NAND Storage in Space – Market Trend and Challenges

ATP Electronics, Inc.

Strategic Business Planning, Segment Market Enablement

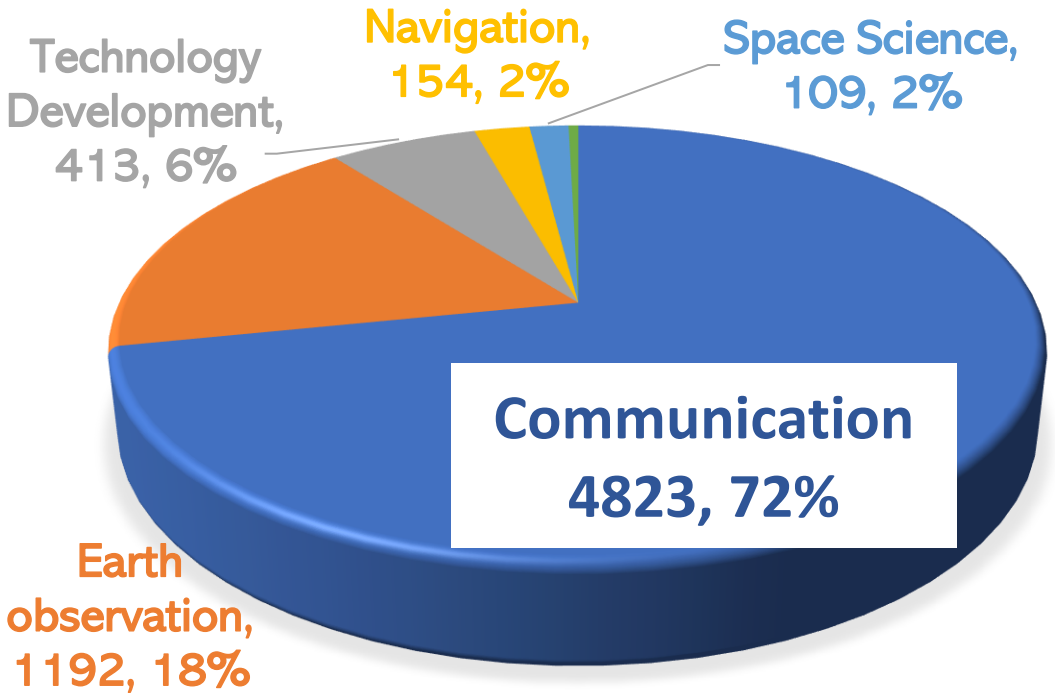
Presenter: Crystal Chang

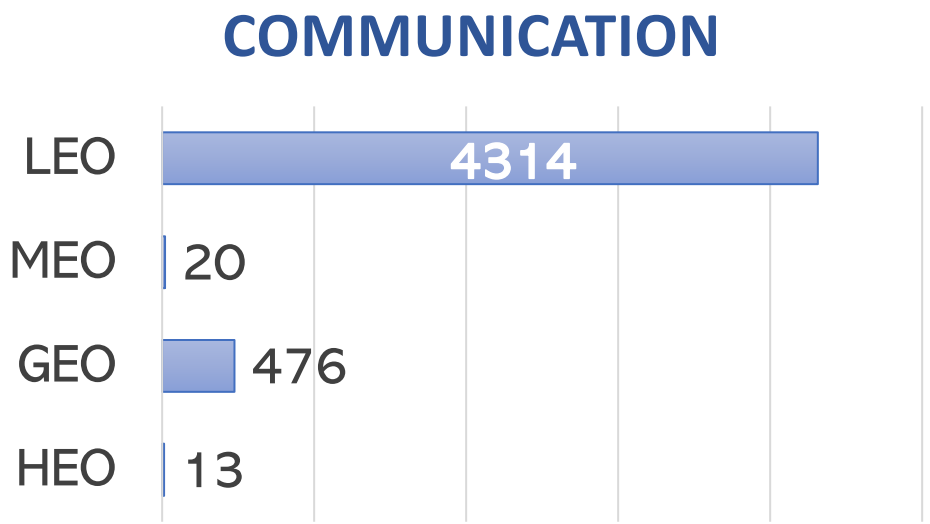
Agenda

- Satellite Quick Facts
  - Megatrend
  - Comparison of Satellite Types
  - Commercialized LEO Satellite Industry
- Challenges
- Space Irradiation Test
- TID test report examples
- Radiation Tolerance Components
- Space Industry Needs...

Satellite Quick Facts

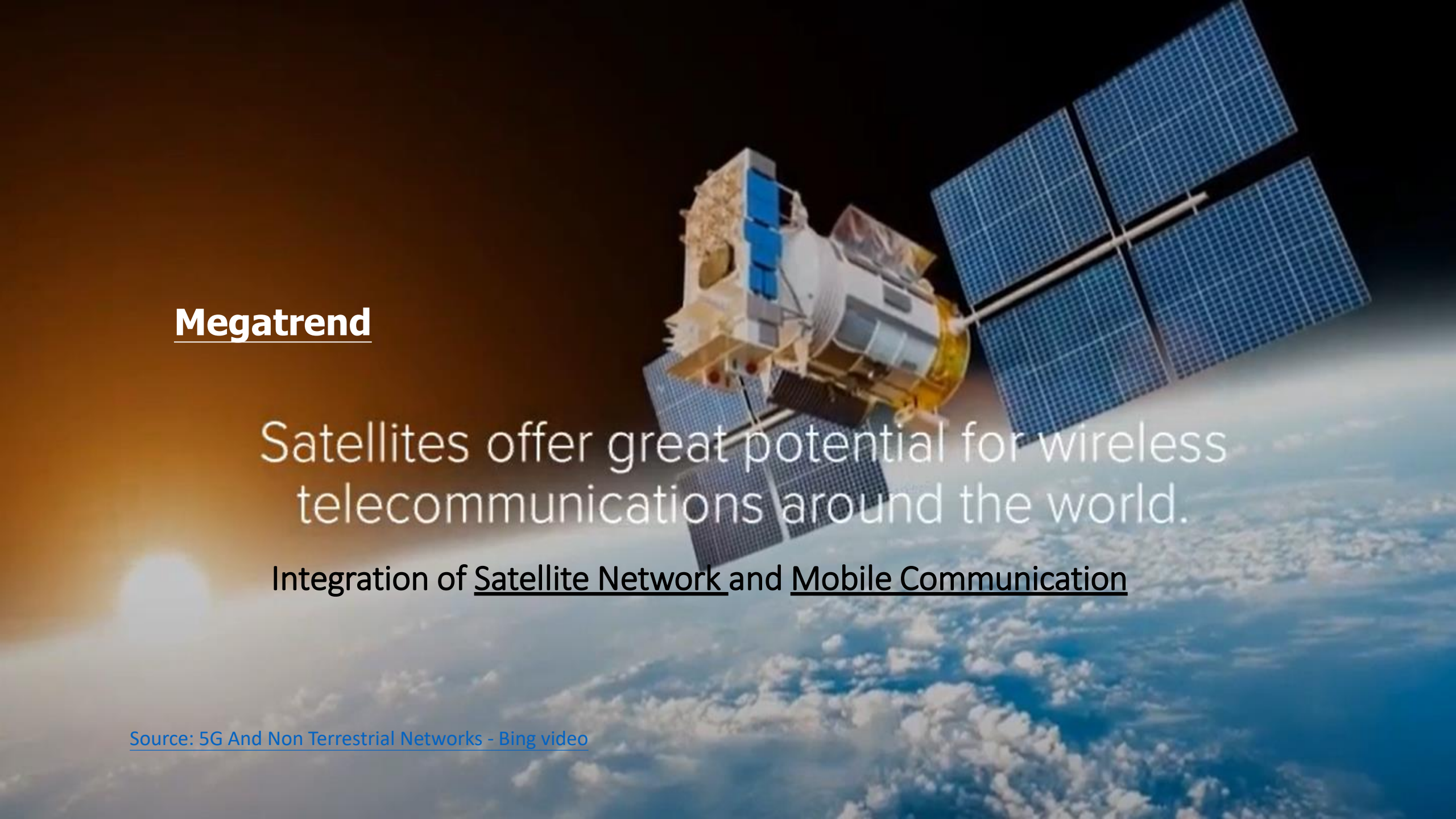
- Total number of operating satellites: 6,718





Data source: UCS Satellite Database, as of 2022/12/31

Megatrend



Integration of Satellite Network and Mobile Communication

Source: 5G And Non Terrestrial Networks - Bing video

Operating Satellites by Type

Comparison Table - Satellite Types

- LEO: Low-Earth Orbit (160-2000km)
- MEO: Medium-Earth Orbit (Above 2000 km)
- GEO: Geostationary Orbit (at 35,786 km)
- HEO: High Elliptical Orbit (Above 36,000 km)

Satellite Type	LEO	MEO	GEO
Altitude	160-2000 km	Above 2000 km	At 35,786 km
Latency (ms)	30~50	125~250	600~800
Network size global service	Thousands of satellites (100% coverage)	6 satellites (96% coverage)	3 satellites (99% coverage)
Orbital period	1.5-2hrs	12hours	24hours
Satellite lifecycle	4-6 years	12 years	15 years

Commercialized LEO Satellite Industry

Flash Memory Summit

Closer to the ground	Low Latency Trend for Data Processing / Communication
Network global service size	Thousands of satellites are needed for full earth coverage. More satellites, more businesses.
4~6 Years Satellites Life Cycle	Continuous demand for replacement/replenish Not requiring Radiation Hardness Assurance parts
New Technology to Reduce Cost	Lower satellite launch cost (e.g. reusable rocket) Lower hardware cost (Dish & Router)

Challenges

- Standards for Space Industry
- Irradiation Test for NAND Flash Devices

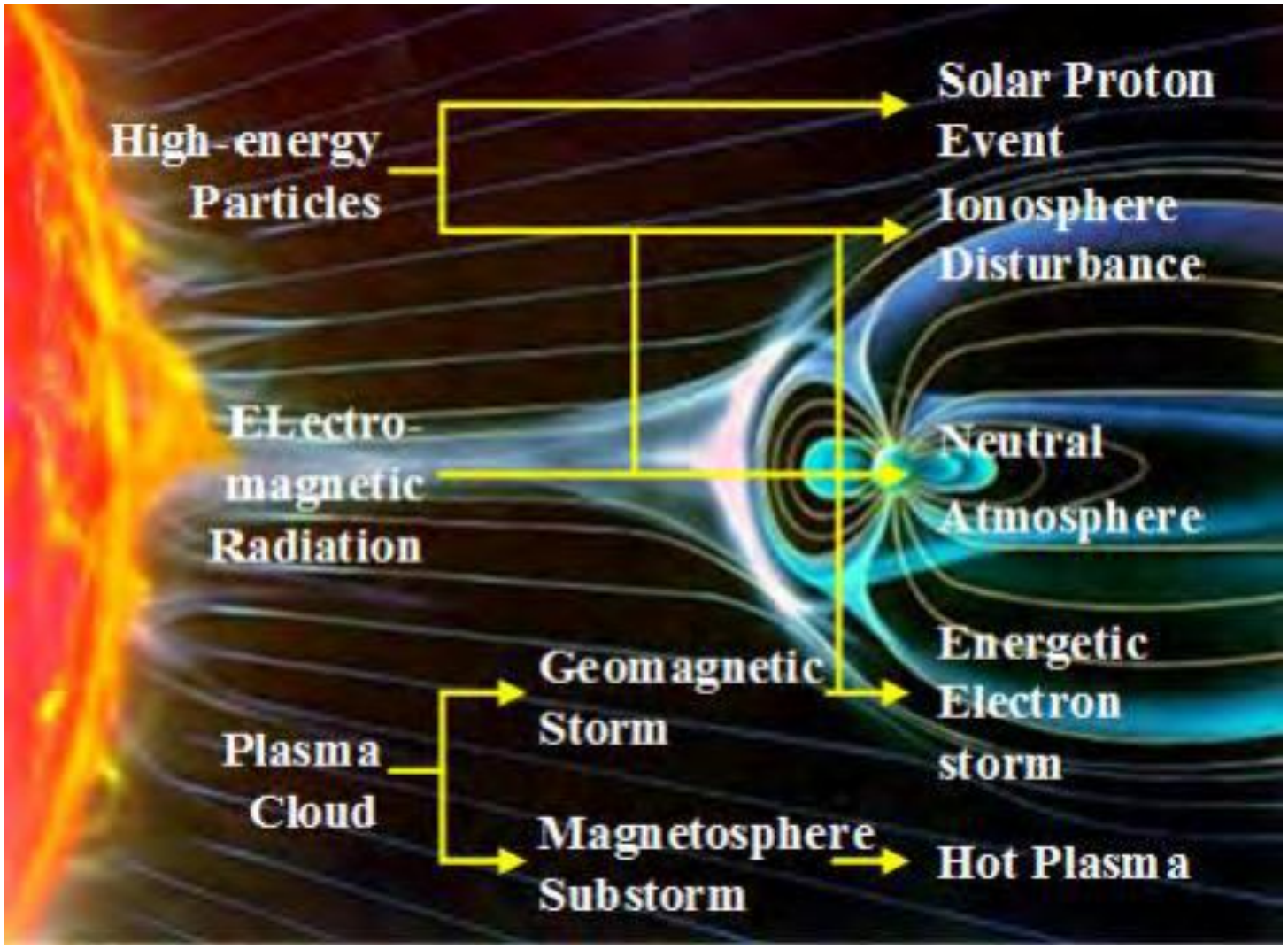


Photo Source: A Review of the Space Environment Effects on Spacecraft in Different Orbits - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Schematic-diagram-of-the-effect-of-solar-storms-on-the-near-earth-space-environment_fig4_334387721

Challenges

No Standardized Testing Requirements in Space Industry

- Unlike automotive industry with AEC-Q standards, the tests in space industry are mission specific and self-defined by customers.
- NASA GSFC (Goddard Space Flight Center) standards
- ESA ESCC (European Space Components Coordination) standards
- Methods:
  JESD57A Heavy Ions, JESD234 Protons, MIL-HDBK-340A, MIL-STD-883/Method 1019.4, MIL-STD-883/test method 1019.8

Detailed test conditions are Not Disclosed in most cases

- Only limited information is shared, probably just the test result (pass or fail)
- No test environment, conditions or criteria for suppliers' reference and improvement

Testing is costly and has low availability

- Expensive and time-consuming
- DUT is discarded after one-time test.
- Lab facility is limited in capability and availability.

Space Irradiation Tests

Flash Memory Summit

Proton TID (Total Ionizing Dose) irradiation test

- **Cumulative (dose) effects** result from **long-term exposure** to radiation environment, mostly due to electrons and protons.
- Typical Unit: Gray (Si) Krad.

SEE (Single Event Effects) irradiation test

- SEE caused by **single Ionizing particle strike**/interaction
- Use **protons** or **heavy Ions** to simulate radiation environment
- Proton SEE irradiation test
- Heavy Ion SEE irradiation test
- Typical Unit: LET (linear energy transfer) MeV (mg/cm^2)

Types of Irradiation Test and Failures: TID

Flash Memory Summit

Total Ionizing Dose (TID) Test

Effects	**Performance degradation or failure in electronics lifespan** e.g. threshold shifts, leakage current, timing changes, startup transient current, functional failures
Goal	**Characterize parameter variations over total dose** and to **determine the threshold** where component performance no longer meets mission requirements.
Factors	Mission orbit (Satellite altitude), mission duration (lifecycle), Criticality of the device **Shielding thickness** (low energy protons, electrons)
Note	**Post-irradiation functional test is required.**
Example	Total Ionizing Dosage for 1 year LEO mission life, 100% margin TID: 10Krad, 2mm aluminum shielding

Types of Irradiation Test and Failures: SEE

Single Event Effect (SEE)

Non-Destructive

Potential Destructive

Destructive

Single Event Upset (SEU)

- Soft error
- Bit errors and data/control sequence corruption

Single Event Functional Interrupt (SEFI)

- Soft error
- Component to reset, lock-up
- Or Detectable malfunction
- Not require power cycling of the device (off and back on) to restore operability

Single Event Latch-up (SEL)

- Hard error
- Results in a high operating current
- Must be cleared by a power reset.

Single Event Burnout (SEB)

- Hardware defect
- Irreversible

EDAC required (Error detection and Correction)

Detecting and Managing Soft Errors by Controller

Total Dose Test Report: Micron 32Gbit SLC NAND (1)

Flash Memory Summit

Table I
Device details and test information.

Full Part Number:	MT29F32G08ABAAAWP
Case Markings:	1106 29F32G08ABAAA
Manufacturer:	Micron
Lot Date Code (LDC):	TBD
Part Function:	NAND Flash Memory
Part Technology:	34 nm CMOS (memory array)
Quantity Tested:	10
Serial Numbers of Control Sample:	11
Serial Numbers of Radiation Samples:	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Package Style:	48 pin TSOP
Test Equipment:	Power Supply (+3.3V), Multimeter, Triad Spectrum TC1200ICMCP memory
Dose Levels (krad (Si)):	10, 20, 50, 70, and 100 krads(Si)
Dose rate (rad (Si)/s):	30 and 0.57 (1 step)

M73A
25nm
SLC

Dose Levels (krad, Si)
10/20/50/70/100 krads (Si)

MIL-STD-883G Test Method 1019.8

Table III.
The number of blocks with at least 1 (but less than 10) bad bit in 4096 total blocks. Functional failure is defined as block erase failure, and is denoted as "F" in the table.

	Cycled between exposures					Read-only between exposures					Control
TID (krad(Si))	DUT1	DUT2	DUT3	DUT4	DUT5	DUT6	DUT7	DUT8	DUT9	DUT10	DUT11
0	4	4	12	10	2	4	2	2	6	10	4
10	8	7	20	13	2	6	10	6	6	13	8
20	5	9	16	2	10	19	65	7	22	34	6
50	1886	2647	510	F	4092	4092	F	629	3064	F	10
70	F	3251	264		F	F		593	F		6
100		F	F					F			8
168 hr anneal	F	F	F	F	F	F	F	F	F	F	8

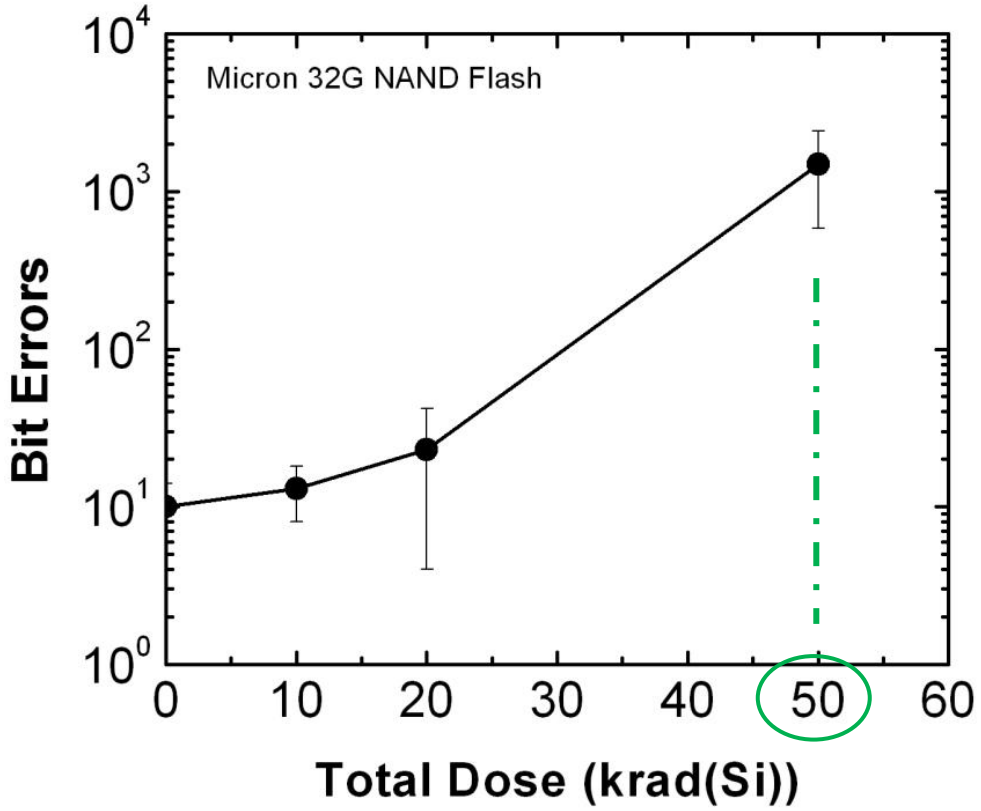
F = Functional failure = Erase failure
Total Dose: 50Krad (Si)

Source: NASA GSFC Radiation Data Base
Total Dose Test Report for the Micron 32Gbit NAND Flash Nonvolatile Memory, DakaiChen, code 561

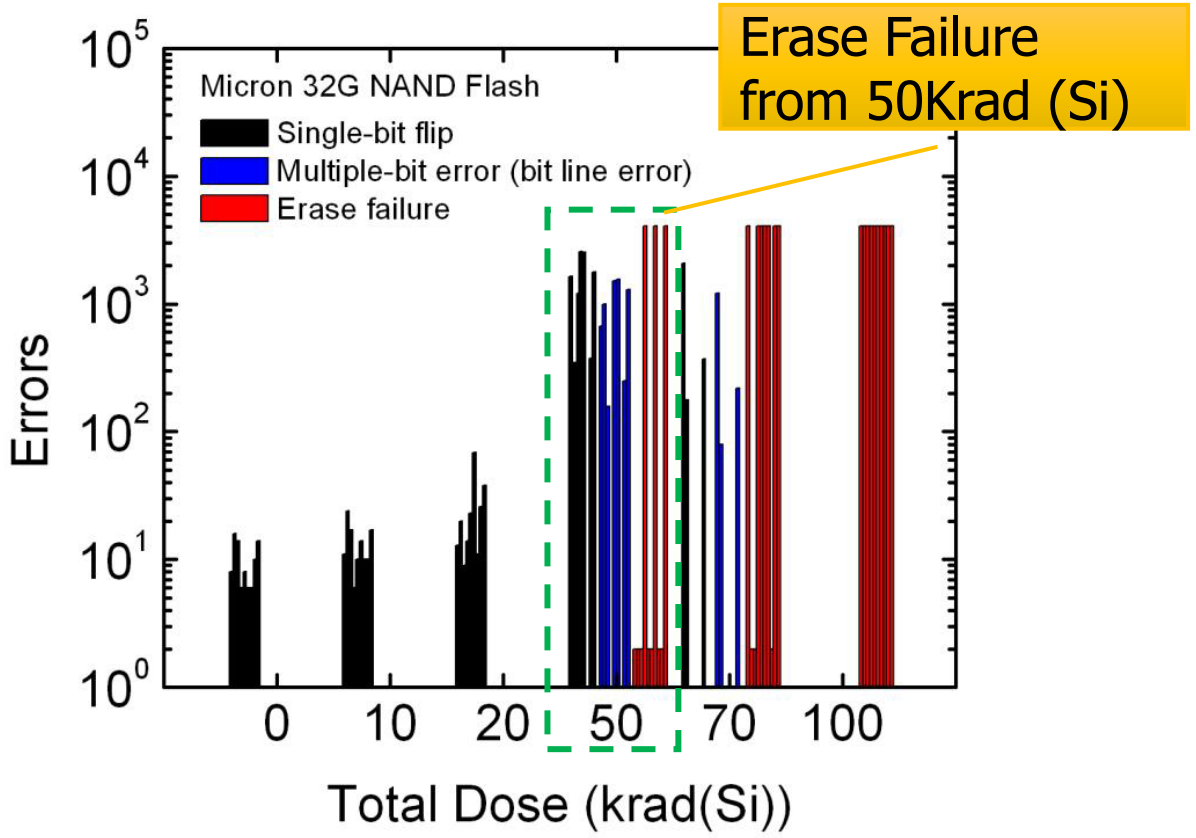
Total Dose Test Report: Micron 32Gbit SLC NAND (2)

Flash Memory Summit

Ave. number of single-bit errors vs. Total Dose



Total number of single-bit, multiple-bit, and erase errors vs. Total Dose



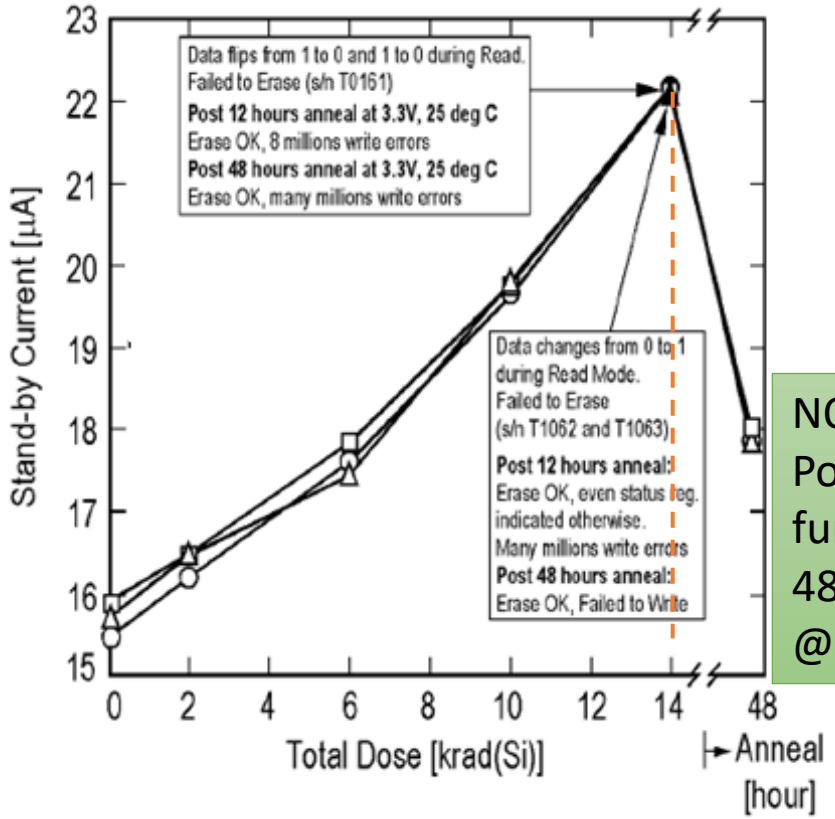
Source:
Total Dose Test Report for the Micron 32Gbit NAND Flash Nonvolatile Memory, DakaiChen, code 561 NASA GSFC

Total Dose Test Report: Intel MLC & Toshiba MLC

Flash Memory Summit

TID of Toshiba 1Gbit MLC
TC58100FT D/C 0240

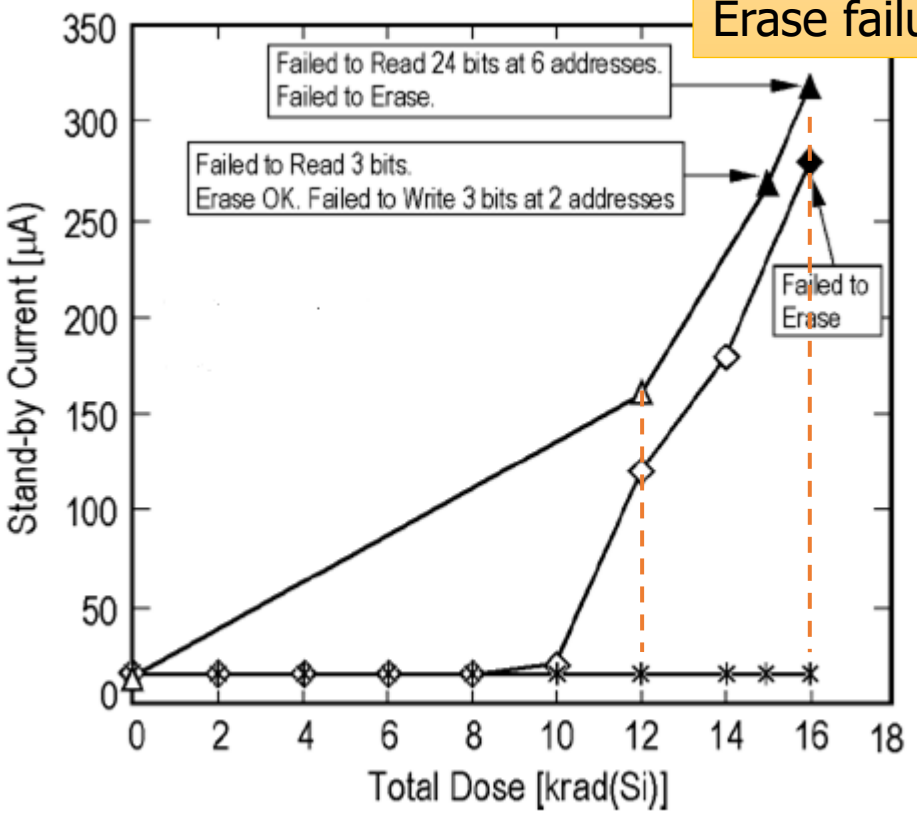
Bit flip: 14Krad(Si)
Erase failure:14Krad(Si)



NOTE:
Post Irradiation function test:
48hours Anneal @3.3V 25C

TID of Intel 256Mbit MLC
28F256K3 D/C 0238

Standby current over spec: 12Krad(Si)
Erase failure:16Krad(Si)



Read/Write/Erase Mode

Source: Jet Propulsion Laboratory, TID, SEE and Radiation Induced Failures in Advanced Flash Memories

Radiation Tolerance Components for LEO mission?

Flash Memory Summit

Component Level	Radiation Hardness Assurance (RHA) or Space Grade	Industrial Grade Or Careful COTS	COTS (commercial off the shelf)
Cost	***	**	*
Availability	* (No stock, Long L/T)	** (Selected & Fly)	*** (Buy & Fly)
Change management	Fixed	Controlled BOM is possible	Change manufacturing process
Risk	Low	Depends	High
Reliability	*** (RHA)	** (Additional test, screening)	*
Features **Radiation Effects (vary by parts)**	• TID 100K rad to 1M rad • No SEL • Characterized single event effects • Low degree of integration • Mature technology (~10 years behind cutting edge) • Lower Density • Lower performance	• Radiation Tolerance Functional on a certain Does by test • Access to cutting edge technology • Suitable for LEO/Small satellites	• Calculated risk in discounting the effects of radiation on electronics • Low orbit & short mission life • Cost-constrained mission • Tolerated failure rate

Source: Doug S, Jonathan D, SSC13-IV-3, Radiation effects and COTS parts in SmallSats

Space Industry Needs...

The trend of satellite communication leads to **Commercialized LEO applications**.

Industrial Grade components with **"Radiation Tolerance"** to minimize the risk and enhance the probability of mission success.

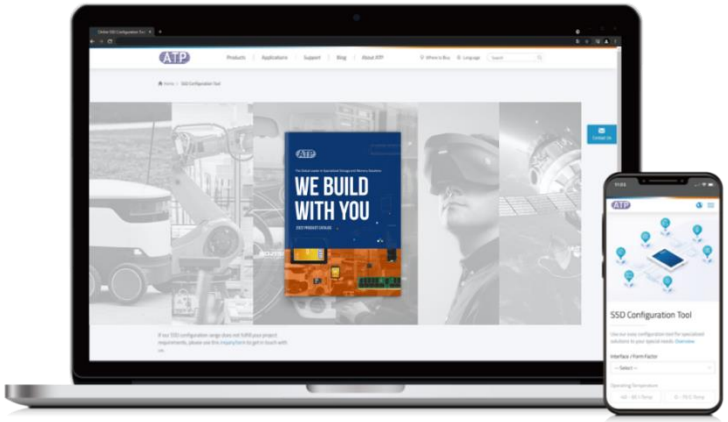
- **Strengthening Collaboration in the Space Ecosystem.**
- **Universal Guidelines/Standards**
- **Cooperation and information sharing by NAND Flash Semiconductors and Reputable institutions.**

E.g. Heavy ion irradiation fluence dependence for SEU of NAND Flash Memory (Micron 16nm MLC) by **Micron, NASA Goddard Space Flight Center and ASRC Space and Defense**

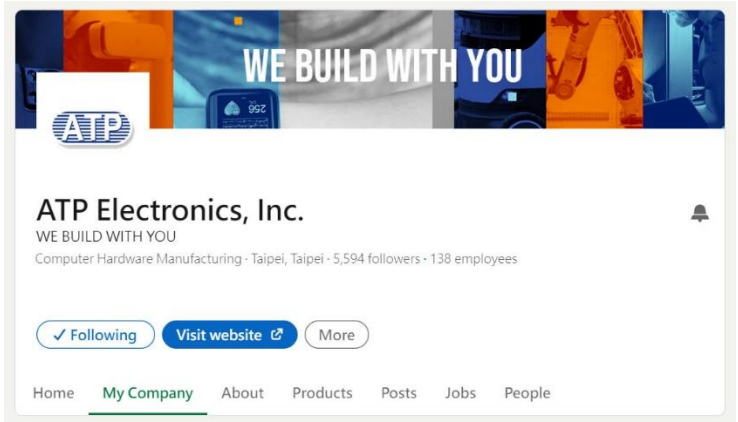
For More Information on ATP Electronics

Flash Memory Summit

Visit our website: www.atpinc.com



Follow us on LinkedIn



Subscribe to our newsletter