Analysis of High Endurance Storage for Write Intensive Automotive Applications

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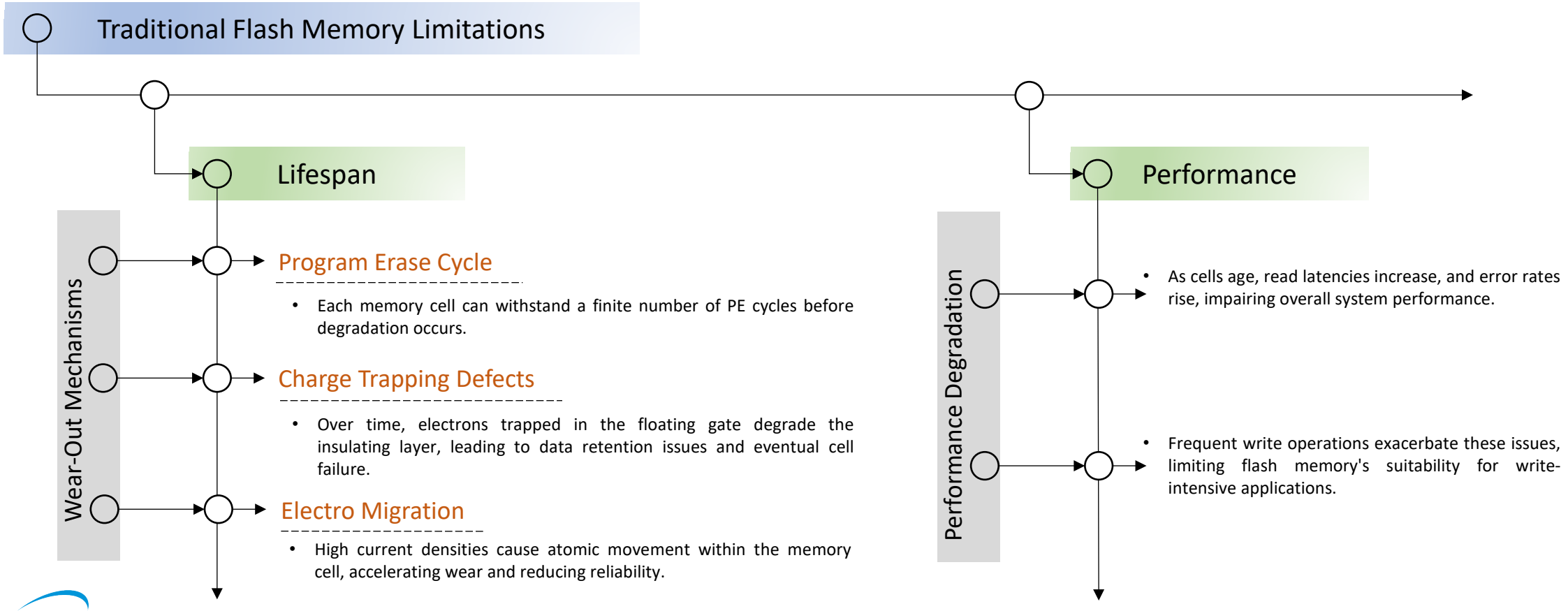
Outline

- Background
- Applications
- Endurance Requirements
- **Case Study (EDR)**
- WAF/PE Cycles
- Conclusion

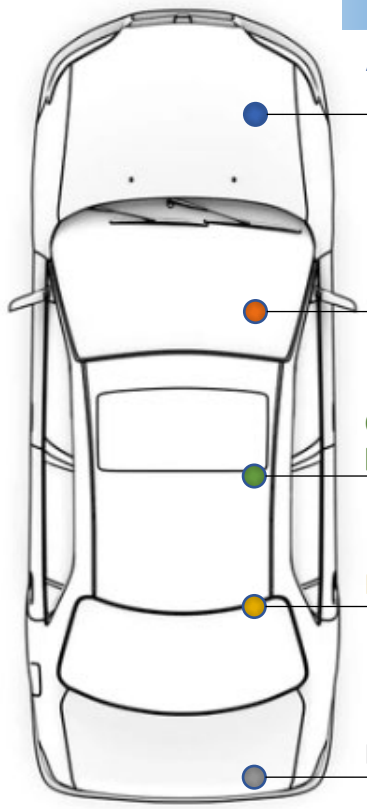
Background

- Flash memory, while revolutionary, faces intrinsic challenges that limit its **lifespan** and **performance**, particularly in **demanding applications**.



Automotive Applications

- In the **automotive applications** it is crucial to have, under **harsh conditions**
  - **Long term reliability** of the data
  - **High endurance**



Applications	Use Case	Data Source	Data Purpose	Endurance
ADAS [Advanced Driver Assistance System]	▪ Lane Keeping ▪ Braking ▪ Adaptive Cruise Control ▪ Obstacle Detection	▪ Camera ▪ Radar ▪ LiDAR ▪ Various sensors	▪ Real-time Decision Making ▪ Post Event Analysis	▪ **High**
EDR [Event Data Recorder]	▪ Vehicle data during Crash or near Crash	▪ Airbag ▪ Brake/Throttle ▪ Seat belt ▪ Speed ▪ Impact Data ▪ Driver Inputs	▪ Car Investigation ▪ Insurance	▪ **High**
OTA Update [Over the Air]	▪ ECU Firmware	▪ Cryptographically verified firmware	▪ Firmware Updates	▪ Low
Maintenance/Health Monitoring	▪ Detection of component wear out	▪ Vibration Data ▪ Temperature ▪ Current Drawn ▪ Fault Codes	▪ Prevent safety critical failures ▪ Avoid breakdown risk	▪ Low
Driver monitoring systems	▪ Driver Alertness ▪ Attention ▪ Behavior	▪ Eye tracking ▪ Facial expressions ▪ Steering behavior	▪ Trigger alerts and interventions	▪ **High**

Typical Endurance Requirement

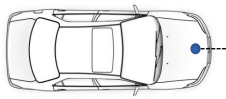
- ❑ Ability of electronics components used in **Automotive systems** to **retain data over time**.
- ❑ Without **degradation** or **failure** due **to repeated read/write cycles**.

Enhanced memory endurance contributes to

- Overall System Efficiency
- Reduces maintenance costs
- supports seamless integration of emerging automotive technologies

Characteristics of High Endurance Memory

- ❑ High Endurance (>100k).
- ❑ Low WAF
- ❑ More sequential workloads
- ❑ Low Retention Requirements
- ❑ More write workload



Endurance Requirement by Application

Application	Endurance Requirement
Engine Control Unit (ECU)	>= 100K cycles
Transmission Control	
Airbag/Safety systems	
Infotainment & Navigation	
Event Data Recorder (EDR)	**>= 1M cycles**
Battery Management System (BMS)	

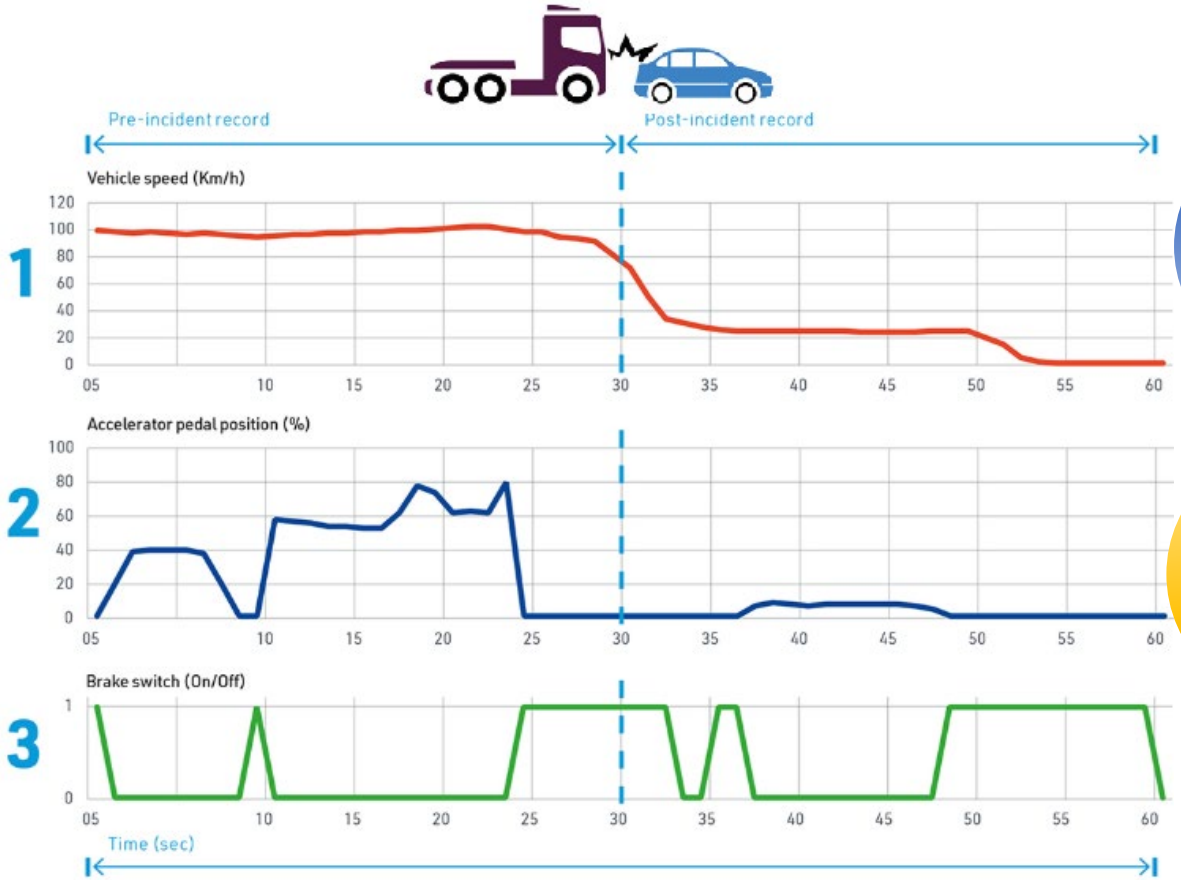
Automotive Specific Requirement

Requirement	Details
AEC-Q100 Qualified	Handle Automotive Grade stress conditions
Extended temperature range	-40C to +125C (or more)
Data Retention	10-20 years
Functional Safety (ISO 26262)	Support fault detection, error correction (ECC) & redundancy

Case Study (EDR)

❑ An emergency data recorder (EDR) in autonomous vehicle

❑ **Capture and store critical data during emergencies**



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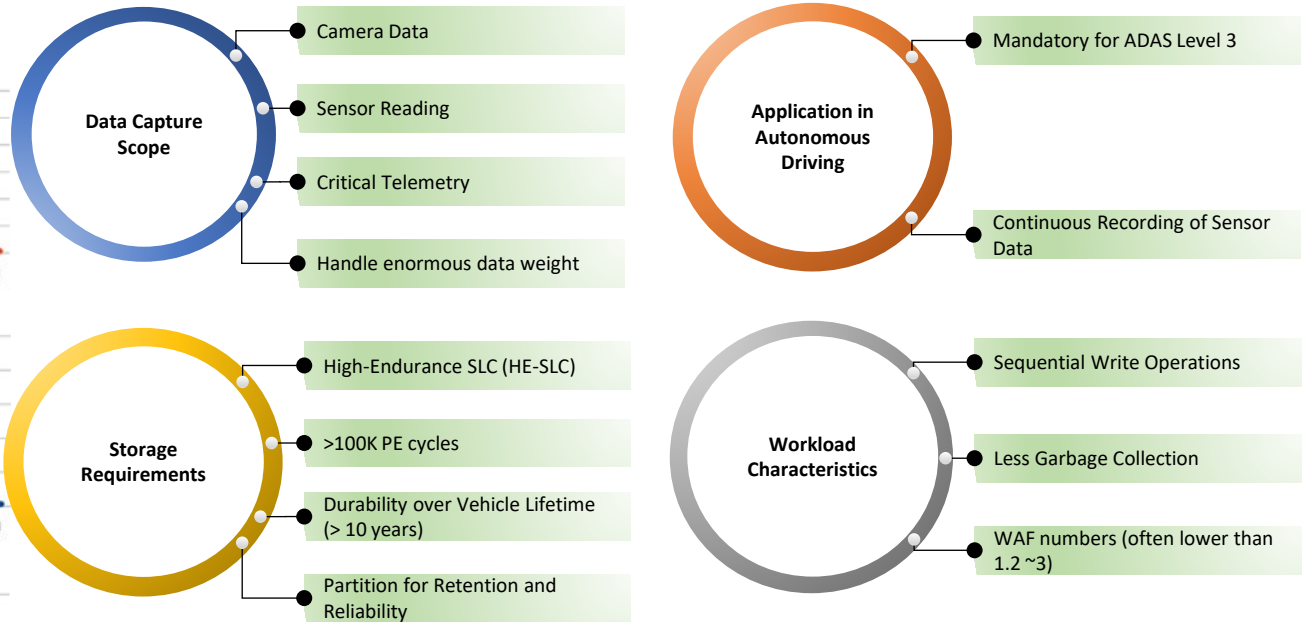
❑ **Handle massive volumes of data generated** by sensors, cameras, and other components.



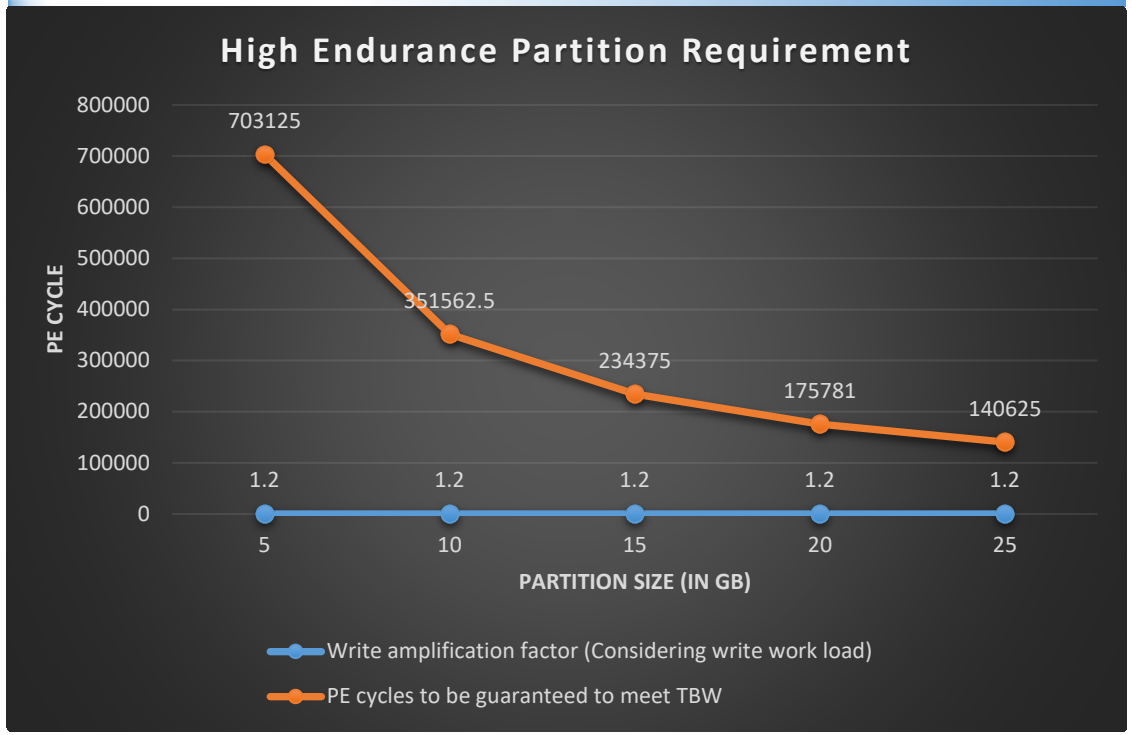
Case Study (EDR)

- Case Study of typical camera data associated with EDR.
  - Usage of Camera in EDR
    - In-Cabin Monitoring
    - Out-Of-Cabin Monitoring
    - Accident Investigation

Camera Data Analysis	
Data Compression Ratio (x:1)	18
Data Recording Frame Rate (fps)	30
Total Camera Data Processed MPs/Frame	50
Total Camera Data Processed (MP/s)	1500
Total Camera Data Processed (MB/s)	3000
Crash recording window (secs)	30
Total crash recording data size in GB per Camera	87.89
Compressed Camera data in GB	4.88

Lifetime Data Analysis	
Average engine hours per Year	500
Total Operation Years	10
Total Operating Hours over life time	5000
Number of times Camera data to be recorded (Considering 30 sec retention period)	600000
Total Life time data (TBW (Terabytes Written))	2861.02

- Memory PE Cycle can be enhanced with
  - Low WAF
  - Increasing Partition Size



WAF / PE Cycle

❑ Write Amplification Factor (WAF)

$$WAF = \frac{\text{Total Bytes Physically written onto NAND Flash}}{\text{Bytes logically written by Host}}$$

Impact of Sequential Workload

- \+ Reduce Fragmentation [Through Efficient Mapping Algorithm]
- \- Garbage Collection
- \- Wear Leveling

Impact of High WAF

- ❑ Reduce Endurance
- ❑ Impact Performance

Factors Increasing WAF

- ❑ **Garbage Collection:** Valid page old block are copied to new blocks before erasing old one.
- ❑ **Wear Leveling:** Data moved more frequently to ensure ever wear.
- ❑ **Invalid Pages:** Invalid page write during GC / internal processes.

Optimization Strategy

- ❑ **Mapping Algorithms:** Efficient mapping algorithms can help minimize unnecessary writes, and improve WAF.
- ❑ **Write Buffering:** Implementing larger write buffers allows grouping small writes into fewer large writes, reducing WAF.
- ❑ **Sequential Access Patterns:** Leveraging sequential access patterns where possible can improve write efficiency and lower WAF.

❑ Strategies to Achieve High PE Cycles

- ❑ **Typical SLC PE Cycles:** Approximately 50,000 (standard specification).
- ❑ **Target Goal:** Achieve >100K PE cycles for enhanced durability.

Zone Management	❑ Isolates HE blocks from regular blocks, preventing premature wear due to shared workloads
Wear Leveling Optimization	❑ Ensures all blocks reach the maximum PE cycle
Software and Firmware Enhancements	❑ Enhanced error correction, Modifications to refresh mechanisms (Data refresh, Purge etc..)
Temperature Control	❑ Preserves memory integrity and delays degradation caused by elevated temperatures

Conclusion

- **High-Endurance** memory represents a significant advancement in flash memory technology, addressing the limitations of traditional SLC, MLC, and TLC configurations.
- By achieving **High PE cycles**, High-Endurance memory offers **unprecedented durability**, making it ideal for demanding applications such as autonomous driving, industrial IoT, and enterprise storage.
- Key takeaways include:

  - ❑ **Extended Lifespan:** HE Memory significantly exceeds the endurance of standard Memory.
  - ❑ **Robust Performance:** Designed to handle write-intensive workloads with low WAF.
  - ❑ **Specialized Partitions:** Low retention for HE memory and High retention for OS areas.
  - ❑ **Industry Alignment:** Strategic foundation for high-endurance, future ready vehicle data systems.

Thank you

Backup

Validation of High Endurance Memory