Taking NAND Past End-of-Life: Dynamic NAND Recovery

Cloud Zeng, Phison Electronics

Ilia Maller, Phison Electronics

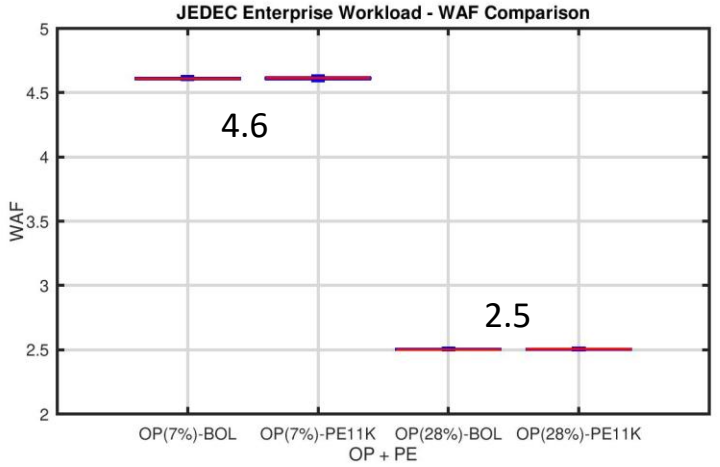
Exceeding Enterprise SSD Reliability/Performance Requirements

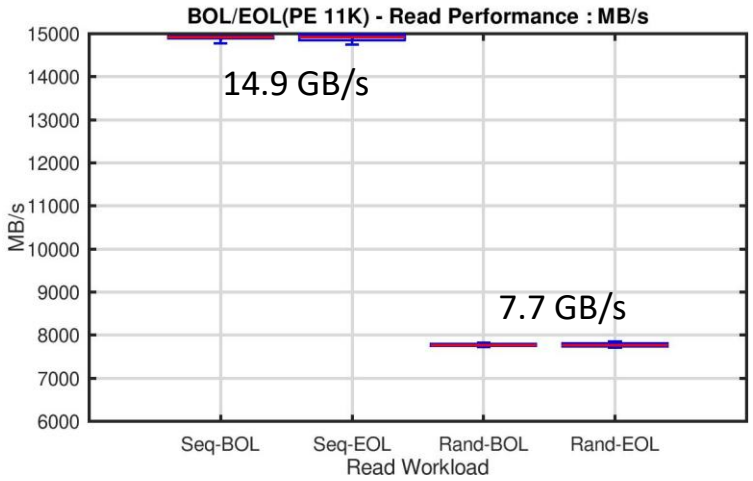
Phison Enterprise SSD – best in class reliability

- Fast Performance Recovery
- Unlimited Power-On Reliability
- Strong QLC Support
- Stable Performance from BOL to EOL
- Up to 11K P/E for cTLC, 3K P/E for cQLC
- Exceeds JEDEC/Customer Requirements

Patented Features:

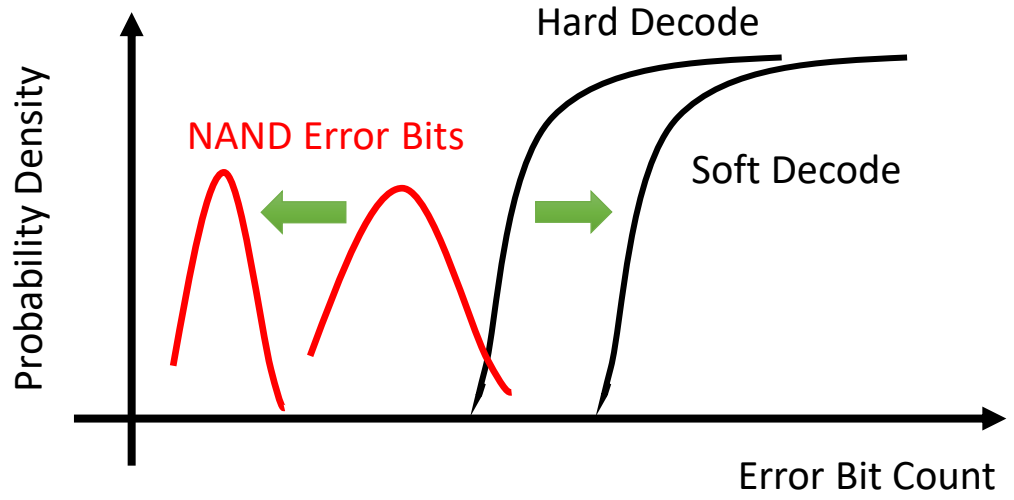
- Optimal Read Level Search *(2 patents)*
- Efficient Tracking Process *(1 patent)*
- Instant Read Performance Monitoring *(1 patent)*
- Refresh (Extra PE) Overhead Reduction *(1 patent)*
- Runtime Retry Table Management *(1 patent)*
- Recovery Sequence Escape/Swap *(1 patent)*
- Quick Tracking Correction *(1 patent)*

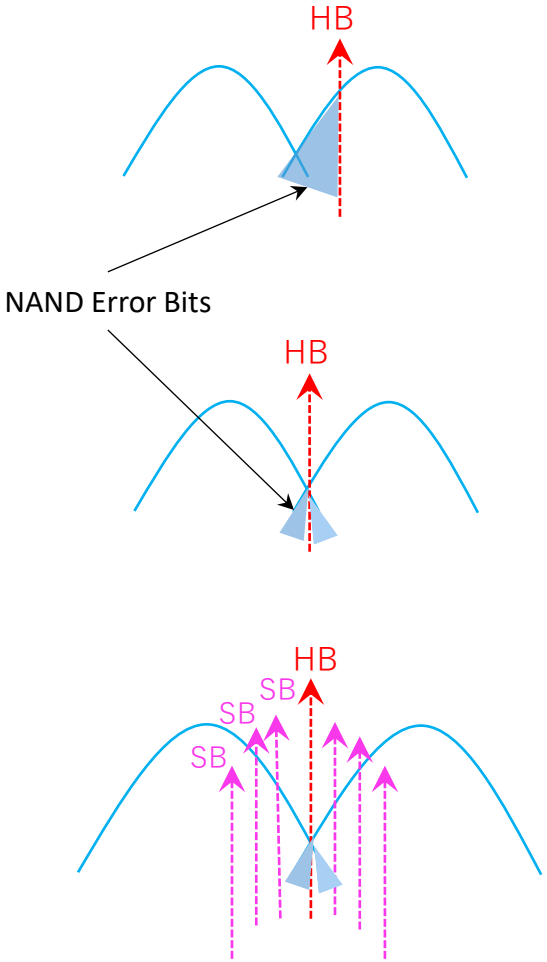




Dynamic NAND Recovery

- Error Accumulation Mechanisms:
  - Read disturb
  - Program/Erase Cycles
  - Cross-temperature: write at high – read at low (HWLR) or write at low – read at high (LWHR)
  - Retention
- Design Goals:
  - Reduce number of read errors bits
  - Increase correction capabilities





Hard Decode:
Retry/Cache/Tracking

Optimal Read Level Search:
Reduce number of error bits

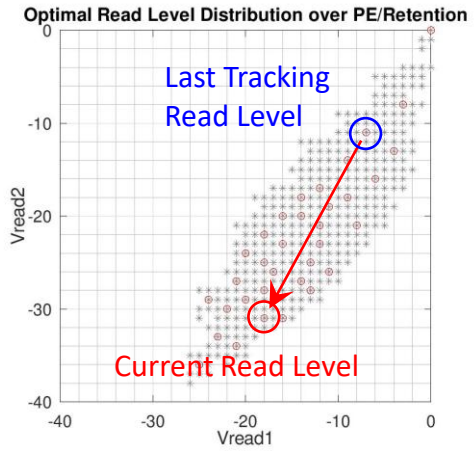
Soft Decode:
Increase correction capability

RAID/Soft RAID

Dynamic Recovery Sequence

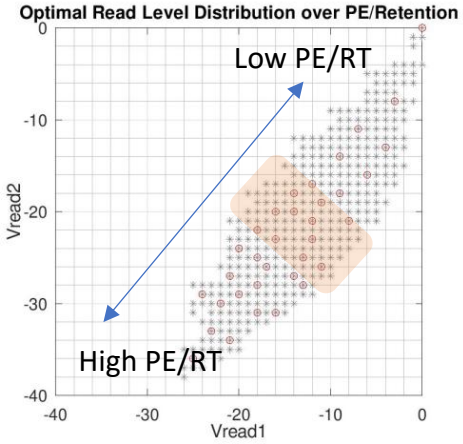
Design Goal: Maintain a low retry trigger rate and minimize recovery steps

Predictive Quick Tracking Correction



- Read level may drift due to PE cycles or retention; update it *before* accessing the memory unit
- If most units last tracked at the blue point are now recovered at the red point, a significant read level shift has occurred
- Stable Retry Trigger Rate: $1e^{-5}$ to $1e^{-6}$

Dynamic Retry Sequence



- Not all retry table entries are equally useful: manage retry table in runtime
  - **Add** new entries if a better read level is discovered
  - **Delete** entries that no longer improve decoding
  - **Reprioritize** entries to reduce total retry steps
- Average Read Retry Trials : 1.06

Runtime Read Level Tracking

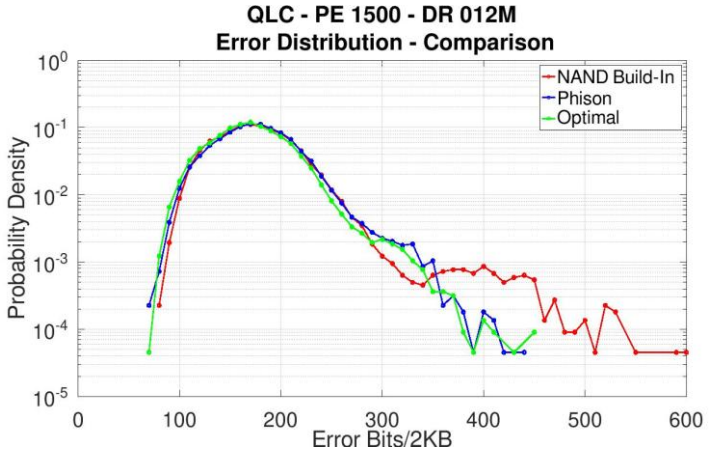
Design Goal: Execute every read command with (near-)optimal read level

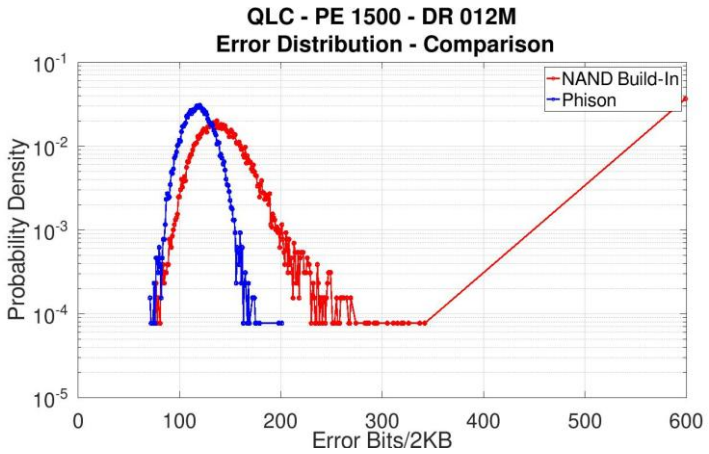
Optimal Read Level Search

- Works for all types of NAND and operation conditions
- Supports any die variation using runtime-generated retry table

Runtime Read Level Tracking

- Periodically records the read level of each memory unit (wordline, block, plane, or die)
- With short tracking intervals, the overhead remains low
- Quick Tracking Correction and the Dynamic Recovery Sequence help reduce reliance on full Read Level Search
  - Search trigger rate : $1e^{-5}$
- Read Level Prediction keeps tracking overhead low
  - Average tracking read count for each page: 1.12

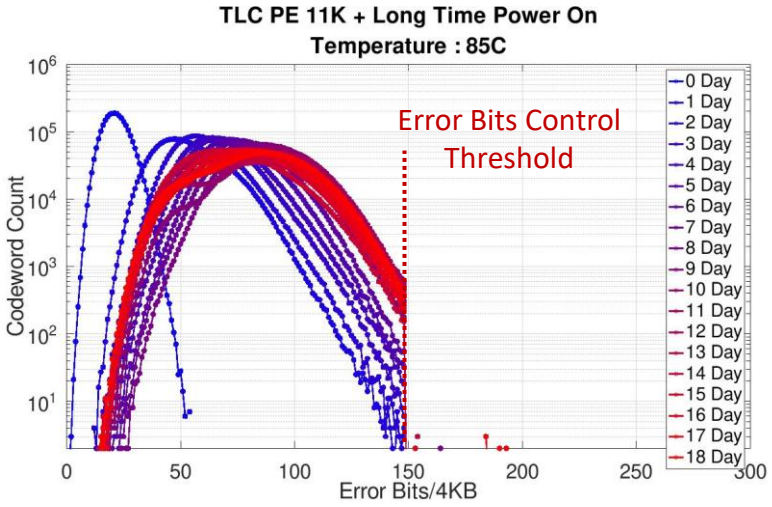




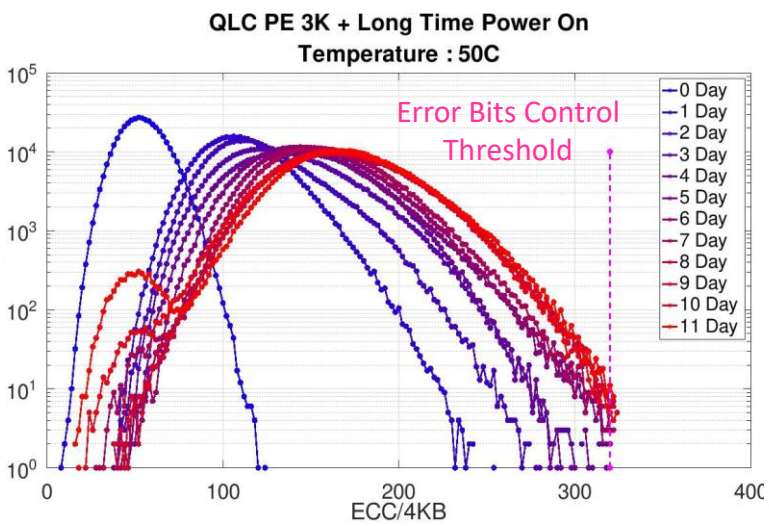
Unlimited Power-On Reliability

- No reads scenario is the worst-case, since no runtime decode statistics can be collected
  - Time-based tracking is required
- Data is relocated before error bits exceed the control threshold
- With short tracking intervals (< 1 day), error accumulation is well controlled

TLC

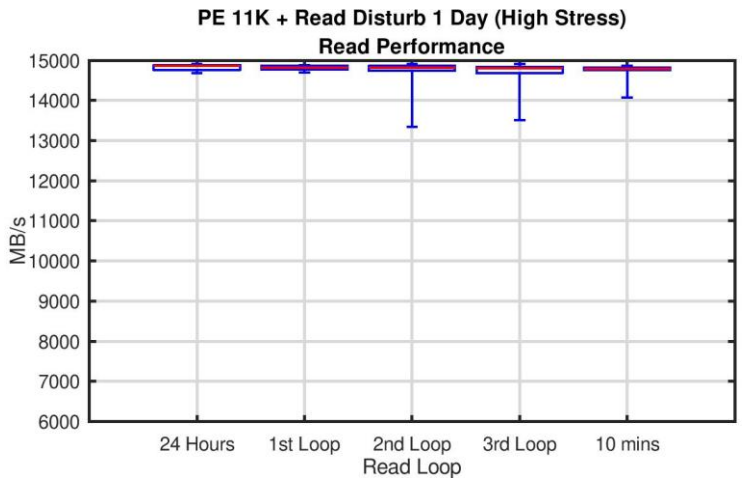


QLC



Power-on retention : no reliability risk

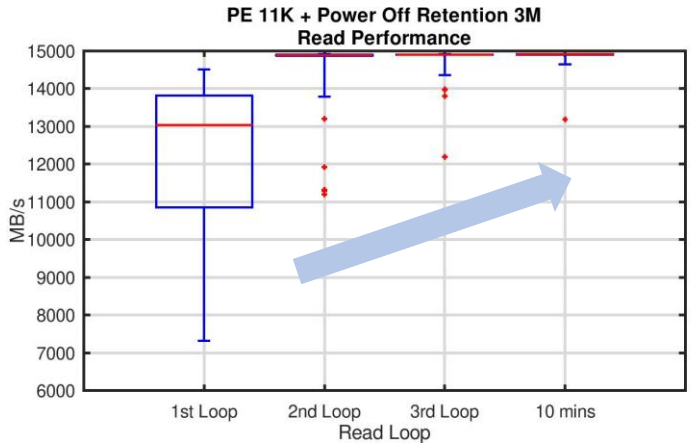
50x Read Disturb Spec

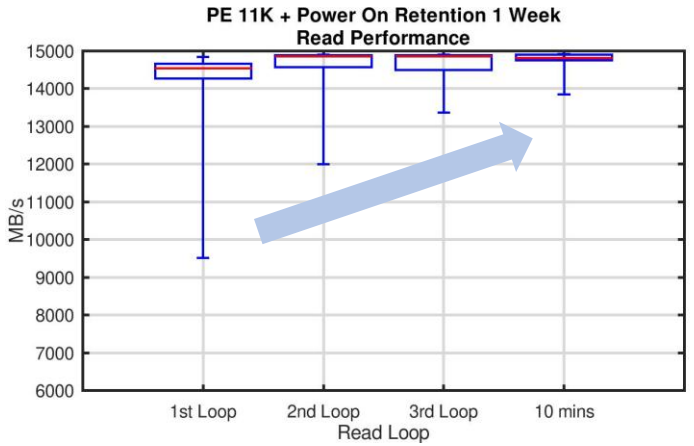


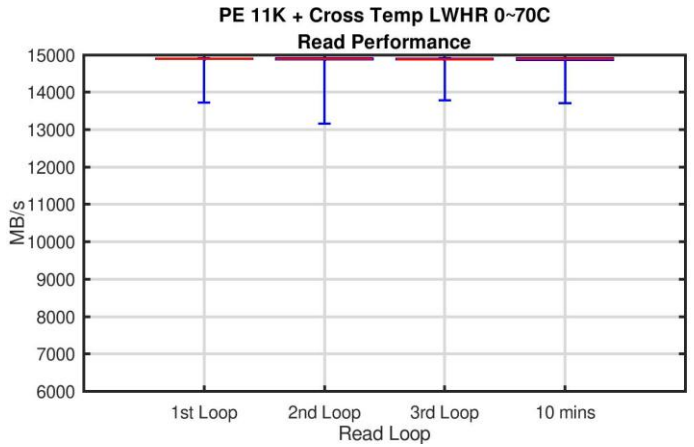
Read disturb : no reliability/performance risk

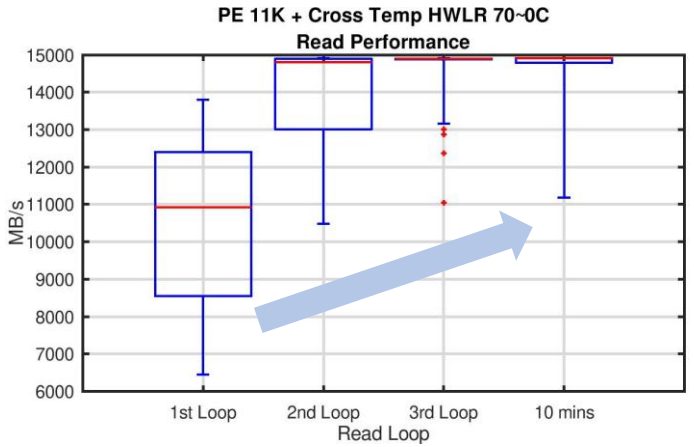
Fast Read Performance Recovery

- Dynamic Recovery Sequence ensures fast and stable read performance
- Recovery verified under worst-case PE + retention combinations:
  - Power-off retention (3 months)
  - Power-on retention (1 week)
  - Cross-temp LWHR (0→70°C) and HWLR (70→0°C)
- Performance recovers within 1–2 read loops in all cases







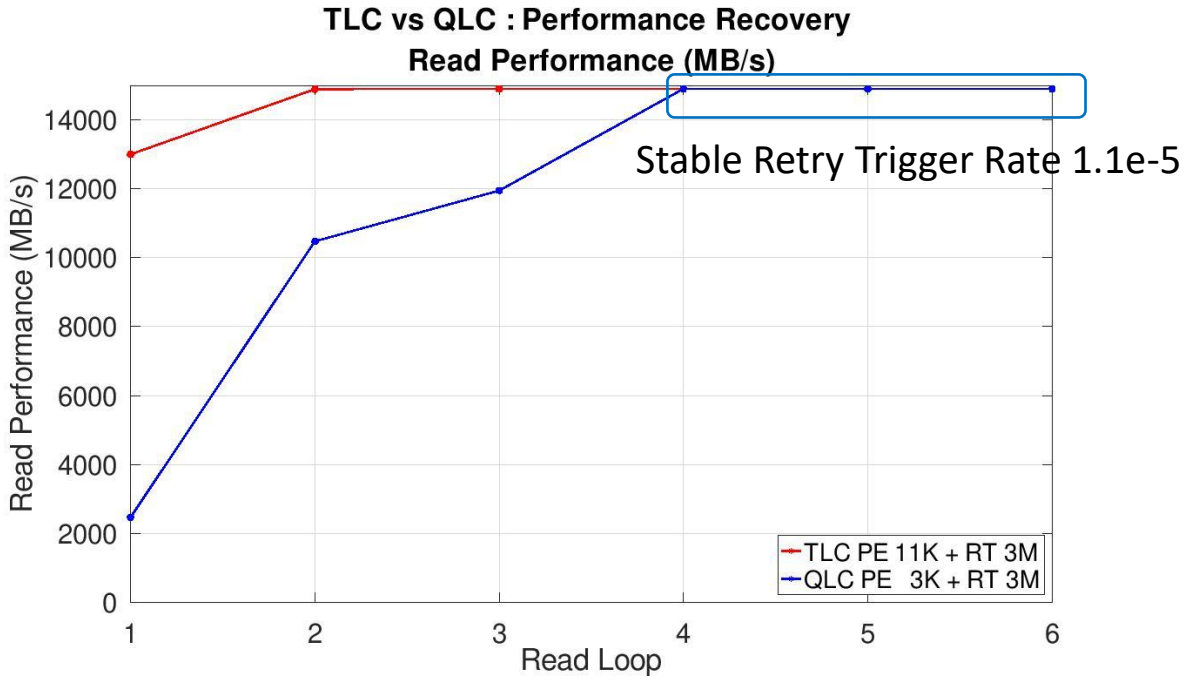


Strong QLC Support

- QLC exhibits more error bits and a faster increase in error rate under stress
  - Dynamic Recovery Sequence shows significant advantage/gain in QLC
  - Data is relocated to recover performance
- To reduce extra P/E cycles, refresh granularity is minimized
  - Refresh overhead reduced by ~ 1,000×

Memory Unit

	Die0		Die1	
	P0	P1	P0	P1
VB0				
VB1				
VB2				
…				
VB999				



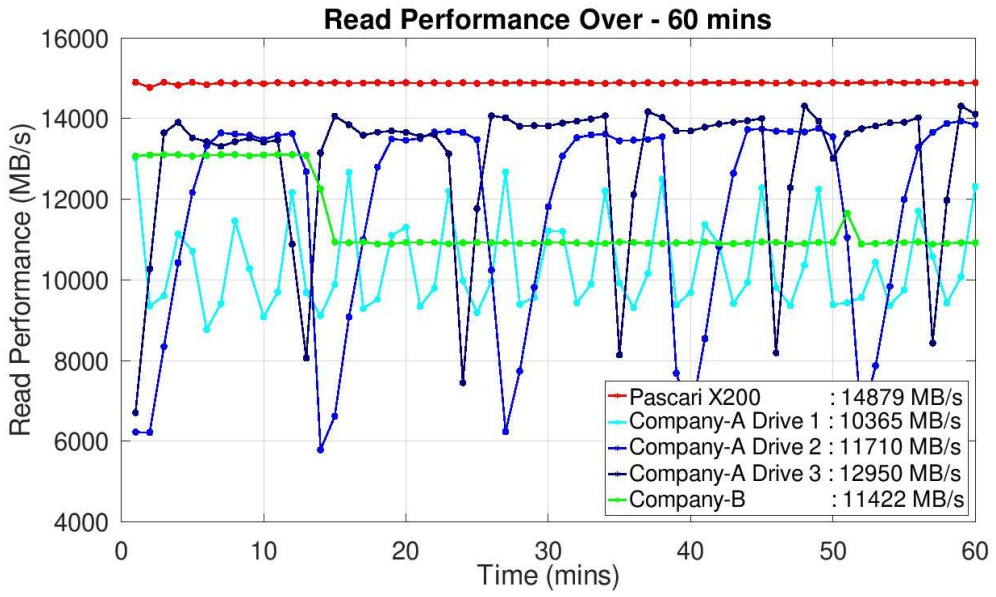
BOL + Power-Off Retention 3Y

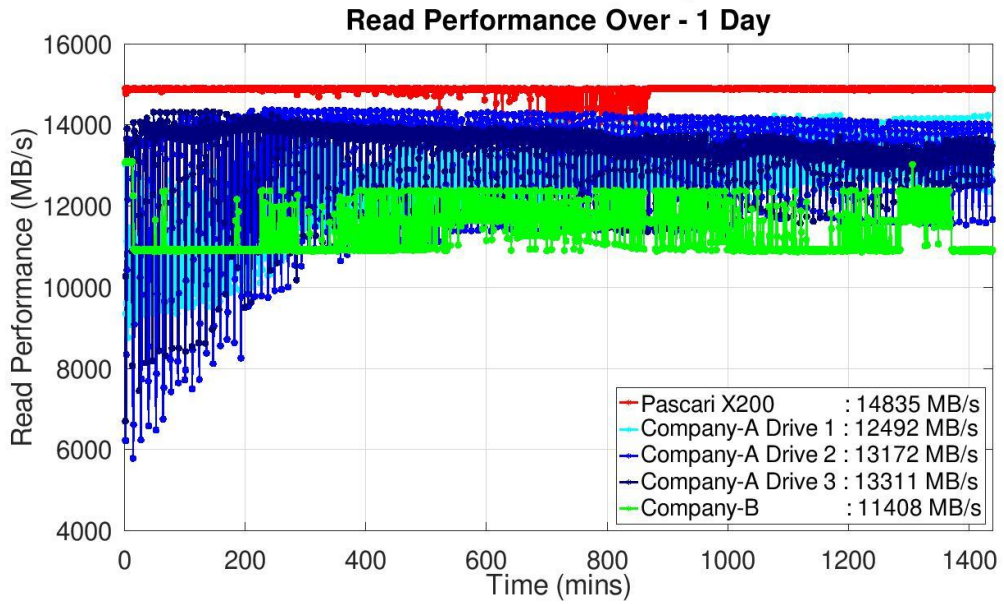
Controller	NAND Flash	**1st Loop** Read Performance
Phison E27	QLC-A	1327 MB/s
Company-A	QLC-A	44 MB/s
Company-B	QLC-A	4.8 MB/s

Controller	NAND Flash	**1st Loop** Read Performance
Phison E27	TLC-A	5378 MB/s
Company-B	TLC-A	839 MB/s

Stress Benchmark: Read Performance Recovery

- Benchmark simulates worst-case NAND degradation:
  - BOL + Cross Temperature
  - 1-year retention
  - Read Disturb
  - Continuous reading for 24 hours
- Results:
  - Phison X200: Drop 0.5 %
  - Company-A: Drop 9%~14%, no recovery
  - Company-B: Drop 13%, no recovery





Summary

Phison Enterprise products meet or exceed JEDEC and customer reliability requirements — with up to 11K PE for cTLC and 3K PE for cQLC.

Phison's patented Dynamic Recovery Sequence, Runtime Read Level Tracking, and Optimal Read Level Search enable:

- Fast performance recovery
- Unlimited power-on reliability
- Strong QLC support
- Stable performance from BOL to EOL

Have questions?

- Contact us at Phison Enterprise
- Learn more on the PHISON Blog

Learn more about Phison Enterprise Storage

PHISON

Thank you