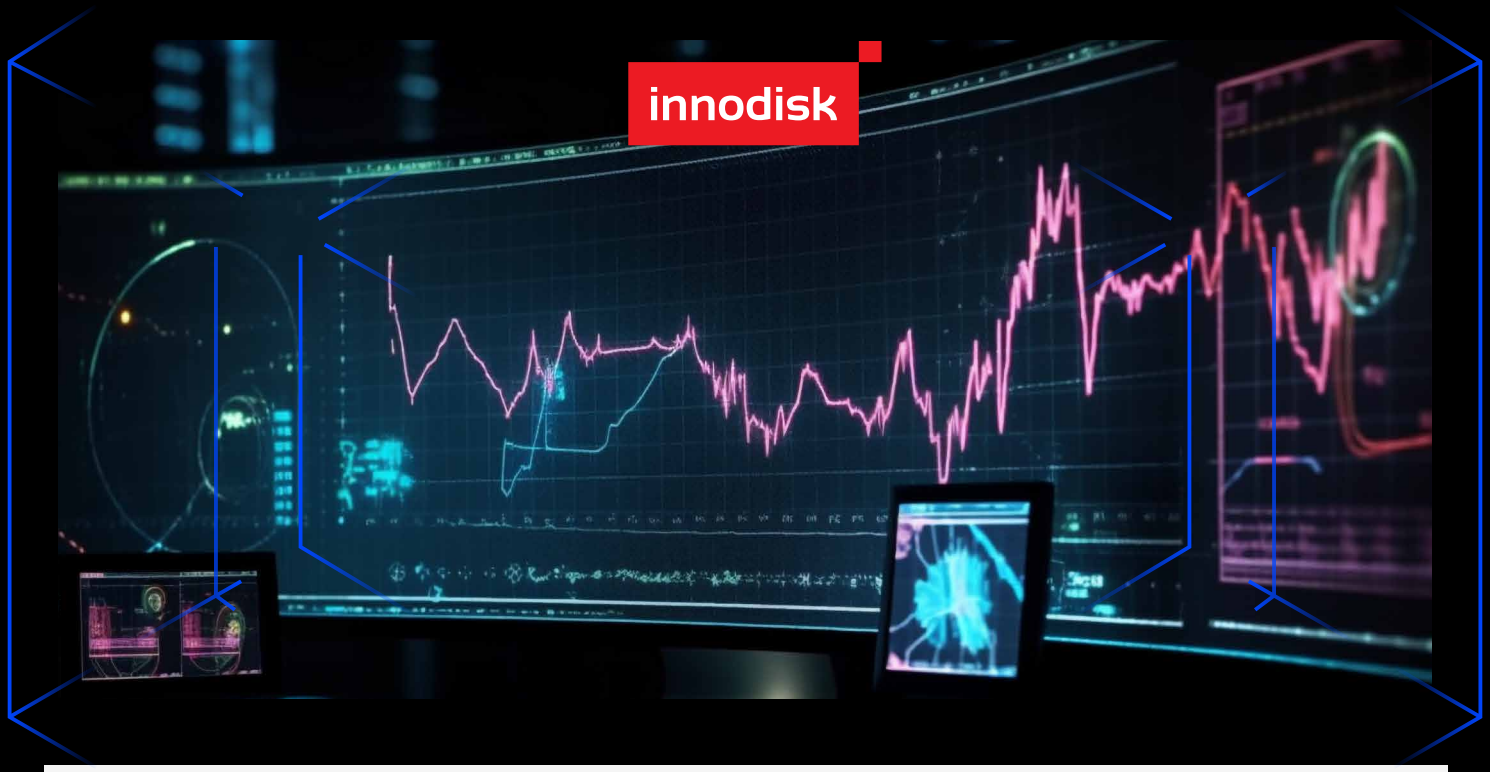


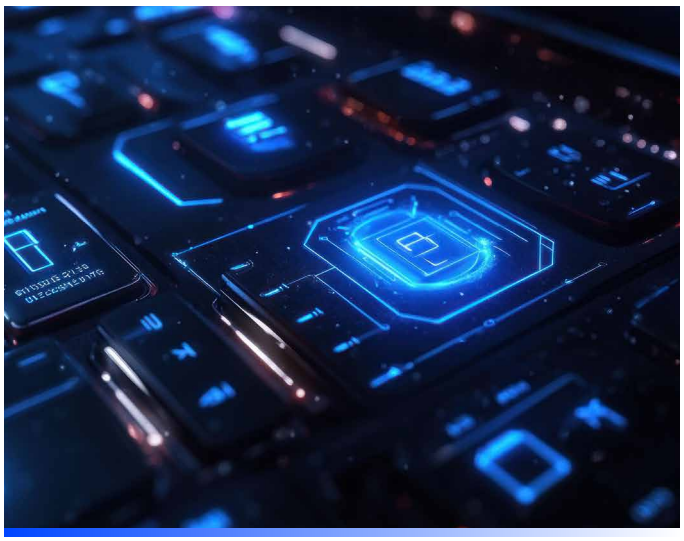
iRetention™ 2.0: Mitigating NAND Flash Data Loss Through Firmware Innovation

Firmware is the critical safeguard that ensures the longevity and reliability of NAND flash memory in solid-state drives. Although all NAND eventually fails, its rate and manner of failure vary depending on conditions such as temperature, usage wear, and read operations. Innodisk's iRetention™ 2.0 protects your data by addressing these data retention challenges through features such as proactive refresh, smart monitoring, and adaptive error correction.

Data Intelligence

INTRODUCTION

NAND flash is the most common memory architecture used in solid state drives (SSDs). It stores data by applying a small electrical charge to each storage cell. This charge encodes specific binary values such as 00, 01, 10, or 11. Data stored on NAND flash can degrade over time because the charge in each cell can leak out. Although SSDs have become essential in many industries, data retention (the cell's capacity to hold onto data) remains a concern. Every integrator should understand the risks of data loss and how fast it can happen.



CHALLENGES

Several factors influence NAND data retention.

External Condition-Heat

Due to the flash cell's structure, higher temperatures will cause data to degenerate at an extremely high rate. This can be explained through simple physical laws: higher temperatures mean particles moving/vibrating faster, and this higher energy translates into a higher chance of charge leaking.

To quantify the impact of temperature on retention loss, engineers use a metric called the Degradation Factor (DF). It is a measure of how quickly data retention declines under certain conditions. DF=1 represents normal retention, while higher values indicate faster data loss. Testing shows that at the 80–85°C range the DF reaches 168. In other words, data will degenerate at a rate of 168 times faster than at standard temperature (<40°C).

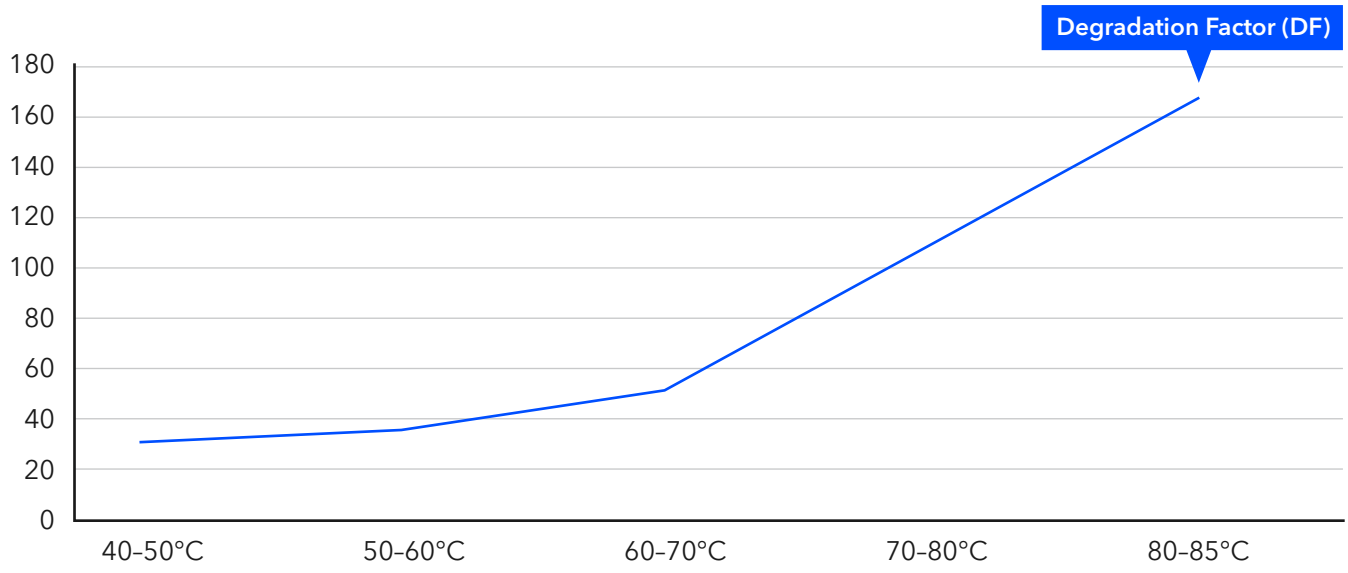


IMAGE 1 Testing shows that at the 80°-85°C range the DF reaches 168. In other words, data will degenerate at a rate of 168 times faster than at standard temperature (<40°C).

Structural Integrity-P/E Cycles

As the number of **program/erase cycles increases**, the flash cell gradually weakens, resulting in reduced data retention capability.

Each erase operation applies a high-voltage charge to the cell, causing slight physical damage over time. This accumulated damage gradually degrades the structural integrity of the cell and reduces its ability to retain data reliably.

The **deletion process is more detrimental** compared to storing data because the charge used to delete the data is larger by several magnitudes.

To better illustrate this degradation, let's look at some real-world figures. For instance, retention testing shows that after 2,200 P/E cycles, data can typically be retained for about 48 days. However, once the cycle count reaches 3,200, retention time drops sharply to just 16 days. This demonstrates how heavy write environments further exacerbate data retention issues over the lifespan of the NAND flash.

Read Disturb

Read disturb is a phenomenon where frequently reading a single page can **affect its neighboring pages** and, in some cases, lead to data loss.

When data is read from a page, a read voltage is sent through all the pages within the block, which can slightly alter the stored values in nearby pages over time.

When electrons leak from NAND cells over time, threshold voltages shift and bit errors may occur. These errors are detected and corrected by ECC (Error Correction Code), but once the number of errors exceeds ECC's correction capacity, permanent data loss can result.

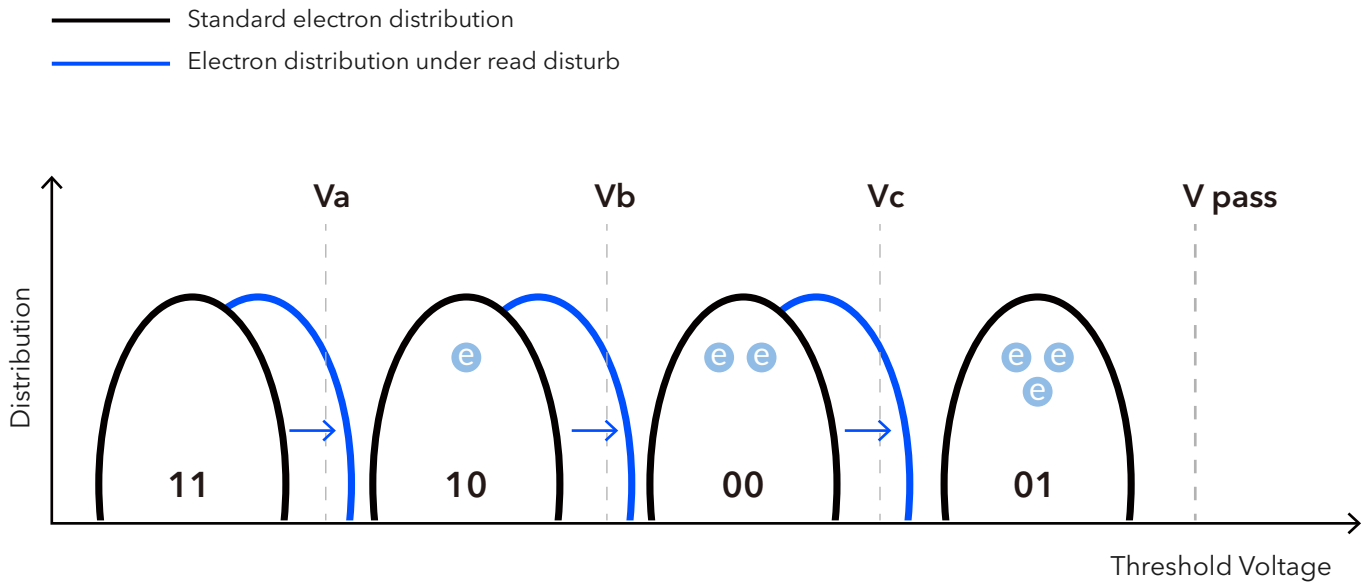


IMAGE 2 Va, Vb, and Vc represent the reference voltage thresholds used to distinguish between different information. Vpass is the pass-through voltage applied to all non-selected pages during a read operation. Repeated exposure to Vpass can gradually shift nearby cells' voltage, causing read disturb.

Smaller NAND Flash Cells

Shrinking cell sizes and increasing IC density in NAND flash aim to fit more storage into smaller packages.

However, one of the **physical realities** of decreasing cell sizes is that the charge in smaller cells will leak at a faster rate compared to legacy NAND flash cells. Although this issue cannot be directly mitigated, it is important to be aware of it when evaluating data integrity.

SOLUTIONS

Innodisk Industrial SSDs are built with high-quality NAND flash chips to ensure compliance with strict data retention standards:

10 years at the beginning of product life / 1 year at end of life (at 40°C).

Most importantly, Innodisk's exclusive firmware technology, **iRetention™ 2.0**, further enhances data reliability by eliminating concerns over long-term storage. The technology combines **preventative** and **corrective** features to address both data retention challenges and read disturb shortcomings.

Preventative

1. **Dynamic micro-charging** periodically and sequentially picks a block and randomly reads a page. This action micro-charges all the cells in the block once through the read action. This mitigates retention degradation, which is usually accelerated by high temperatures and natural cell aging, thereby extending the reliability of stored data.

2. **Smart read** performs a read task across the whole SSD during boot up, ensuring stable future read operations and reducing disturb accumulation.

3. **Dynamic scan** performs regular scans to detect potential weak or defective data early. Pages are then refreshed through flushing and recharging, helping to counteract the cumulative damage caused by repeated program/erase cycles.

Corrective

4. **Fast read retry** eliminates bland attempts of all possible read-voltage combinations by analyzing historical retry results and prioritizing the patterns with the highest success rates. For example, if previous read errors were often corrected by slightly lowering the read threshold, the firmware will attempt that adjustment first. This targeted approach significantly improves the probability of a successful read in fewer attempts, thereby shortening overall latency and reducing stress on the NAND cells.

5. **Dynamic normal threshold voltage** means the read threshold voltage in NAND is not fixed forever. As cells age or experience charge leakage/drift, the “optimal” voltage window for correctly distinguishing between states can shift upward or downward. Dynamic normal threshold voltage addresses this by recording the most recently successful retry voltage and applying it as the new baseline for future reads. By adapting to gradual threshold shifts, the SSD increases the likelihood of reading data correctly on the first attempt, minimizing repeated retries and improving both performance and data integrity over the device’s lifespan.

Together, these technologies form a comprehensive safeguard against SSD data loss and degradation, ensuring long-term reliability even under harsh environmental and workload conditions.

CONCLUSION

As SSDs continue to serve critical roles in industrial and embedded applications, ensuring long-term data reliability has become more than a performance goal-it is a design necessity.

In response, Innodisk has equipped all of its SSDs with iRetention™ 2.0, a firmware-level solution that proactively mitigates NAND degradation through intelligent monitoring, refresh optimization, and adaptive error correction.

Unlike conventional retention solutions that use fixed refresh intervals, iRetention™ 2.0 continuously adjusts its behavior based on real-time temperature and usage patterns-delivering smarter and more efficient protection.

WHY INNODISK?

At Innodisk, we believe that any challenge can be overcome through cooperation. By maintaining a strong line of communication all the way from inquiry to implementation, we ensure a tailor-made solution that fits your application. We remain committed to innovation with our continual focus on hardware, firmware, and software integration.

HEADQUARTERS
INNODISK CORPORATION
5F., No. 237, Sec. 1, Datong Rd., Xizhi Dist., New Taipei City 221, Taiwan (R.O.C.)
T +886-2-7703-3000 **F** +886-2-7703-3555 **E** sales@innodisk.com