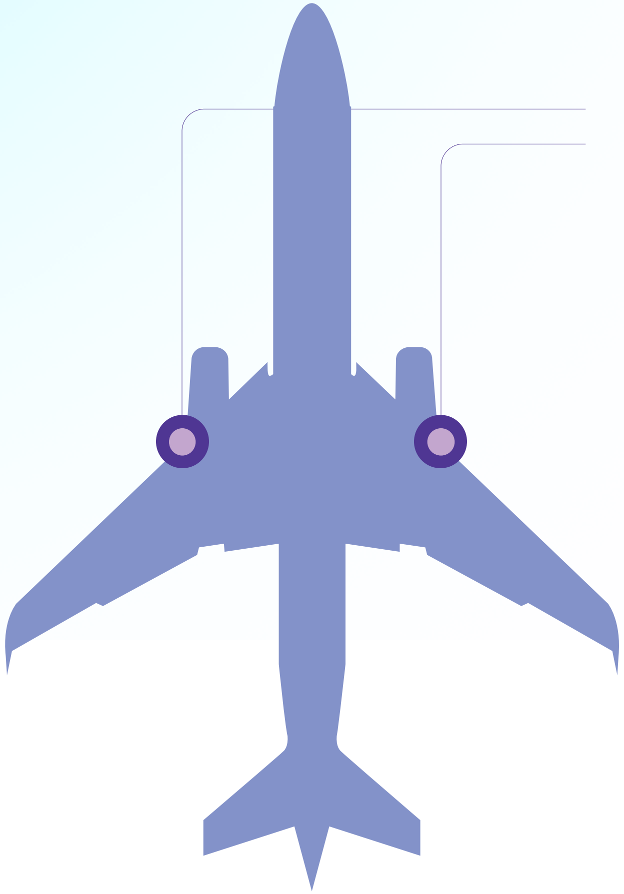
- IOT
- 5G

Number of Satellites Launched Per Year



Data source: Union of Concerned Scientist

Big Data Takes Center Stage



20 TB x 2 x 6 x 28,537 x 365

20 TB	x 2	x 6	x 28,537	x 365
20 terabytes of information per engine every hour	twin-engine Boeing 737	six-hour cross-country flight from New York to LA	# of commercial flights in the sky in the US on any given day.	days in a year

= 2,499,841,200 TB

Sensors data from a cross-country flight

Data source: Big Data in the Aerospace Industry

NAND Storage Radiation Test for Space Application

To ensure the storage devices can withstand the radiation environment of space without experiencing critical failures, there are some key radiation specifications and metrics to consider

Total Ionizing Dose (TID)

- ✓ Measure the cumulative ionizing radiation dose absorbed by a device
- ✓ measure in Gy (Grays) or rads (radiation absorbed doses)
- ✓ ASTM E1249, ESA/SCC Basic Specification No. ESCC 22900

Single Event Effects (SEE)

- ✓ Effects of a singe ionizing particle hitting a device and causing a transient or permanent change.
- ✓ MIL-STD-883 Method 1019.7, ESA/SCC Basic Specification No. ESCC 23600

Neutron Radiation

- ✓ Significant concern in space environments, especially in deep space mission.
- ✓ Can cause displacement damage.
- ✓ MIL-STD-883 Method 1017.2, ESA/SCC Basic Specification No. ESCC 25100

Total Non-Ionizing Dose (TNID)

- ✓ Refer to the cumulative of non-ionizing radiation dose.
- ✓ ESA/SCC Basic Specification No. ESCC 22910

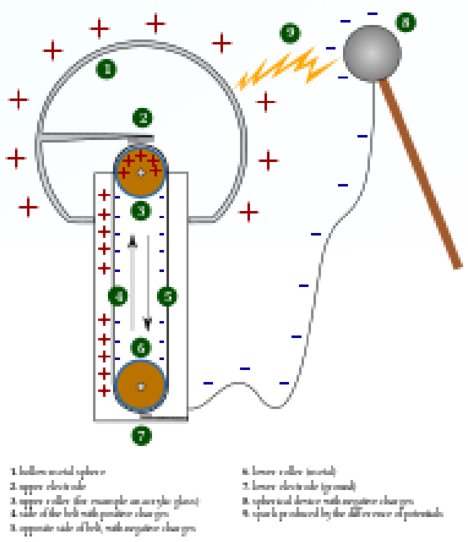
Temperature and Vacuum

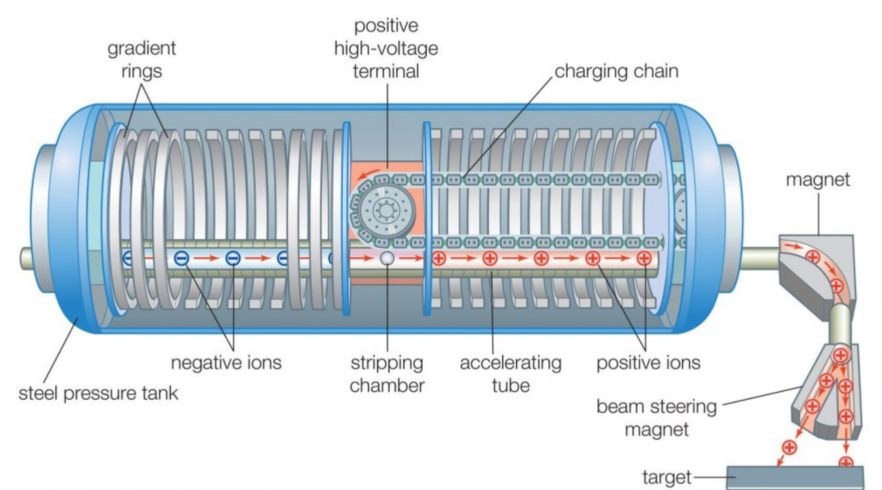
- ✓ MIL-STD-883 Method 1008
- ✓ ASTM E595

Heavy Ion and Proton Radiation Test

	Heavy Ion Radiation Test	Proton Radiation Test
Standard	JESD57A, ASTM F1192, Sandia Nat'l Lab. SAND2008-6983P	JEDEC JESD234 Sandia Nat'l Lab. SAND2008-6983P
Equipment	Van de Graaff Cyclotron	Proton accelerator 40~500 MeV

Van de Graaff Generator

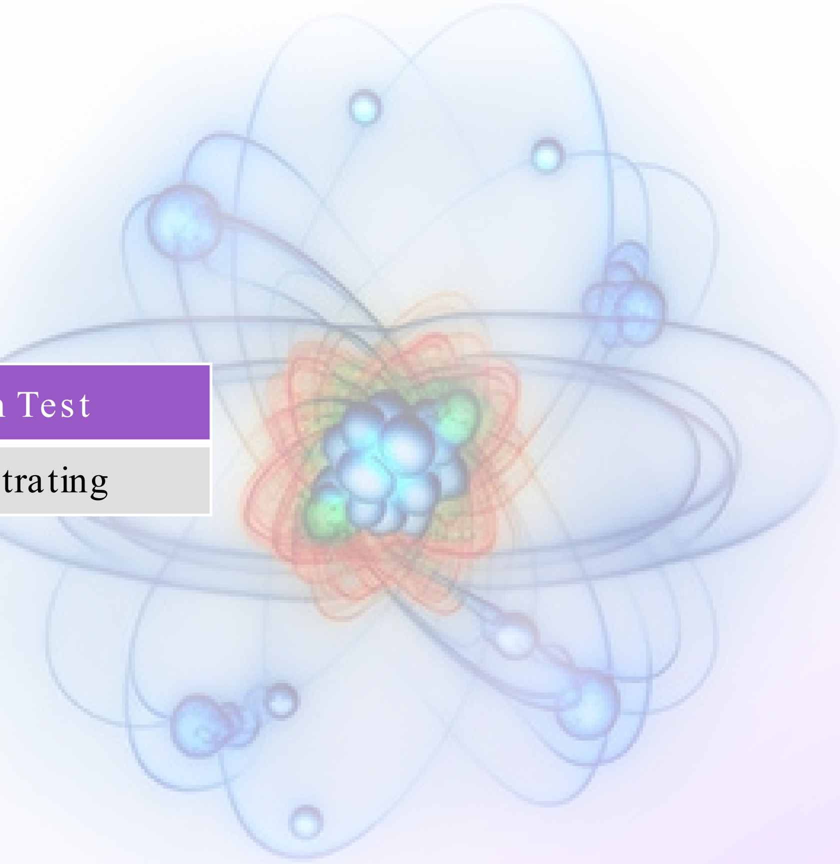




Heavy Ion and Proton Radiation Test - Preparation

- To successfully test a part,
  the beam must reach the sensitive region

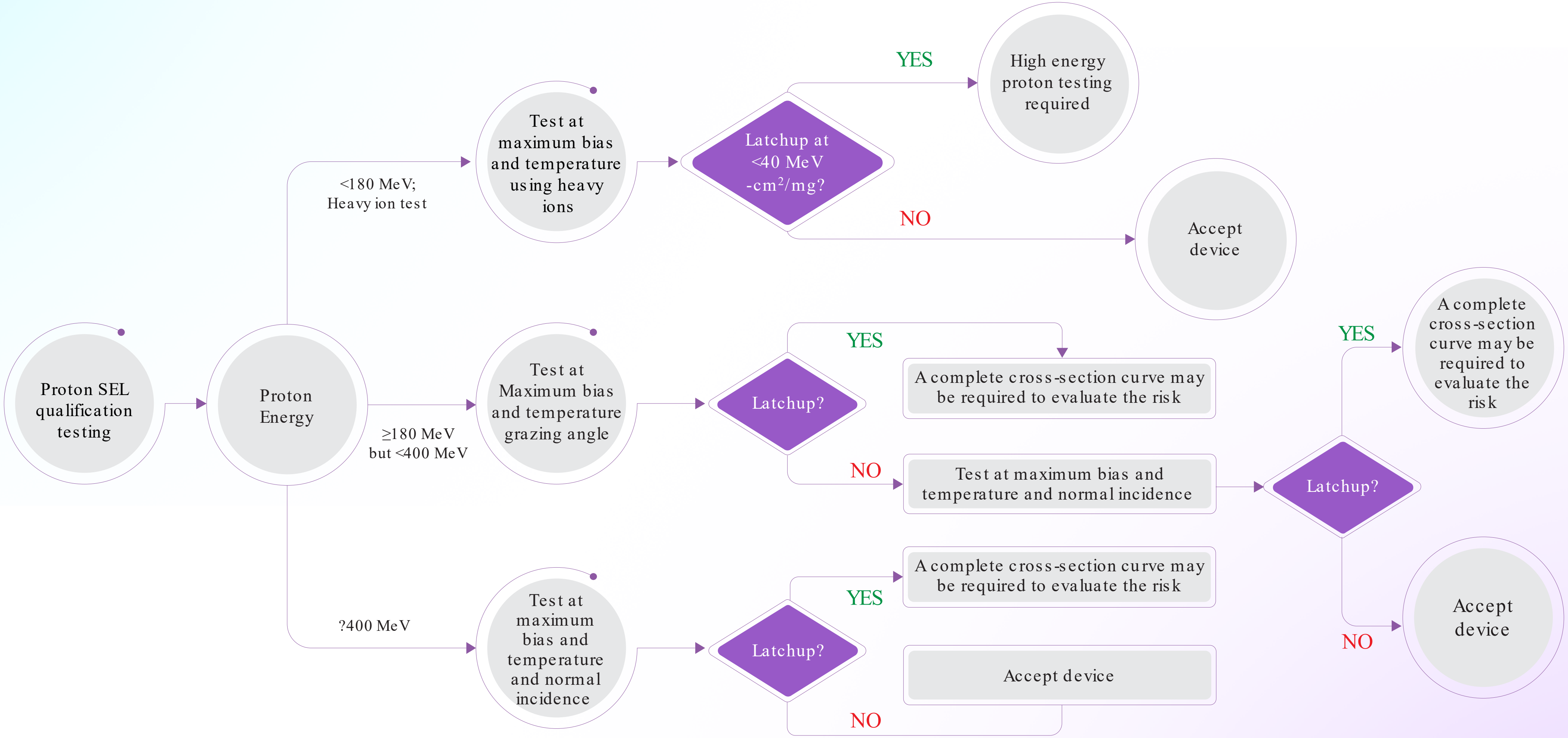
Heavy Ion Radiation Test	Proton Radiation Test
Ranges typically 10s to 100s of microns	> 10 MeV are very penetrating



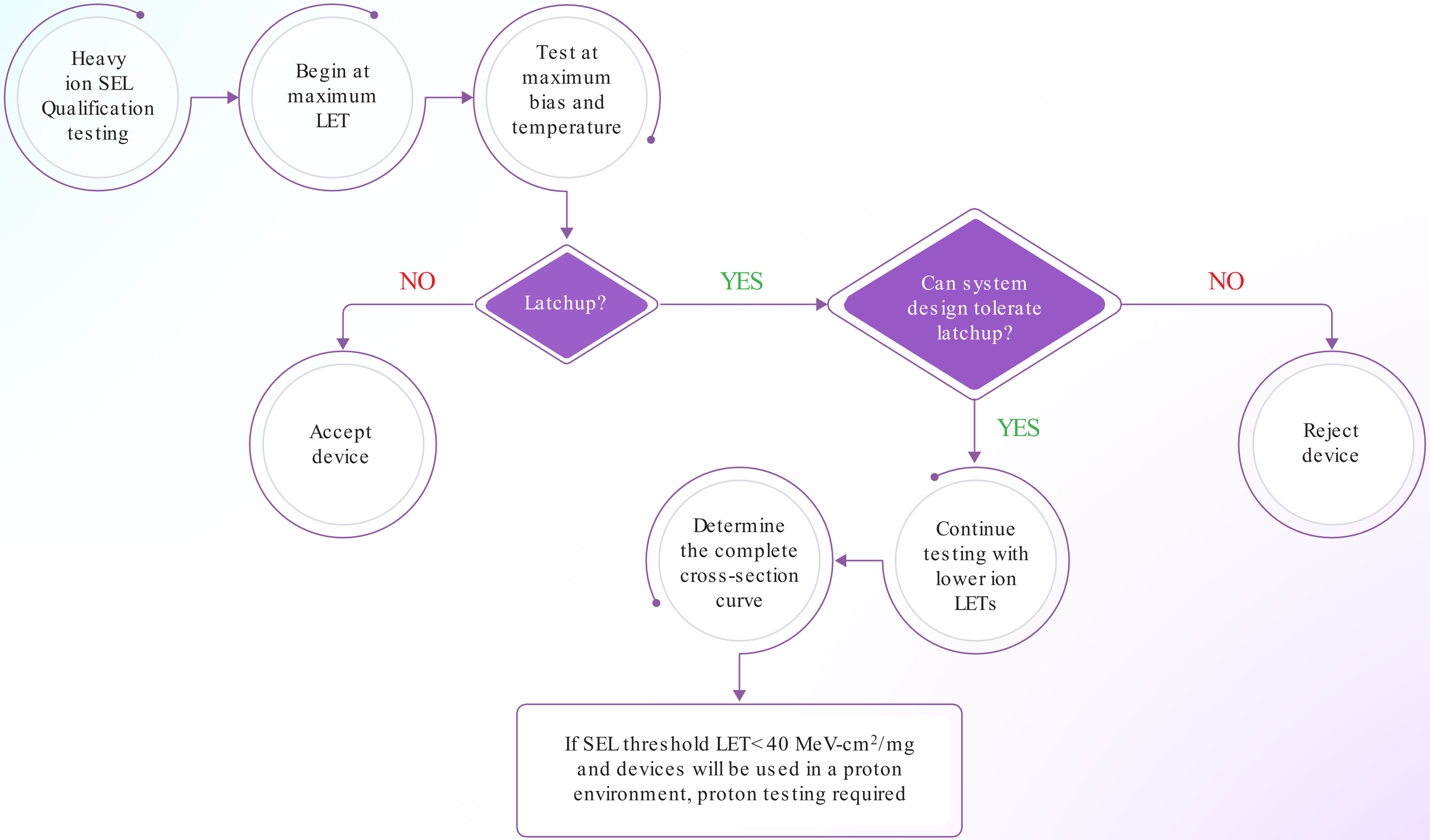
Heavy Ion and Proton Radiation Test - Setup

Heavy Ion Radiation Test	Proton Radiation Test
Vacuum Air	Vacuum
Nearby equipment less concern	Nearby equipment needs shielding
Cable lengths – 20m-100m	Cable lengths – 20m-100m
Sample size = 4	Sample size = 5

Proton Radiation Test – Qualification chart



Heavy Ion Radiation Test – Qualification chart



NAND Flash and Other Storage Technologies in Aerospace

Technology	Type	Pros	Cons
NAND Flash	Non-volatile memory	- High data density - Fast read speeds - Low power consumption - Cost-effective per gigabyte	- Limited write endurance - Data retention issues under extreme conditions
Solid State Drives (SSDs) (using NAND Flash)	Non-volatile memory (NAND flash-based)	- Fast read/write speeds - More durable (no moving parts) - Lower latency	- Higher cost per gigabyte than HDDs - Limited by NAND flash endurance
DRAM	Volatile memory	- Extremely fast read/write speeds - High endurance	- Volatile (data lost without power) - Higher cost per gigabyte - Higher power consumption
MRAM (Magnetoresistive RAM)	Non-volatile memory	- High speed - High endurance - Low power consumption - Non-volatile (retains data without power)	- Higher cost per gigabyte - Lower density compared to NAND flash
FRAM (Ferroelectric RAM)	Non-volatile memory	- Fast read/write speeds - High endurance - Low power consumption - Non-volatile (retains data without power)	- Higher cost per gigabyte - Lower density compared to NAND flash - More complex manufacturing process

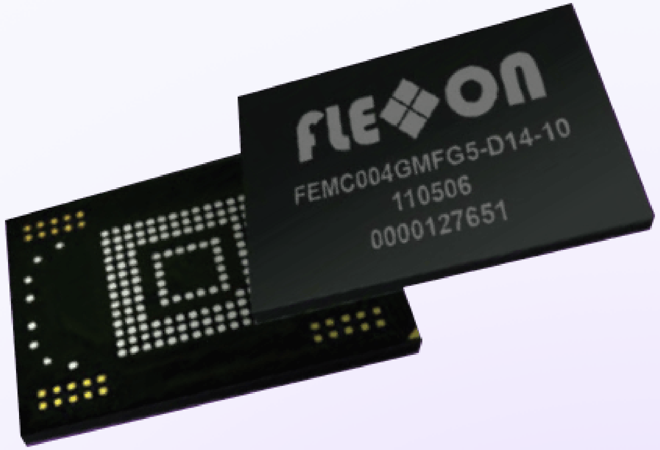
Flexxon Rad-Hard Memory

HIX Series

Certification

CE & FCC Certified

eMMC (XTRA VII Series)



COTS vs RAD-HARD NAND Storage

Feature	COTS NAND Flash Storage	Rad-Hard NAND Flash Storage
Purpose	General use, consumer and enterprise applications	Space and high-radiation environments
Radiation Resistance	Not designed to withstand radiation; may suffer data corruption or loss	Specifically designed to resist radiation effects (e.g., single-event upsets, total ionizing dose)
Cost	Typically lower cost per gigabyte	Higher cost due to specialized design and testing
Performance	High performance suitable for general applications	May have slightly lower performance due to additional error-correcting codes and radiation-tolerant designs
Endurance	Standard endurance, typically 3,000 to 100,000 P/E cycles depending on type (SLC, MLC, TLC)	Enhanced endurance; often includes wear leveling and error correction to extend lifespan in harsh environments
Data Retention	Generally good, but can degrade under extreme temperatures and conditions	Improved data retention in extreme environments; designed to maintain data integrity longer in space conditions
Environmental Suitability	Suitable for standard temperature and humidity ranges	Designed to operate reliably under extreme temperatures, radiation, and other harsh space conditions
Form Factor	Various consumer and industrial form factors	Often custom or specific form factors tailored to aerospace needs
Error Correction	Basic error correction depending on the consumer grade	Advanced error correction, including ECC (Error Correction Code) tailored for space environments
Availability	Widely available from various commercial suppliers	Limited availability; often sourced from specialized vendors or customized for specific missions
Certification	Generally not certified for space or high-radiation environments	Certified for aerospace and radiation-hardened applications

Summary

COTS NAND Flash Storage

✅ General commercial use

✅ Good performance

✅ Cost-effectiveness

❌ Lacks radiation resistance

❌ Not suitable for harsh space environments

Rad-Hard NAND Flash Storage

✅ Engineered to withstand radiation and extreme conditions

✅ Enhanced data integrity and durability at a higher cost

✅ Additional Features

- Advanced error correction
- Improved endurance

Future Plans

- Generational scaling in 3D layer count and feature size will continue
    - Test piece parts when able, but SSD-type testing possible as well
- Evaluate combined effects, particularly as TLC/QLC cells continue to erode margins and increase RBER
    - TID/SEE/Endurance/Retention all tightly coupled

Questions?

THANK YOU

Erik A. Nilsen, PhD
Chief Technology Strategist

Contact Us

SINGAPORE
28 Genting Lane, #09-03/4/5 Platinum 28,
Singapore 349585
Tel: +65-6493 5035

UNITED STATES
Eberle Building, Suite 300, 107S B St, San Mateo, CA 94401, United States

Tel: +1 667 786 9752

www.flexxon.com

flexxon@flexxon.com

Thermal Management in rad-hard NAND Storage

Passive Cooling

Thermal management is critical for the longevity and performance of NAND storage, especially in high-radiation environments such as space missions. Here's how different thermal management strategies can impact NAND flash storage.

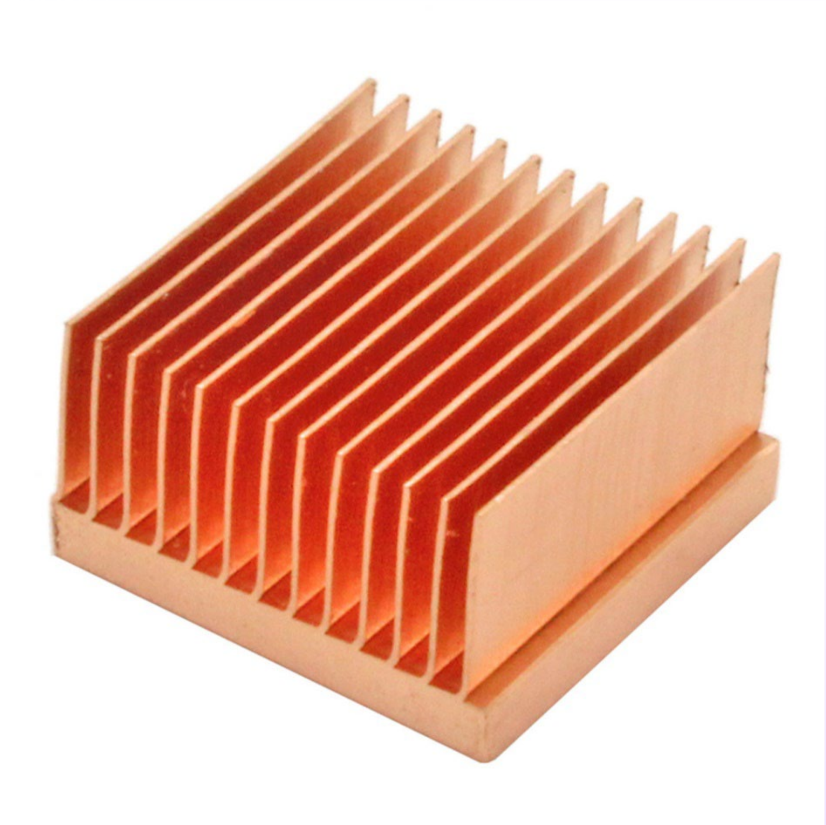
Description

Utilizes heat sinks, thermal pads, and thermal vias to dissipate heat without mechanical or electrical components.

Effects

Longevity
Helps maintain a stable operating temperature, reducing thermal stress and prolonging NAND flash life. Excessive heat can accelerate wear-out mechanisms in NAND cells, so managing heat helps extend lifespan.

Performance
Effective in preventing thermal throttling, where the performance of the NAND flash might degrade if it overheats. Proper passive cooling maintains performance by keeping temperatures within optimal ranges.

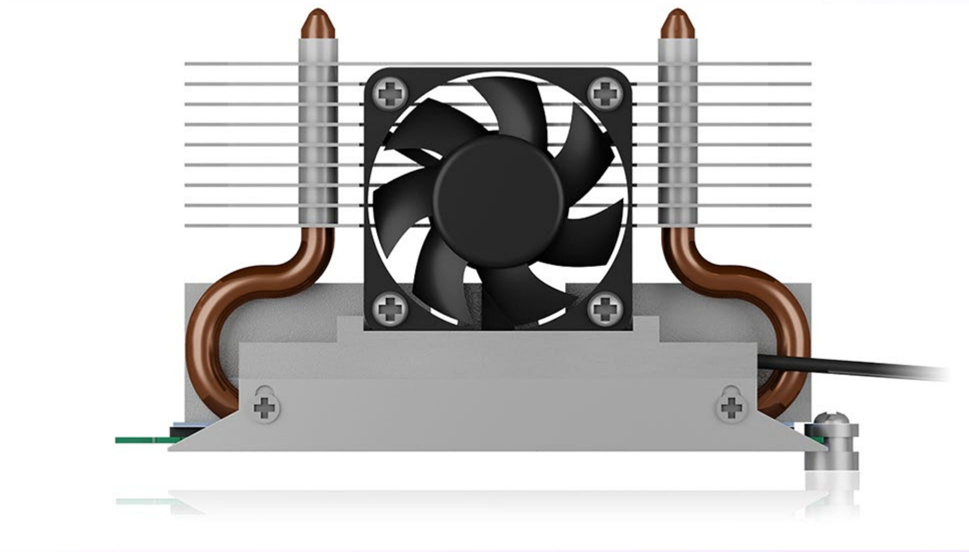


Thermal Management in rad-hard NAND Storage

Active Cooling

Description

Involves the use of fans, liquid cooling systems, or other mechanical means to activ
control and reduce the temperature of the NAND flash storage.



Effects

Longevity

Active cooling systems can more precisely control the temperature, which can be beneficial in high-radiation environments where temperatures can fluctuate. This controlled environment minimizes the thermal stress on NAND cells and reduces the risk of accelerated degradation.

Performance

Ensures that NAND flash operates at peak performance by preventing overheating, which can cause slowdowns or throttling. Active cooling can be particularly useful in environments with high thermal loads or where passive solutions are insufficient.

Thermal Management in rad-hard NAND Storage

Thermal Insulation

Description

Utilizes insulating materials or coatings to minimize heat transfer between the NAND storage and its environment.

Effects

Longevity

Protects NAND flash from extreme temperature variations and helps in maintaining a stable internal temperature. Reduces the risk of thermal stress and damage due to rapid temperature changes, which can improve reliability and lifespan.

Performance

Helps maintain consistent performance by preventing both overheating and excessive cooling. By insulating against external temperature changes, the NAND flash can operate more reliably within its designed thermal range.

Thermal Management in rad-hard NAND Storage

Thermal Redistribution

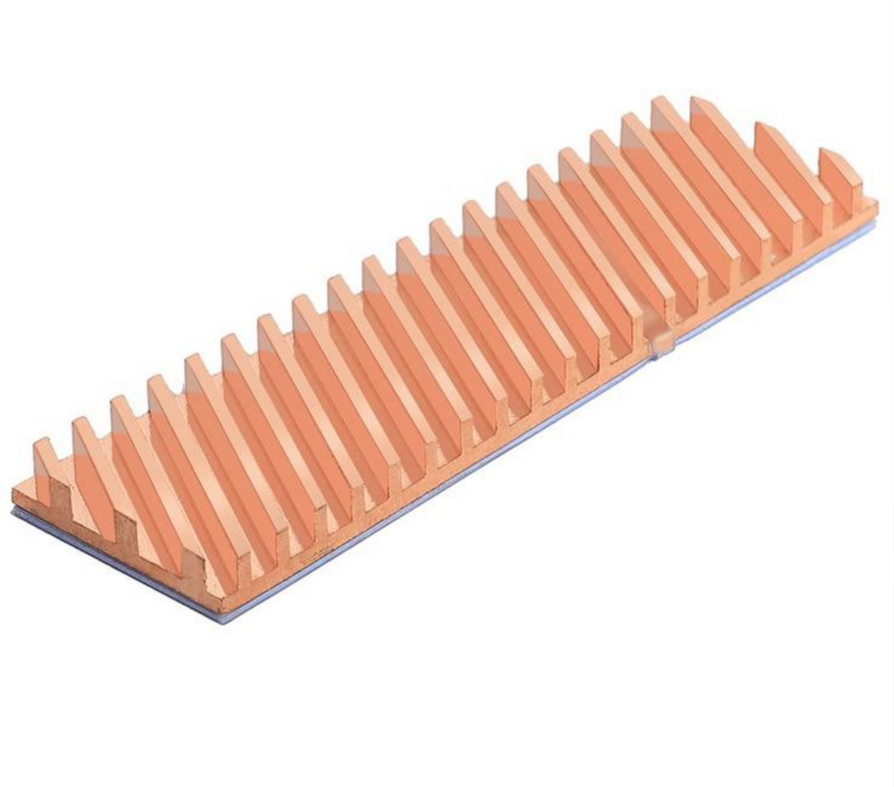
Description

Uses thermal spreaders or conductive materials to evenly distribute heat away from hot spots.

Effects

Longevity
Reduces localized overheating that can lead to faster wear-out of NAND cells. Even heat distribution minimizes the risk of hot spots that can accelerate degradation, thereby enhancing longevity.

Performance
Promotes uniform performance across the NAND flash storage by preventing thermal bottlenecks. Even heat distribution helps ensure that all components operate efficiently without being affected by hot spots.



Temperature Monitoring and Control

Description

Involves using sensors to monitor temperatures and adjust cooling systems or other mechanisms to maintain optimal thermal conditions.

Effects

Longevity

Enables precise management of temperature to avoid conditions that could lead to accelerated wear or failure. Dynamic adjustments based on real-time temperature data help in maintaining optimal conditions for NAND cells.

Performance

Allows for real-time adjustments to prevent performance degradation due to temperature fluctuations. By responding to temperature changes dynamically, performance remains stable and reliable.

Rad-Hard NAND: Smaller Node Challenges

1. Effect of Radiation

Smaller Feature Sizes

As semiconductor feature sizes decrease (e.g., from 65nm to 7nm), the components of integrated circuits become more vulnerable to radiation effects such as single-event upsets (SEUs), single-event latch-ups (SELs), and total ionizing dose (TID) effects.

Increased Sensitivity

Smaller transistors have reduced physical dimensions, leading to higher sensitivity to radiation-induced charge accumulation and other effects that can disrupt normal operation.

Rad-Hard NAND: Smaller Node Challenges

2. Engineering Approaches to Maintain Reliability

Radiation-Hardened Design
Implementing design techniques that make devices more resilient to radiation. This includes using hardened cells, redundant circuitry, and specialized layouts to mitigate the effects of radiation.

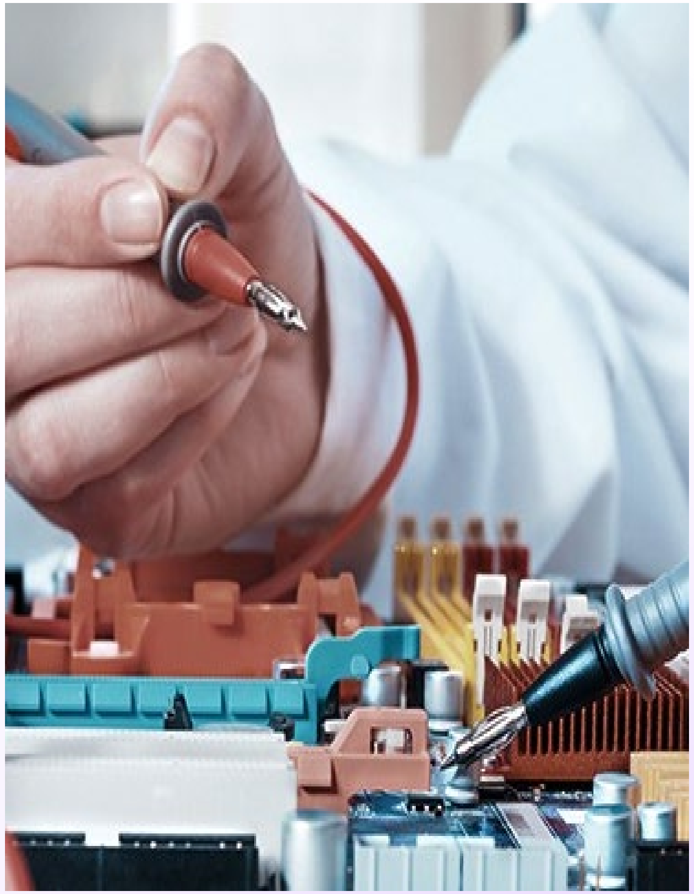
Error Correction Codes (ECC)
Employing ECC to detect and correct errors caused by radiation-induced faults. ECC techniques include SEC-DED (Single Error Correction - Double Error Detection) and more advanced codes tailored for specific applications.

Shielding
Adding physical shielding around the semiconductor components to reduce the impact of radiation. This can involve materials or designs that absorb or deflect radiation before it reaches the sensitive parts of the circuit.

Redundancy
Incorporating redundant components and systems that can take over in case of radiation-induced failures. This includes redundant processing units, memory arrays, and data paths.

De-rating
Designing components to operate below their maximum capacity to increase their tolerance to radiation effects. This often involves derating voltage and current levels to ensure reliable operation under radiation exposure.

Specialized Materials
Using radiation-tolerant materials and processes, such as silicon-on-insulator (SOI) technologies or high-k dielectrics, which can better withstand radiation-induced damage.



Rad-Hard NAND: Smaller Node Challenges

Summary

Smaller Feature Sizes increase vulnerability to radiation effects due to the reduced physical size of components, which makes them more susceptible to radiation-induced disruptions.

Engineering Approaches to maintain reliability at smaller feature sizes include radiation-hardened designs, error correction codes, physical shielding, redundancy, de-rating, and the use of specialized materials. These methods are essential to ensure the continued functionality and reliability of electronic components in high-radiation environments.

Flexxon SSD CE Certified

HIX Series

EN 55032 / CISPR 32

- Emission Test
- Measures radiated and conducted emissions

EN 55024 / CISPR 24

- Measures device's susceptibility to electromagnetic disturbances and interference from external sources.

AS/NZS CISPR 32 Class B

- Similar to the CISPR 32 test
- Specific to Australia and New Zealand markets

IMMUNITY EN 61000-3-2

- Immunity test against voltage fluctuations and flicker caused by external sources.

EN 61000-3-3

- Immunity test against voltage dips, short interruptions, and voltage variations.

Flexxon SSD FCC Certified

HIX Series

FCC CFR Title 47 Part 15 Subpart B: Section 15.107 & 15.109

- Ensures that devices do not emit excessive electromagnetic radiation

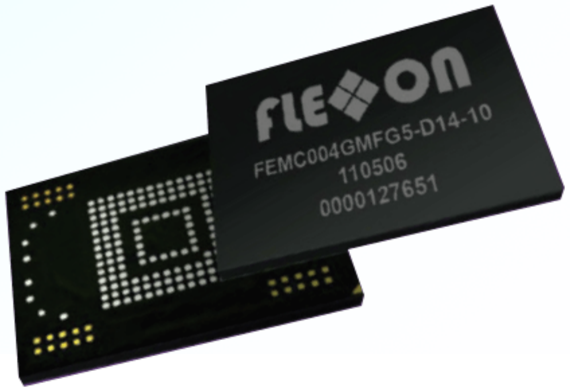
ANSI C63.4-2014

- Measures EMI (include radiated and conducted emissions)

ICES-003 Issue 6: 2016 Class B

- Canadian standard EMC tests

Flexxon eMMC (XTRA VII Series)



Automotive Grade
Up to AEC Q100 Grade 2 (-40C-105C)

Certification
CE, FCC Certified

Radiation Test
Passed the 1 Gy X-ray test

Mainstream Capacity
3D TLC: 32GB~128GB
3D pSLC: 8GB~32GB

Applications

Military & Avionics

Drone

Networking system

SEFI cross section vs. LET