Western Digital.


TECHNICAL BRIEF

# Reimagining HDDs with OptiNAND™ Technology

Prepared by:
Western Digital

## Introduction

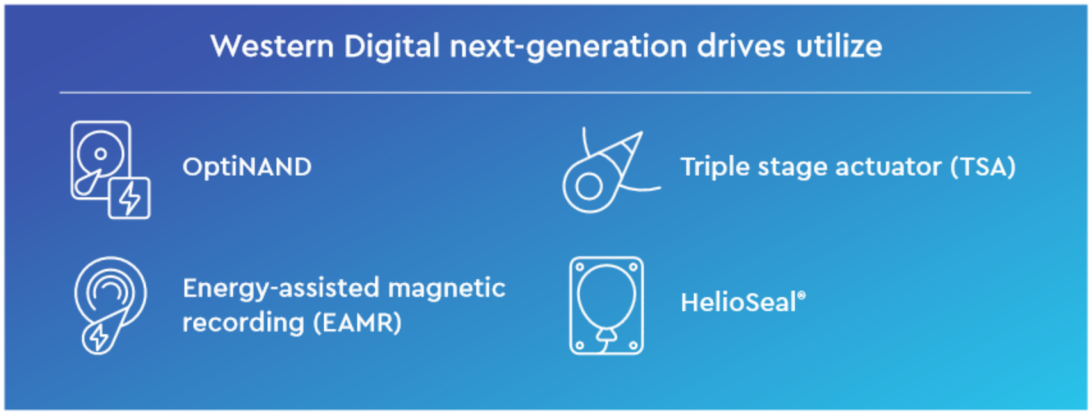
The runaway train that is data proliferation shows no signs of slowing. More than twice the amount of data will be created in the next five years than has been created since the advent of digital storage.[1] New sources such as AI/ML, blockchain, sensors, 5G networks, connected automobiles and more are driving this growth—and with it, a rapidly increasing need for robust, reliable storage. Our customers are relying on Western Digital to help them meet this need.

Western Digital's technological expertise and leadership, together with a diverse portfolio of high-performance HDD and flash products, make us uniquely positioned to help customers meet this demand at scale. We are now expanding our vast portfolio with an innovative solution created entirely in-house at Western Digital.


## OptiNAND™ Technology

When it comes to cost-effective storage of data at scale, hard disk drives (HDDs) continue to play a central role. IDC projects that in 2025, HDDs will represent 82%[2] of capacity sold to the enterprise market. Investments in HDD technology remain critical to supporting worldwide data growth.

Western Digital has developed OptiNAND™ technology for flash-enhanced drives by vertically integrating our leading NAND flash with our world-class HDDs. OptiNAND integrates an iNAND® Universal Flash Storage (UFS) Embedded Flash Drive (EFD) with traditional spinning disk media, and incorporates innovative changes to the firmware algorithm and system-on-a-chip (SoC). OptiNAND is not a hybrid technology. This reimagined storage architecture brings together the two fundamental technologies of Western Digital to deliver a solution that will enable new innovations, forming the basis for future capacity, performance and reliability gains.

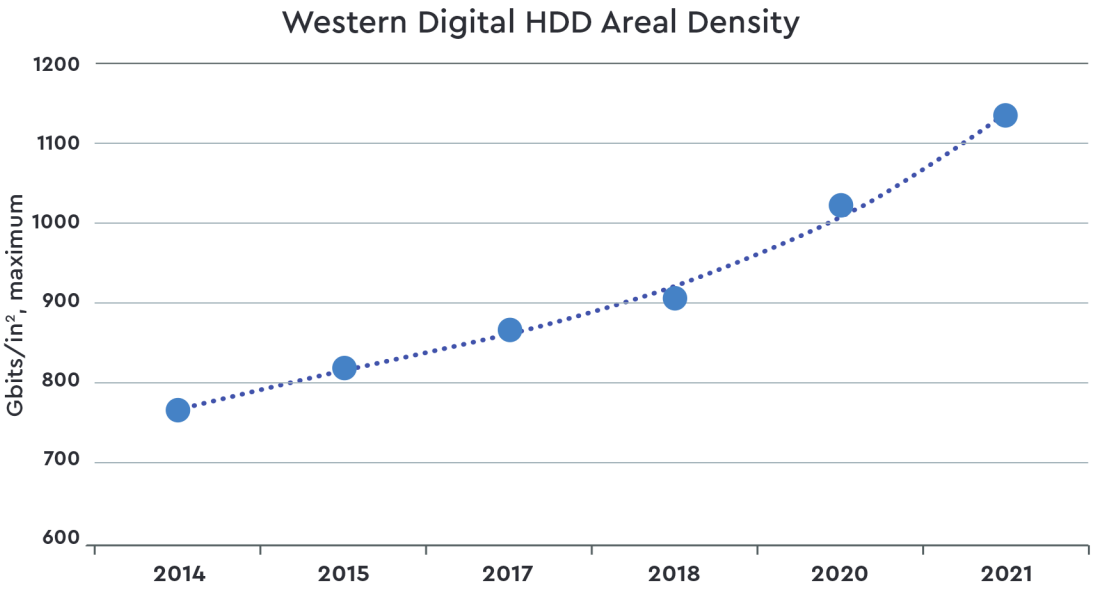


HDD architectures now contain as much memory and processing power as PCs from the early 2000s. Before OptiNAND, non-volatile memory in an HDD was used primarily for booting and storing tiny amounts of metadata. As HDD storage architecture has become more sophisticated, the addition of a flash layer is a logical step in the system's memory hierarchy. Flash is more cost-effective than DRAM, with data persistence across power cycles. Flash also provides faster access than disk, enabling time-sensitive calculations to be performed while keeping the disk free to perform host operations.

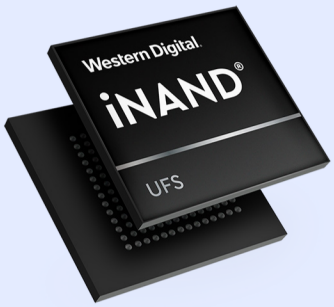
The new OptiNAND-enabled memory hierarchy utilizes the drive SoC to control communication with the iNAND EFD. With OptiNAND, key drive housekeeping functions can take advantage of an increase in metadata capability. This can reduce future DRAM needs as well as enable more sophisticated mechanisms to achieve greater capacities, increased performance and enhanced reliability.

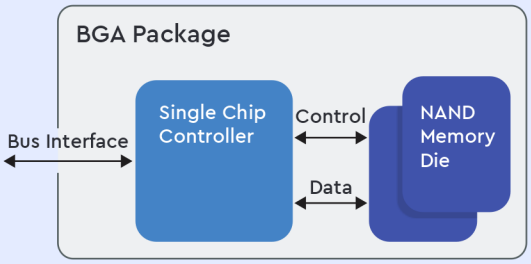
## Capacity

OptiNAND, combined with triple stage actuator (TSA) technology, enables higher areal density through increased tracks per inch (TPI) to provide the highest capacities. HDDs generate gigabytes of metadata that can be utilized to increase areal density. This data is too large to be cost-effectively maintained in DRAM, while retrieving this data on demand from disk interferes with host operations and performance. OptiNAND enables cost-efficient storage and fast access to this massive quantity of metadata that can be stored and accessed in real time, freeing up valuable space on the rotating media for user data.



## Western Digital iNAND Technology




iNAND EFDs are built on Western Digital's proven 3D NAND flash and can be optimized to deliver the right combination of program/erase (P/E) cycles, performance, data retention and temperature requirements.

**iNAND products consist of:**

- Single Chip Controller compliant with JEDEC specs
  - e.MMC 5.1, UFS 2.1, UFS 3.0, UFS 3.1
- Multiple NAND die, depending on configuration
- Single BGA package

NAND flash can store multiple bits within a single NAND cell. Single Level Cell (SLC) stores one bit/cell, while Triple Level Cell (TLC) can store 3 bits/cell. SLC offers higher performance, higher P/E cycles and higher data retention margins compared to TLC, which enables 3X storage in the same footprint as SLC. iNAND technology can enable both SLC for write-heavy operations and TLC for read-heavy operations in the same device.

Repeatable runout (RRO) is the portion of the position error signal that is repeatable for every spindle revolution. RRO metadata is generated in the factory during manufacturing. In prior generation HDDs, the RRO metadata would be stored on a disk, whereas OptiNAND stores this data in iNAND, freeing up disk space for the customer while enabling faster data access.

Write operations are recorded to reduce adjacent track interference (ATI). In prior generation HDDs, write operations were recorded at the track level, while refreshes were done for entire tracks. OptiNAND records write operations in iNAND at the sector level. This metadata is used to refresh sectors instead of whole tracks. Eliminating excess refreshes allows tracks to be placed closer together without performance loss.

The first generation of products with OptiNAND delivers an unbeaten 20TB[3] capacity in a nine-disk platform (2.2TB/platter) with CMR recording format.

## Performance

During an emergency power off (EPO) event, OptiNAND can flush more than 100MB of write cache data into iNAND while prior generation HDDs could only flush ~2MB of data to serial flash. With the capacity to store more than 100MB of data during EPO, random write performance in write cache disabled (WCD) mode can approach that of write cache enabled (WCE) mode. In addition, drive latency is improved with proprietary firmware optimizations focused on requiring fewer ATI refreshes and reducing the need for write cache flushes in WCE mode.

## Reliability

In the event of an EPO, OptiNAND can securely flush and retain nearly 50x more customer data than prior generation HDDs that flush data to DRAM. Meanwhile, OptiNAND technology will extend the capability of energy-assisted PMR (ePMR) for multiple generations, allowing customers to continue benefiting from a proven recording technology.

Western Digital's vertical integration includes HDD and iNAND manufacturing (using NAND from a joint venture with Kioxia). This provides for adequate supply allocation and stable flash nodes. With Western Digital's unique capabilities in design, development, testing and qualification of flash-enhanced drives, customers can count on the drive's reliability.

## Summary

Western Digital has reimagined HDDs with OptiNAND technology, which integrates an iNAND EFD with traditional spinning disk drives and incorporates innovative changes to the firmware algorithm and SoC. These flash-enhanced drives feature a pioneering storage architecture that brings together the two fundamental technologies of Western Digital to deliver a solution that will enable new innovations and form the basis for future capacity, performance and reliability gains.

OptiNAND has broken through the conventional boundaries of storage, adding to Western Digital's legacy of industry-first technologies like EAMR, TSA and HelioSeal, enabling customers to navigate the phenomenal worldwide growth in data.

## Learn More

Energy-Assisted Magnetic Recording Technology for Higher HDD Capacities

Essential Mechanical Innovations to Drive Industry Leading Capacities

### NAND Glossary

**SLC: Single Level Cell** — one bit per storage cell

**TLC: Triple Level Cell** — three bits per storage cell

**P/E cycles:** the number of times a NAND device can be programmed and erased while maintaining its data retention requirement

**Endurance:** the number of P/E cycles a NAND device is specified for

**Data Retention:** the amount of time that a NAND device will retain its data

### HDD Glossary

**ATI: Adjacent Track Interference** — interference from the proximity of tracks written next to each other on the media

**EPO: Emergency Power Off** — a sudden loss of power during which power stored inside the HDD during spin down is used to flush the write cache non-volatile cache to prevent data loss

**RRO: Repeatable Run Out** — portion of the position error signal that is repeatable for every spindle revolution; the irregularity of the servo track during servo track write can be caused by various disturbances, but some coming from sources like spindle motor are repeatable

**TPI: Tracks per Inch** — a measurement of the density of tracks on a hard drive spinning disk

**ePMR: Energy-assisted PMR** — an EAMR technology that applies an electrical current to the main pole of the write head during the write operation

[1] IDC press release, March 24, 2021: "Data Creation and Replication Will Grow at a Faster Rate than Installed Storage Capacity, according to the IDC Global DataSphere and StorageSphere Forecasts"

[2] IDC Worldwide Hard Disk Drive Forecast Update, 2021–2025 – Doc #US47633120; and IDC Worldwide Solid State Drive Forecast Update, 2021–2025, May 2021, Doc #US46412021

[3] One gigabyte (GB) is equal to one billion bytes and one terabyte is equal to one trillion bytes. Actual user capacity may be less due to operating environment.

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