the Future of Memory and Storage

Enhance Radiation Tolerance and SSD recovery strategies

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Agenda

- Market Trend on LEO satellites
- Requirements for Radiation Tolerance & Reliable SSD
- Radiation impacts on SSD
- Multi-layered Protection
- Power-saving requirements

Megatrend

Satellites offer great potential for wireless telecommunications around the world.

Integration of Satellite Network and Mobile Communication

[Source: 5G And Non Terrestrial Networks - Bing video]

Global Space Exploration and Security Initiatives

U.S. Space Policy

The U.S. government’s support for SpaceX and the potential adjustment of the National Space Council’s role.

EU Satellite Development

EU's efforts to develop an independent military intelligence satellite system

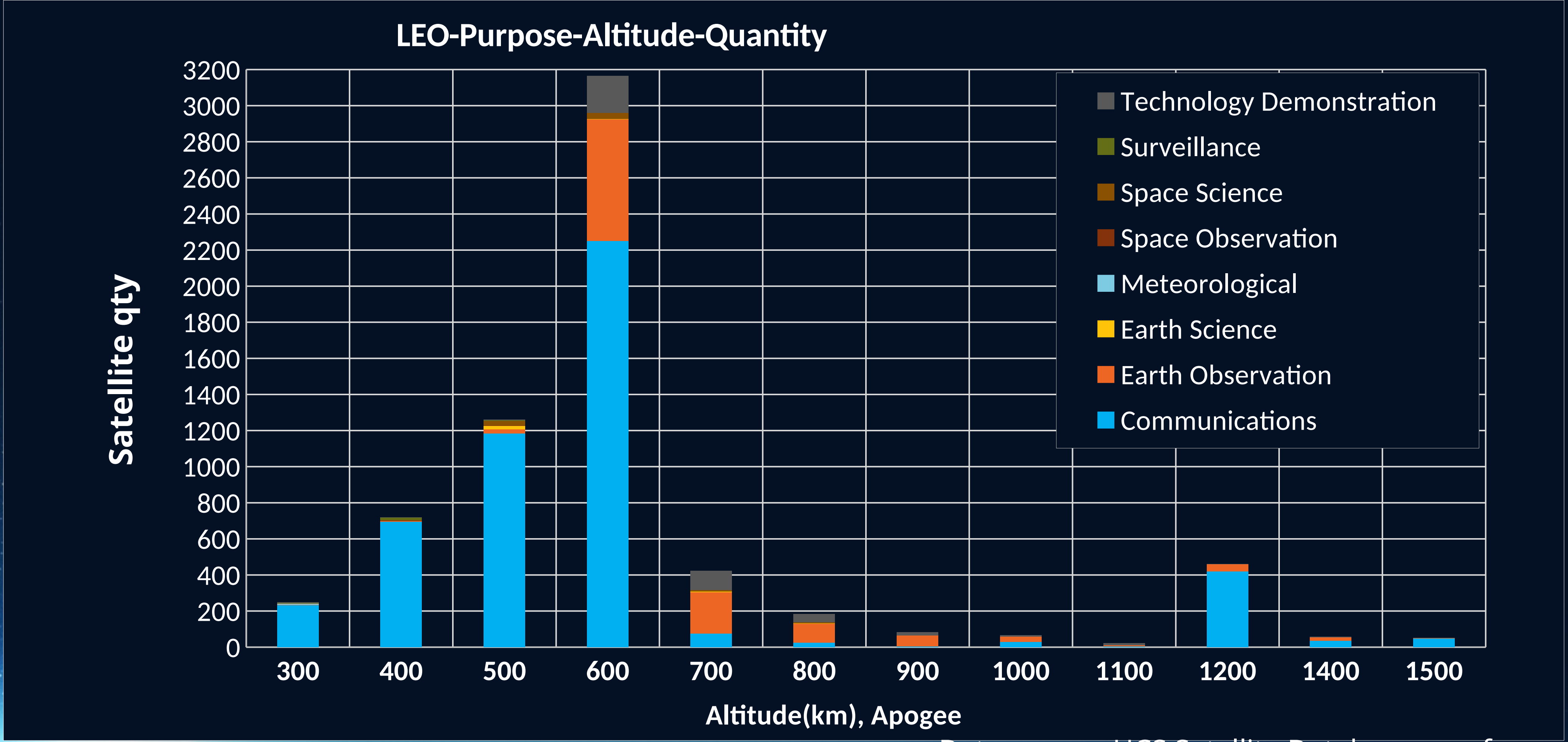
IRIS^2 Program

EU's plan to deploy 290 satellites for secure connectivity

Govsatcom Program

EU's initiative to integrate member states' military satellite systems

Altitude (km) distribution of LEO Satellites



Data source: UCS Satellite Database, as of 2023/05/01

Requirements for Radiation Tolerance & Reliable SSD

- Larger capacity : >1TB SSD for satellite communication (image, streaming)
- Light Weight / saving space: BGA SSD (1TB) or M.2 2280 (4TB), no housing
- Minimum components: remove capacitors, DRAMless SSD solution
- Mission life: 5 years (typical)
- TID (Total ionizing dose): 15Krad (varies by case)
- SEE (Single event effect): ~ 64 MEV Protons (varies by case)
- Test criteria:
  - SSD back to function after power cycling
  - User Data corruption may be accepted (there are backups)
- Power-saving management
- Method to monitor SSD status, Failure analysis of post radiation test

Can TLC-based SSD overcome above challenges ?

Mitigating Radiation Effects in SSDs

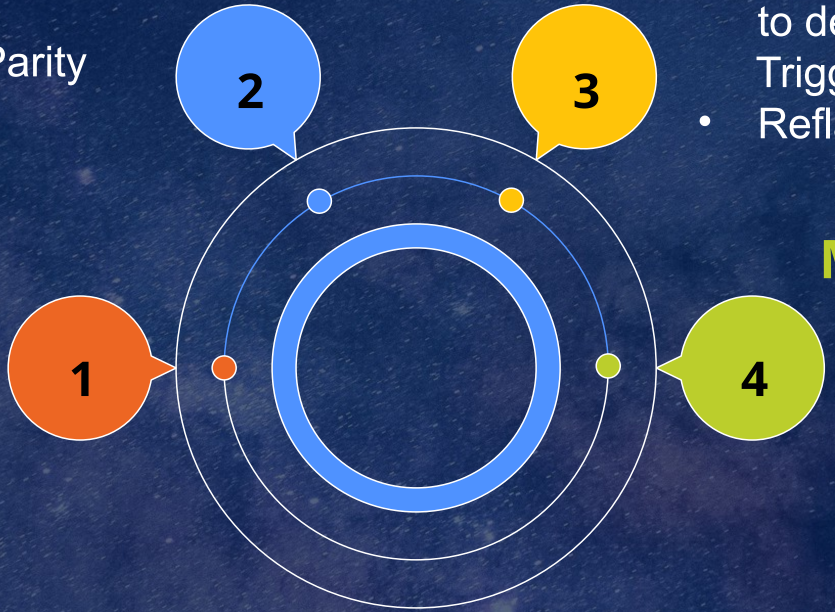
Minor Scenarios		**ATP’s Protection**
User Data Corruption	**Data Protection**	• User Data Protection: Firmware mechanism. LDPC, RAID Parity, Read Retry • End-to-End Data Protection Engine. • Sudden Power Off Recovery (SPOR)
Meta Data Corruption (Link table, file system)		
Bit Flip Error		• Bit Flips Handling: 1-bit error correction, 2-bit error detection.
SSD Becomes Read-only		• Use the hardware GPIO-Erase pin to clean the drive*
Firmware/ISP Code Corruption	**Function Recovery**	• The ISP firmware is backed up across NAND dies and recovered by locating the backup Info block using checksum. • If all backups are corrupted, the SSD becomes bricked
SSD Becomes Bricked		• Assure the SSD is in ROM code mode (ROM pin) • Use ATP Vendor Specific Command to reflash the FW
Hardware Damage	▨	(Hardware RAID / Backup Drives)

Major Scenarios

*Execute this function to try SSD recovery; all data will be erased.

Note: The protection methods vary by product configurations.

Multi-Layered Protection



Data Protection

- Bit Flip Correction
- LDPC, Read Calibration
- End-to-end Engine
- Block Level RAID Parity

Function Protection*

- SSD becomes Read-only –GPIO erase Pin
- SSD becomes bricked – Watch dog timer to detect abnormality and re-boot drives Triggered by 110nm NOR Flash MCU
- Reflash FW

Error Prevention

- ATP RDT (Rapid-Diagnostic-Test)
- Auto Scan & Dynamic Data Refresh

Monitor and Analysis

- S.M.A.R.T. tool to monitor SSD status
- Event log analysis
- ECC analysis

*Note: Features support by product and the data will be wiped.
Host system support is required in some cases, please contact ATP for “We Build With You” program.

ERROR PREVENTION

1. ATP Rapid Diagnostic Test (RDT)
2. Auto Scan System with Dynamic Data Refresh

ERROR PREVENTION:
ATP Rapid Diagnostic Test (RDT)

100% Test in Mass Production

EXTREME CONDITION SCREENING

RDT tests NAND at –40°C to 85°C to simulate harsh space environments.

WEAK BLOCK ELIMINATION

Detects and removes weak NAND blocks to ensure only reliable ones are used.

FULL DRIVE COVERAGE

Tests 100% of the SSD, including user area, firmware, metadata, and spare blocks.

CONTROLLER LEVEL EXECUTION

RDT is executed directly by the controller to accelerate the process.

ERROR PREVENTION:
Auto Scan System with Dynamic Data Refresh

To prevent read disturb and data retention by scanning NAND Flash and relocating data from risk blocks to healthy blocks. If the scanned blocks consist high error bits or uncorrectable errors, the blocks will be marked as bad blocks and won't be used again.

- Read count exceeds the threshold

- Periodically auto-scan in all system and data areas

Risk Rank

🟧	High
🟦	
⬜	Low

User Data Corruption. Threshold voltage shifts in NAND flash memory, leading to read errors.

DATA PROTECTION SOLUTION

- **Read Retry**
- **Low Density Parity Check Code (LDPC)**
- **Redundant Array of Independent Disks (RAID) Parity**

DATA PROTECTION

End-to-End Data Protection Engine

End-to-End Engine ensures long-term data integrity with layered error detection and correction technologies from transmission to storage

- Cyclic Redundancy Check
- Error Correction Code
- Low-Density Parity-Check Code

Sudden Power Off Recovery (SPOR)

Sudden Power-Off Recovery (SPOR) technology minimizes data loss during sudden power outages by backing up ISP code and securely tracing valid mapping addresses stored in strong pages.

DATA PROTECTION

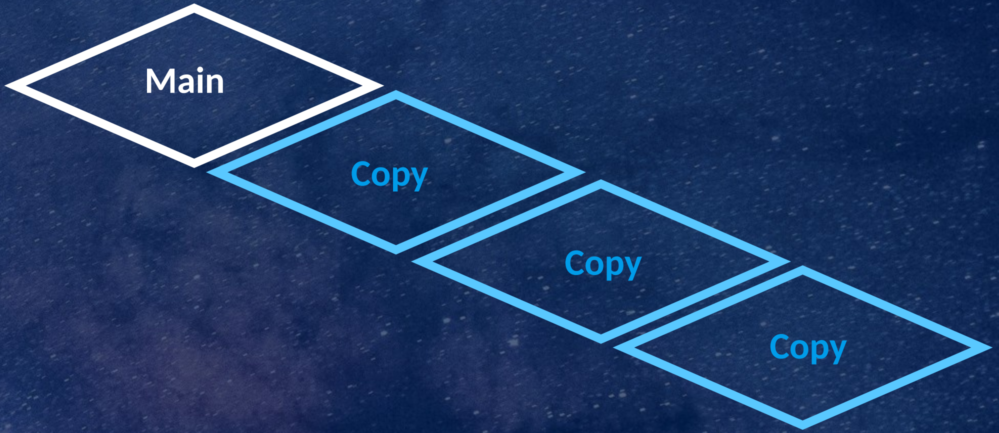
Bit Flips Handling:
1-bit Errors Correction,
2-bit Errors Detection

Before
10110000

After
10110010

After Correction
10110000

Multi-backup In-System Programming (ISP) firmware across NAND dies



FUNCTION PROTECTION

When SSD enter read-only mode

A dedicated hardware GPIO erase/reset pin can be activated, allowing the SSD to clear internal error flags and restore write functionality.

*However, all user data might be wiped.

FUNCTION PROTECTION

When SSD is bricked

b. Auto Reset by MCU (110nm NOR Flash)

SSD Auto Recovery Mechanism (via MCU)

1. MCU controls ROM Mode to enter firmware update (ISP) mode
2. Watchdog timer monitors firmware heartbeat
3. If no response, triggers hard reset to reboot system
4. After reboot, MCU decides whether to stay in ROM Mode for recovery

Ensures self-recovery and stable operation in space missions

FUNCTION PROTECTION

When SSD is bricked

a. Reflash by Host

1: Enter ROM Code Mode

- Configure the host PCB I/O to control the ROM Mode pin.
- Host power cycling the SSD to force entry into ROM mode.

2: Reflash Firmware

- Download the firmware via host.
- Use vendor-specific commands (VSC) to write the new firmware.

3: Return to Normal Mode

- Host power cycling the SSD again to restore it to In-System Programming (ISP) mode.
- The SSD is restored to a functional state.

Energy-Saving Strategies for Satellite

- Solar Panel Power conversion rate: **30%–35%**
  - Exposure to radiation, extreme temperature fluctuations, and micrometeoroid impacts can degrade solar panels
  - Efficiency declines over time due to radiation-induced degradation

- Backup storage or advanced energy-saving strategies are required for long-duration darkness (e.g., lunar night or deep space missions)

- **Power-Saving and Energy Management Requirements**
  - Mission-based power allocation (common)
  - Low-power hardware design (e.g. Power-saving SSD)
  - Thermal energy reuse (rare case in Satellites, more in ISS applications)

ATP Service Monitoring and Analysis

1. S.M.A.R.T TOOL
2. EVENT LOG
3. ECC ANALYSIS

S.M.A.R.T (Self Monitoring Analysis Reporting Technology)

A user-friendly interface for monitoring the health status and life expectancy of product

- Hosts can issue SMART CMD to acquire the attribute information.
- Hosts can also download/save the SMART info periodically

Attribute Information	
Critical Warning	Controller Busy Time
Composite Temperature	Power Cycles
Available Spare (Threshold)	Unsafe Shutdowns
Percentage Used	Media and Data Integrity Errors
Data Units Read	Number of Error Information Log Entries
Data Units Written	Warning Composite Temperature Time
Host Read/Write Commands	Critical Composite Temperature Time

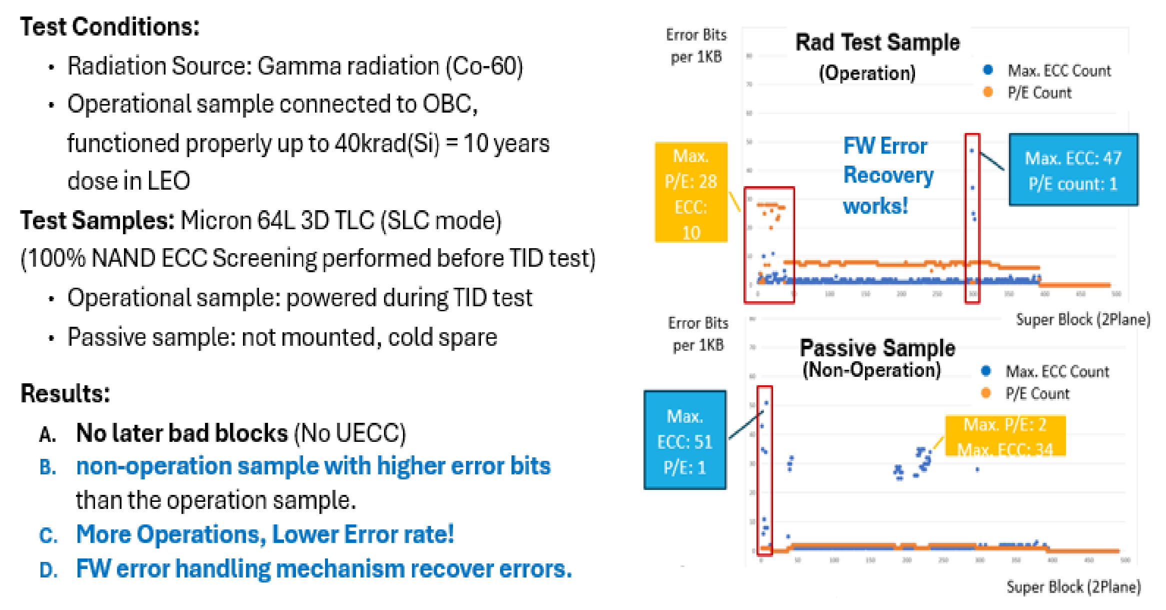
"Real-time" power consumption can be retrieved through ATP specific vendor CMD in S.M.A.R.T. (by project)

- ## Event Log Analysis

  Exclusive Insight into SSD Behavior Under Radiation Stress

- ## ECC Analysis

  ECC analysis in NAND Flash compares error bit variations before and after testing to verify firmware correction capability under radiation and temperature stress, identifying potential vulnerabilities and failure risks.



Test Conditions:

- Radiation Source: Gamma radiation (Co-60)
- Operational sample connected to OBC, functioned properly up to 40krad(Si) = 10 years dose in LEO

Test Samples: Micron 64L 3D TLC (SLC mode)
(100% NAND ECC Screening performed before TID test)

- Operational sample: powered during TID test
- Passive sample: not mounted, cold spare

Results:

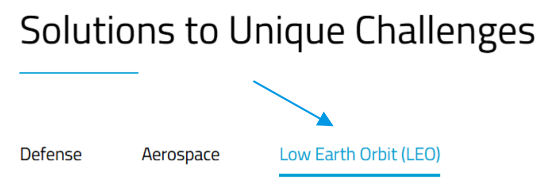
A. **No later bad blocks** (No UECC)
B. **non-operation sample with higher error bits** than the operation sample.
C. **More Operations, Lower Error rate!**
D. **FW error handling mechanism recover errors.**

ATP RADIATION-TOLERANT AND HIGH-RELIABILITY MEMORY FOR SPACE AND AEROSPACE

PROTECTION COVERING
ERROR PREVENTION,
DATA PROTECTION, AND FUNCTIONAL RECOVERY
TO MANAGE THE RADIATION IMPACTS

the Future of Memory and Storage

ATP’s Radiation tolerance and reliable memory solutions for Low Earth Orbit (LEO) visit:



Solutions to Unique Challenges

About ATP Electronics

ATP Electronics (“ATP”) has dedicated over 30 years of manufacturing excellence as the premier provider of memory and NAND flash storage products for rigorous embedded/industrial/automotive applications. As the “Global Leader in Specialized Storage and Memory Solutions,” ATP is known for its expertise in thermal and high-endurance solutions. ATP is committed to delivering add-on value, differentiation and the best TCO for customers. A true manufacturer, ATP manages every stage of the manufacturing process to ensure quality and product longevity. ATP upholds the highest standards of corporate social responsibility by ensuring sustainable value for workers, the environment, and business throughout the global supply chain.

For more information on ATP Electronics, please visit www.atpinc.com or contact us
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