Quantum®

TECHNOLOGY BRIEF

LTO-8: The Saga Continues—Increased Performance, Capacity, and Data Reliability

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INTRODUCTION

This technology brief provides a detailed description of technology improvements for LTO-8 tape drives and media which have increased capacity, performance, and reliability. The LTO-8 drive is available in two versions: full-height (FH) and half-height (HH) drive form factors. Section 2 of this document compares each drive version to help customers understand which is best for their environment and use case.

The LTO tape format has become the market-dominating standard for magnetic recording tape drives and media over the past years. The technology has progressed from LTO-1 (2000) and most recently has delivered the latest generation with the release of LTO-8 (2017).

COMPARING LTO-7 AND LTO-8 SPECIFICATIONS

- Capacity: 100% increase
- Performance: 20% increase
- Tape drive durability improvements
- Media reliability improvements, which are particularly valuable with increasing demands for long-term retention: 100x increase in data reliability due to improved bit error rate (BER) and advanced Barium Ferrite (BaFe) media

Feature	LTO-5	LTO-6	LTO-7	LTO-8 M Format (FH)	LTO-8 (FH)
Native capacity	1.5 TB	2.5 TB	6 TB	9 TB	12 TB
Compressed capacity	3.0 TB	6.25 TB	15 TB	22.5 TB	30 TB
Native performance	140 MB/sec 500 GB/hr	160 MB/sec 576 GB/hr	300 MB/sec 1.08 TB/hr	300 MB/sec 1.08 TB/hr	360 MB/sec 1.38 TB/hr
Compressed performance	280 MB/sec 1 TB/hr	400 MB/sec 1.4 TB/hr	750 MB/sec 2.7 TB/hr	750 MB/sec 2.7 TB/hr	900 MB/sec 3.24 TB/hr
Hard BER	1 in 10^{17}	1 in 10^{17}	1 in 10^{19}	1 in 10^{19}	1 in 10^{19}
Read/write back to	LTO-3/LTO-4	LTO-4/LTO-5	LTO-5/LTO-6	LTO-7/LTO-M8	LTO-7/LTO-M8

TECHNOLOGY IMPROVEMENTS AND CHANGES THAT PROVIDED THE RESULTS

LTO-8 continues to deliver the capacity and performance improvements which were introduced with LTO-7. In the next section, which explains many of the technology improvements, all "LTO" references apply to both LTO-7 and LTO-8. Any differences between LTO-7 and LTO-8 are specifically identified.

Capacity: LTO capacity increased with the final transition to using BaFe media. Some manufacturers started this transition with LTO-6 and adopted the new media formulation. This change is now complete for all LTO Consortium partners. The BaFe media composition has smaller magnetic particles, which allow increased recording bit density, resulting in higher capacity. A new servo format was adopted to reduce signal noise, improve positional sensitivity, and implement a higher bandwidth servo—which were enablers for higher capacity, higher transfer rates, and improved data durability. Another key differentiator for LTO is the Aggregated Rewrite format that achieves smaller-capacity overhead, therefore, higher-efficiency tape areal utilization. This is accomplished by compressing all unwritten user data sections due to media errors and rewriting them at the end of each data set, resulting in lower- capacity overhead: 3% with LTO versus 5% with LTO-6.

Performance: LTO tape drives have increased the data buffer to 1 GB from the 512-MB buffer used in prior generations. The increased buffer size helps the tape drive continue to write data in streaming mode—even when ingest data rates are not consistent. Another major change for LTO that impacts performance is a new recording head design that uses 32-R/W channels, an increase from the 16-R/W channel head used in prior LTO formats. It is the combination of the new head design and the increased data density using the BaFe media that delivers the increased performance for LTO. In newer generations of LTO, the media is moving at a slower rate (LTO-8 @ 4.731 m/sec, LTO-7 @ 5.01 m/sec vs. LTO-6 @ 6.83 m/sec) compared to prior generations while still increasing maximum data performance. Slower tape speed is an enabler for future generations of LTO drives to offer higher data rates while still using 32 data channels.

Data integrity: LTO has a new error-correcting code (ECC) data format, which results in higher data durability compared to LTO-6 when used with new and improved BaFe media and the new high-performance servo system. The LTO ECC format is based on a two-dimensional interleaved dual error-correction code, where the inner code is operated in error detection and correction mode, where the outer code is in erasure mode. LTO's unique two-dimensional interleaving algorithm randomizes media defects and burst errors. This randomization enables ECC to work efficiently, resulting in extremely low BER numbers. Starting with LTO-7, the channel number has been increased to 32 from 16, and the inner ECC has been modified to include header metadata along with the user data such that both are now protected by a stronger ECC format. The LTO-7 and LTO-8 format is (249,237,13) where LTO-6 format is (240,230,11). The LTO code word is 9 bytes longer with two bytes more parity. This new architecture is the key to achieving even lower BER numbers compared to LTO-6. It is this change that made it possible for the BER detection specification for LTO to be increased to no more than a single bit error for every 1×10^{19} of bits transferred. This data-integrity checking is 100x better than LTO-6 and is considered to be enterprise-class data-integrity checking.

The LTO BER specification is based on a calculation of uncorrectable C2 ECC events, assuming all errors are random and uncorrelated. This is a theoretical analysis, since experimentation-based estimates will require approximately 130 years at a 300-MB/sec data rate to encounter an error event. These theoretical calculations are based on an LTO-7 with a 32-channel, multi-dimensional, deep-interleaving format architecture, and the new ECC format with advanced BaFe media, assuming all byte errors are random and uncorrelated. This assumption has been experimentally verified. More complex reliability models, which are based on the theory of renewal processes, can account for correlated errors and defective header and synchronization fields [2]. Therefore, the theoretical analysis of the error correction scheme implemented in LTO leads to an uncorrectable error rate over the lifetime of the drive of one error per 1E19 bits read.

Tape drive and media durability: The LTO tape drive has also undergone significant changes starting with LTO-7. All of the tape path guide rollers now have a flangeless design—providing a smoother tape path that is less likely to cause any damage to the tape edge. This design has also proven to be less likely to incur media debris buildup, which will reduce cleaning and service requirements. Figure 1 shows the LTO linear actuators system with tape guiding and a magnetic head with read and write elements resulting in a read-while-write process.

[1] S. Furrer, M. A. Lantz, J. B. C. Engelen, A. Pantazi, H. E. Rothuizen, R. D. Cideciyan, G. Cherubini, W. Haeberle, J. Jelitto, E. Eleftheriou, M. Oyanagi, Y. Kurihashi, T. Ishioroshi, T. Kaneko, H. Suzuki, T. Harasawa, O. Shimizu, H. Ohtsu, and H. Noguchi. "85.9 Gb/in2 Recording Areal Density on Barium Ferrite Tape," IEEE Transactions on Magnetics, vol. 51, no. 4, April 2015.

[2] S. S. Arslan, J. Lee, J. Hodges, J. Peng, H. Le, and T. Goker, "MDS Product Code Performance Estimations Under Header CRC Check Failures and Missing Syncs," IEEE Transactions on Device and Materials Reliability, vol. 14, no. 3, Sept. 2014.

Servo format changes: LTO has a new servo format very similar to the one that is used in enterprise-class tape drives. It is still the same timing-based servo format as in LTO-6 and prior generations. However, there are two key changes that result in improved tracking performance and data reliability. The servo format is more compact, with increased sensitivity and lower noise because of its new geometric compactness by increasing azimuth angle and shortening of the overall dimensions where both allow higher tracking bandwidths. Also, data band detection is now embedded as encoded data words into the servo format information, which makes the band ID detection stronger due to servo format ECC.

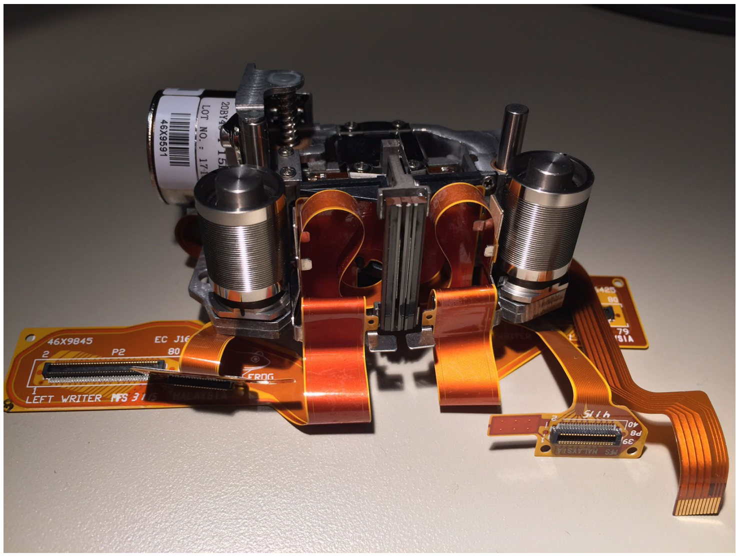

Figure 1. Special grooved rollers without flanges integrated with the multi-stage linear actuator for optimum tracking performance without touching tape edges.

Long-term data retention: The change to BaFe media will enable customers to reliably retain data for longer periods of time compared to prior media generations. This point is particularly valuable as the role for tape is becoming more about storing data for long-term uses cases such as data archiving, where media may not be accessed for a number of years.

Figure 2 shows how much data a single cartridge will be able to reliably store over its planned lifespan. It is easy to see how these technology advancements provide nearly 3x the cartridge life expectancy compared to previous LTO generations.

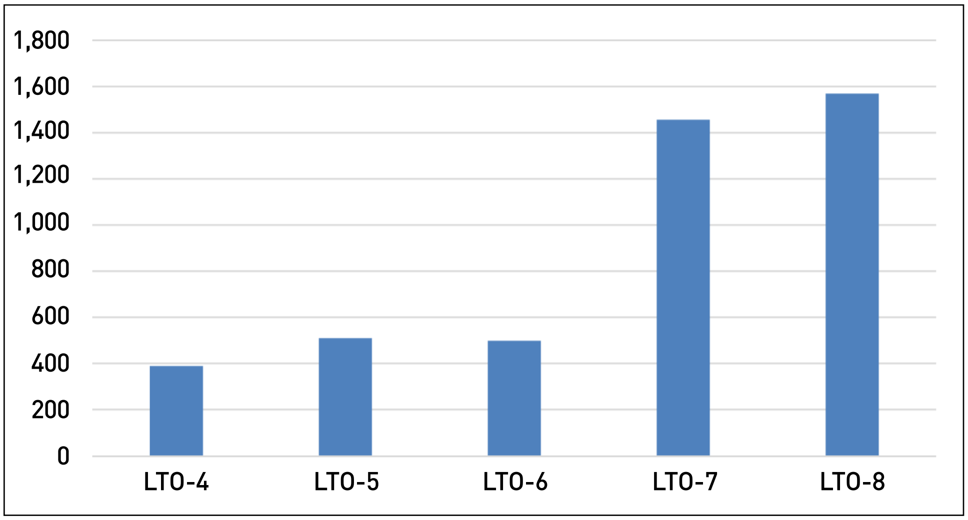

Figure 2. Total terabytes transferred to EOL of cartridge

LTO-8 FULL-HEIGHT VS. LTO-8 HALF-HEIGHT DRIVE FORMATS

LTO-8 is available in both FH and HH drive formats. What are the differences and why would you choose one over the other?

A clear majority of the technology and improvements that have been implemented are shared between both LTO-8 FH and LTO-8 HH tape drives. There are a few small differences, mostly due to the FH drive having more real estate for the circuitry and mechanical assemblies. The following chart shows how the two drives are alike as well as where they differ.

Technical Feature	LTO-8 FH	LTO-8 HH
MTBF of 250,000 power-on hours at 100% duty cycle	Yes	Yes
MSBF: cartridge load/unload cycles	300,000	80,000
Read-after-write data integrity verification	Yes	Yes
Integrated head cleaner	Yes	Yes
Library Drive Interface (LDI)	Yes	Yes
Microcode updatable	Yes	Yes
Speed matching	Yes	Yes
Encryption capable	Yes	Yes
Automation Drive Interface (ADI) support	Yes	Yes
Graceful dynamic brake function at power loss	Yes	Yes
LTFS capable	Yes	Yes
8-Gb Fibre Channel interface	Yes	Yes
Serial Attached SCSI (SAS) at 6-Gb/sec interface	No	Yes
Cartridge auto-eject on over temperature	Yes	Yes
Single-character display (SCD) and LED panel	Yes	Yes
Encryption LED	No	Yes
Customer-centric statistical analysis reporting system	Yes	Yes
Improved pin pick and threader mechanics to return leader pin to cartridge	Yes	Yes
New high-bandwidth dual-stage actuator	Yes	Yes
Restriction of Hazardous Substances (RoHS) compliance	Yes	Yes
32-channel implementation to support Ultrium generation 7 media	Yes	Yes

Besides having the same capacity and performance, most of the features delivered in LTO-8 are the same when comparing the FH and HH tape drives. When examining the drives at the next level of detail, there are differences that are not as obvious.

Technical Feature	LTO-8 FH	LTO-8 HH
Tape speed (maximum during locate/search)	10 m/sec	9 m/sec
Tape speed (maximum during rewind)	10 m/sec	9 m/sec
Acceleration	10 m/sec	5 m/sec
Reposition (back hitch)	3.6 sec	5.2 sec
Average time to record from load point	56 sec	60 sec
Average rewind time	59 sec	62 sec
Cartridge insertion force (required)	1,530 gm	1,000 gm
Cartridge insertion force (maximum allowed)	3,060 gm	1,500 gm
Shock during operation	30 G	10 G
Vibration during operation	.67 G	.30 G

FH drives have larger motors: A simple place to start understanding these differences is size. The FH drive has significantly more space to allow for the use of larger and more robust mechanical assemblies, increased airflow for cooling electronics, as well as the use of larger motors that move the tape during writing, reading, and tape positioning.

The use of larger motors in the FH drive actually provides a number of advantages over the HH version of LTO-8. The next section explains how the use of larger motors impacts a number of LTO tape drive characteristics.

FH drives provide increased mechanical reliability: The use of larger motors in this part of the LTO drive operation is relatively simple mechanics. Even though both the FH and HH drives have the same reliability ratings, by using larger motors to move the recording media, the larger motors are operating at a much lower percentage of the designed maximum performance. Ultimately, this will increase the overall mechanical reliability of the tape drive.

FH drives move media faster: The FH LTO-8 drive moves media faster than the HH drive; and in use cases where files are being accessed randomly from various locations on the cartridge, this can have a significant impact on the overall sustained data performance rates. For customers using the Linear Tape File System (LTFS) features of LTO, this may be particularly true in that files are stored as they are written, and there is no way to predict which files are going to be accessed prior to the actual read request being received.

FH drives support faster media acceleration: The second advantage of using the larger motors in the FH drive is media acceleration. Acceleration comes into play when data transfer rates are not sufficient to maintain reading/writing in "streaming mode." If a host is not sending data fast enough, or is not acknowledging the receipt of data soon enough, the drive will slow down through the LTO drive native speed matching capability; but if the data rates fall below a certain threshold, the drive will eventually stop moving tape. During a write operation, the drive will attempt to perform speed matching to a minimum of 112 MB/sec, and if the data stream drops below this threshold, the tape motion is stopped. When the data stream resumes, the tape drive will move the media backwards a short distance, come back up to speed, and then resume writing. This process is also known as "back hitching." With the faster acceleration of the FH drive for environments where back hitching occurs regularly, the FH drive will clearly have advantages over the HH drive.

FH drives are more immune to shock and vibration: The base plate in the FH LTO-8 is made of aluminum compared to a composite base plate used in the HH drive. The metal base plate provides significantly more immunity to shock and vibration that can cause problems if these factors exceeded.

Cartridge insertion force: With a vast majority of LTO drives and media being installed in automation or a library, it is important to make sure the robotic mechanism is handling media properly into and out of the tape drive. Even though a majority of the libraries in use today are being designed to handle media within these specifications, Quantum recommends that organizations have the most durable and robust mechanism available. This is particularly true when the library will be mounting/dismounting tapes at a high rate in archive use cases where the FH drive is rated to handle 300,000 load/unload cycles, compared to 80,000 cycles for HH drives.

Thermal protection: Temperature is one the worst enemies of magnetic media. Both the FH and HH drives will automatically protect media from being subjected to over-temperature conditions. As shown in figure 3, the FH drive has a much lower operating temperature, even when operating at full performance.

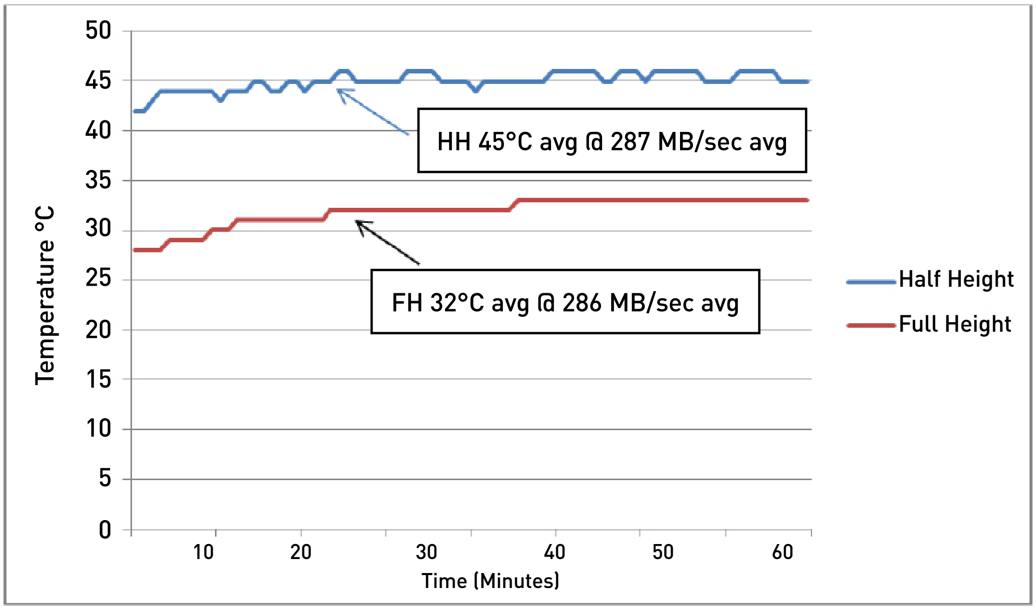

Figure 3. LTO sets new milestones for performance, capacity, and reliability with the release of the LTO tape drive.

Media durability has been increased to offer customers a more reliable long-term storage technology.

Although both the FH and HH versions of the tape drive have many common characteristics, there are several differences that clearly make the FH drive the better choice for high-duty cycle environments, as well as use cases where the drives will be accessing files that are stored in multiple locations on the same cartridge, and also where the drives will be required to load/unload many cartridges during normal use. This factor is particularly true for archive use cases as well as where the LTO LTFS is being used.

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