Trends in Enterprise Hard Disk Drives

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The storage capacity and performance of Enterprise HDDs have been steadily enhanced in the past, but now HDD development has reached a turning point. For the 3.5-inch HDD, 300-GB capacity has been achieved for 10 000-rpm drives to satisfy storage requirements. Now, there is a shift towards 15 000-rpm drives in pursuit of higher performance. Moreover, to address the requirements for compactness, power saving, and higher performance through the use of multiple spindles, 2.5-inch HDDs are now commercially available. Regarding Small Computer System Interface (SCSI), the limits of transfer speed have been reached, resulting in a switch towards Serial Attached SCSI (SAS) that employs high-speed serial transmission technology. In response to these market changes, Fujitsu has added a range of AL-9SE 2.5-inch HDDs to its AL-9 series and assumed the industry lead by supporting SAS (3 Gb/s). This paper summarizes trends in the general market and technologies for enterprise HDDs, and gives an overview of the features and technologies of the AL-9 series; Fujitsu's latest series of HDDs designed to cater to current market needs.

1. Introduction

Enterprise HDDs are specifically designed for such mission-critical applications as core servers and large-scale storage systems, and account for about 10% of worldwide HDD shipments. There are consistent needs for both higher performance and reliability in the enterprise HDD market. Fujitsu considers enterprise HDDs an important segment of the market, given their role as a vital element of the infrastructure of mission-critical systems.

Until now, high storage capacity and high performance have been pursued for enterprise HDDs with the 3.5-inch HDD as the industry standard form factor. However, a turning point has been reached regarding several key factors, including the introduction of the 2.5-inch Small Form Factor (SFF) HDD, the shift from the parallel Small Computer System Interface (SCSI) to the Serial Attached SCSI (SAS), and the meeting of market requirements for higher capacity. This situation can be attributed to the growing need among blade servers and rack-mounted servers for HDDs of smaller size and higher performance, and the growing number of configurations that employ HDDs with different characteristics in a layered or tiered fashion within systems.

Since Fujitsu began shipping its AL series of 3.5-inch HDDs as high-end products of high performance and high reliability in 1994, HDD storage capacity, functionality, and performance have been steadily enhanced.[1] The AL-9 series (introduced in 2004) has a maximum capacity of 300 GB and more recently, a range of 2.5-inch high-performance, high-reliability HDDs has been added to the product lineup in response to new market needs for compactness and power saving.

This paper summarizes the trends in the market and technologies regarding enterprise HDDs, and gives an overview of the features and technologies of AL-9 HDDs, the latest models in the AL series.

2. Market trends in enterprise HDDs

There has been a constant need for enterprise HDDs used in server and storage systems requiring high performance and high availability to provide high storage capacity simultaneously with high performance and reliability. Regarding storage capacity, as the tiered or layered storage configurations that can employ a variety of HDDs with different characteristics become increasingly popular, the maximum requirement per spindle for high-performance HDDs is now 300 GB. In view of the rapidly increasing needs for compactness and power saving, we see the 2.5-inch form factor replacing the 3.5-inch form factor as the mainstream in enterprise HDD products of the future.

The factors in the background of layering HDDs are the diversification of storage connection forms (e.g., Network Attached Storage [NAS], Storage Area Networks [SANs]) as the use of networks has expanded, and the changes in data management methodologies based on the concept of Information Lifecycle Management (ILM). For instance, the use of near-line storage for large-volume online data (for which access frequency is comparatively low) has been expanding. For this type of storage, HDDs for which cost and capacity are emphasized over performance are typically used. Such HDDs may also be broadly considered one type of enterprise HDD, although this paper defines enterprise HDDs as those operating at over 10 000 rpm and providing high performance and assured 24/7 continuous operation.

HDD rotational speeds have been increased as a means of achieving higher performance. At present, 10 000-rpm, 3.5-inch HDDs are most commonly used, though the proportion of 15 000-rpm, 3.5-inch HDDs will certainly increase in the future. As for the 2.5-inch HDDs in the AL-9 series, the market expects to see 15 000-rpm products as soon as possible in addition to existing 10 000-rpm models, as was done for 3.5-inch products. **Figure 1** shows a forecast for the worldwide shipments of enterprise HDDs by form factor and rotational speed.

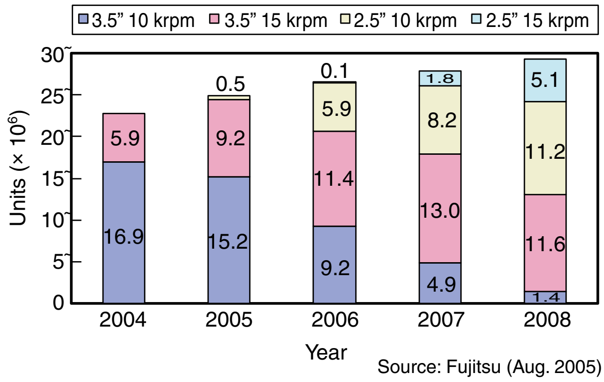


Figure 1
Forecast for enterprise HDD shipments (by form factor, rotational speed).

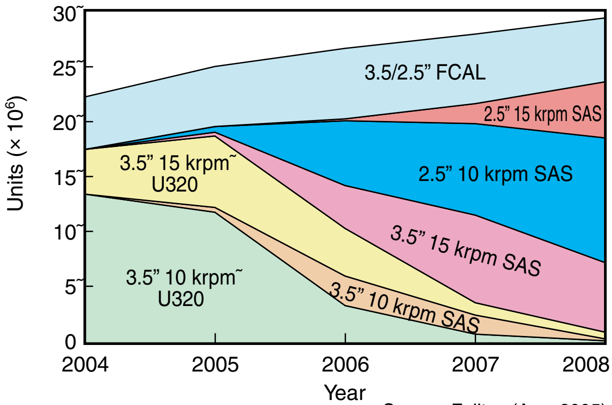
A major turning point has also been reached regarding interfaces that have realized high performance and abundant features in enterprise HDDs.[2] Until now, parallel SCSI and Fibre Channel Arbitrated Loop (FCAL) have been the two major interfaces supporting enterprise HDDs. For parallel SCSI, which was introduced 20 years ago, a limit has been reached in terms of technology for increasing data transfer speeds and there is now a rapid shift towards SAS that uses high-speed serial transmission technology. **Figure 2** shows a forecast for enterprise HDD shipments by interface and form factor.

3. Technology trends in enterprise HDDs

Various innovations have been made to achieve higher performance and reliability in enterprise HDDs. The following discusses the major requirements for enterprise HDDs and the trends in technologies in response to these requirements.

1) High storage capacity

The needs for higher storage capacity have been met by enterprise HDDs by doubling the stor-



FCAL: Fibre Channel Arbitrated Loop
SAS: Serial Attached SCSI
U320: Ultra 320 SCSI

Figure 2
Enterprise HDD shipments forecast (by form factor, interface).

age capacity of each new generation. At present, the maximum capacities of 3.5-inch HDDs are 300 GB for 10 000-rpm devices and 147 GB for 15 000-rpm devices. The enhancement of areal recording density through improved performance achieved by GMR heads and multilayer media for longitudinal recording, and advances made in servo technology to enable high-precision tracking, for example, have made such increases in storage capacity possible.

Conversely, to prevent increases in data recovery time due to the maximization of capacity and degradation of performance due to access contention accompanied by the high concentration of data, 300 GB now appears to be the limit of capacity demand per spindle of high-performance HDDs. Thus, it is becoming normal to assign HDDs with optimum capacity, performance, reliability, and cost characteristics within systems in consideration of the attributes of data access. For example, HDDs of ultrahigh storage capacity (for which precedence is given to storage capacity and cost over rotational speed, seek speed, and other aspects of performance) are used for near-line storage applications.

The future evolution of magnetic recording technology in the enterprise HDD market, such as for enhancing areal recording density, will be geared towards cost optimization (by reducing the number of platters and employing more compact design using smaller-diameter platters) and higher performance.

2) High rotational speed

In view of the tremendous contribution made by reducing average rotational latency to improve access time, enterprise HDDs have continually employed higher rotational speeds. For 3.5-inch HDDs, 10 000 rpm and 15 000 rpm are now standard, and 2.5-inch HDDs (expected to undergo rapid diffusion) that operate at 10 000 rpm are now being commercialized.

Regarding the basic technologies that have supported increasingly higher rotational speeds, advances have been made in spindle motor technologies and reliability enhancements, as typified by the Fluid Dynamic Bearing (FDB) motor. Moreover, the technologies for maintaining high recording densities to suppress mechanical vibration and media flutter imposed by high rotational speeds have become increasingly important. Consequently, small-diameter platters of 65 to 70 mm have been used for HDDs operating at 15 000 rpm. In addition, the shroud and spoiler for the form and location to suppress turbulence have been optimized, with improvements made to counter actuator vibration, thus further enhancing recording density, performance, and reliability simultaneously.

Ultrahigh-speed HDDs rotating at speeds exceeding 20 000 rpm have also been researched but not commercialized due to heat generation, power consumption, noise, vibration and other problems in characteristics, and a lack of long-term reliability. Current efforts in achieving ultrahigh performance are focusing on increasing spindle density by employing 2.5-inch enterprise HDDs. This is considered a rational technical trend in view of the advantages provided for various characteristics and scalability.

3) High-speed data transfer

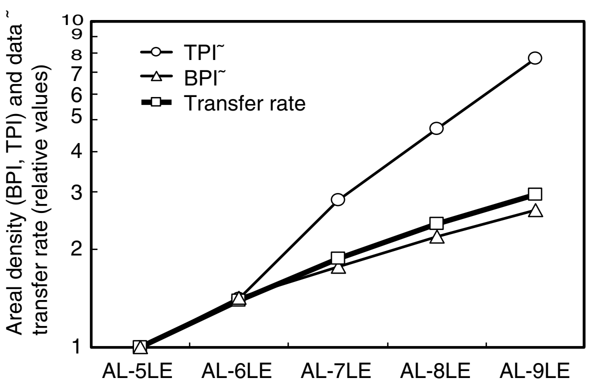
In pace with increases in recording density, data transfer speeds within the HDD have inevitably become faster and the latest HDDs operating at 15 000 rpm achieve transfer speeds of 150 MB/s.

The major key factors controlling maximum transfer speed are the characteristics of read and write elements of the head for high frequency recording, performance and signal processing features of the read channel LSI and preamp LSI, and transmission characteristics of signal routes between such LSIs and the head slider. In view of the recent trend toward increasing recording density through track density (TPI: Tracks per Inch) rather than linear recording density (BPI: Bits per Inch), data transfer speeds have increased by about 25% per generation (**Figure 3**).

4) High-speed access

As a basic characteristic of HDDs, access performance is expressed in terms of average seek time and average rotational latency. However, now that SCSI and FCAL command queuing functions have come into general use, it can no longer be said that these values effectively express access performance.

When command queuing is used, the reordering of commands is conducted to achieve the most effective access time based on the relationship between the position of heads (at command completion) and the position to be accessed by the next command. The evaluation for reordering is generally based on the time for movement in both the seek direction and the direction of rotation. Effective access performance is therefore largely dependent on the seek speed over a relatively smaller distance and the stability of seek settling, the reordering algorithm, and the performance of the controller that executes the reordering process.



Note: Taking the areal density (BPI, TPI) and data transfer rate of the AL-5E as 1.

Figure 3
Areal density (BPI, TPI) and data transfer rate.

Cache functions are also an effective means of improving access performance. For a typical cache memory size of 8 to 16 MB, the caching algorithm for both read and write operations has been optimized to achieve better command response times.

5) High-speed interface

Since its introduction in the early 1980s, parallel SCSI has been instrumental in facilitating ease of use and such scalability as logical block addressing. Although parallel SCSI has been able to meet the needs for enhanced functionality and performance through a large-scale expansion of functions and increases in data transfer speed on several occasions during this period, technical limits on increasing transfer speed by using parallel buses have now been reached for the current U320 interface (with a maximum data transfer speed of 320 MB/s).

SAS, the successor to SCSI, employs high-speed serial transmission technologies similar to those of the Fibre Channel interface in the physical layer, with the command set and other logical layers compatible with SCSI. SAS provides transmission speeds of 3 Gb/s (300 MB/s) with point-to-point connections, and since Wide Link (which provides multi-lane connections using several transmission lines in parallel) is also possible, scalability is truly excellent. **Figure 4** shows the throughput (MB/s) measured when several HDDs are connected to SAS. As well as the advantage of compactness due to its small number of signal lines, SAS is expected to rapidly replace SCSI in the next few years.

FCAL has seen much use in high-end RAID systems, its principal application, and will continue to be a major interface in the future. In

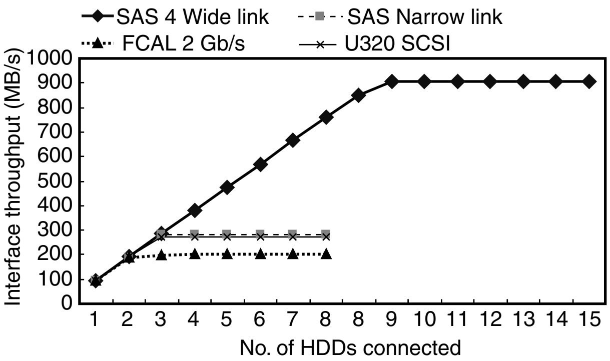


Figure 4
Number of HDDs connected vs. throughput (64k-byte sequential read).

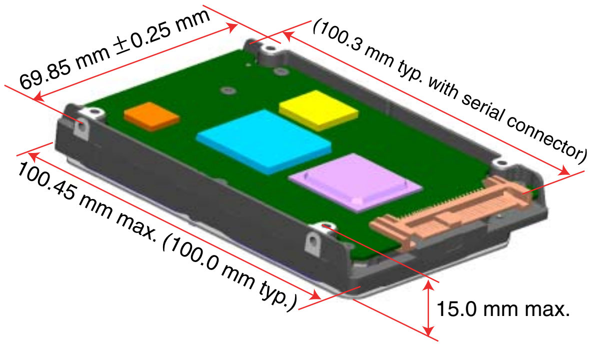


Figure 5
External dimensions of 2.5-inch SFF (SAS connector; SFF-8201).

response to the continuing needs for increasingly higher levels of performance, HDDs for the 4-Gb/s (400-MB/s) version of FCAL are now being developed for commercial availability.

6) Compactness

Among enterprise HDDs, the 3.5-inch low-profile (1 inch in height) type has achieved an optimum balance of capacity, performance, and cost. The 3.5-inch HDD has been the standard form factor for a long time. However, from the second half of 2005 onwards, transition to the smaller 2.5-inch form factor is forecast to gain pace. The reasons behind this are that operation at 10 000 rpm and the 73-GB range are now possible with the 2.5-inch HDD, and the current market needs for saving power, space, and achieving higher performance with a multiple-spindle configuration.

In 2003, the industry's SFF Committee targeted the 2.5-inch enterprise HDD and revised SFF-8201 by adding the form factor of a 15-mm high device, as well as specifications for serial interface connectors.[3] **Figure 5** shows the major external dimensions of the 2.5-inch SFF. For high-performance HDDs, there is likely to be a rapid shift to the 2.5-inch form factor in the next few years since the demands for capacity per spindle have been satisfied, and small-diameter disks are advantageous in terms of reducing mechanical vibration, speeding up seek operations, and reducing power consumption, heat generation, and noise.

7) High reliability

Based on the assumption of continuous 24/7 operation, the reliability requirements for the HDD itself are also very strict, although reliability at the subsystem level has been achieved in enterprise systems by mirroring HDDs or using RAID.

To maintain and further upgrade reliability throughout the service life of a product, it is essential to improve the manufacturing processes, for example, by completely eliminating micro particles and controlling static electricity, in addition to improving design to ensure the stability of head flying height and on-track accuracy for achieving higher recording densities that require lower flying height and smaller track pitches.

Other efforts regarding the controller are also ongoing. These efforts include enhancing error correction and recovery functions, fault prediction functions (SMART: Self-Monitoring And Reporting Technology), and self-diagnosis functions (DST: Drive Self Test), as well as upgrading the data integrity features for data paths within the HDD and data routes in the interfaces.

4. Development of Fujitsu enterprise HDDs

Fujitsu has been supplying the 3.5-inch enterprise HDD AL series since 1994. The AL series has been further developed since its initial introduction with the intention of providing higher performance, functionality, and reliability when used for such applications as server systems, workstations, and storage systems. **Figure 6** shows the evolution of the AL series since 1999. The 10 000-rpm HDD saw full-scale expansion in 1999 with the AL-5 series and has continued to occupy a major position in the product lineup until now. In response to needs for higher performance, 15 000-rpm HDDs were introduced in 2001 with the AL-7 series.[4] In order to achieve higher rotational speeds and seek speeds, 2.75-inch media and a high-performance actuator were employed, achieving a maximum storage capacity of half that of the 10 000-rpm HDD. This established two product groups: one oriented towards high performance with 15 000-rpm devices and the other oriented towards high storage capacity with 10 000-rpm devices. After continuous capacity and performance enhancements were made, the AL-9 series released in 2004 had a maximum capacity of 300 GB at 10 000 rpm and 147 GB at 15 000 rpm.

In the AL-9 series of enterprise HDDs, 2.5-inch, 10 000-rpm models (AL-9SE) have been added to the product lineup. These new models have been introduced to address space-saving and power-saving needs, as well as in response to a new system approach involving tiered storage architecture and ultrahigh-performance subsystems made possible through higher spindle densities. As mentioned previously, the 2.5-inch form factor will likely replace 3.5-inch as the standard form factor in the future.

Figure 7 shows the increase in storage capacity in recent years for each rotational speed for the AL series. As mentioned above, the maximum requirement for storage capacity per spindle of high-performance HDDs is now 300 GB. In next-generation devices, we believe that the AL-9LE Plus will be the last generation in Fujitsu's 3.5-inch, 10 000-rpm HDD lineup since the maximum capacity will reach 300 GB for 15 000-rpm, 3.5-inch HDDs in the next generation, coupled with the increased capacity of

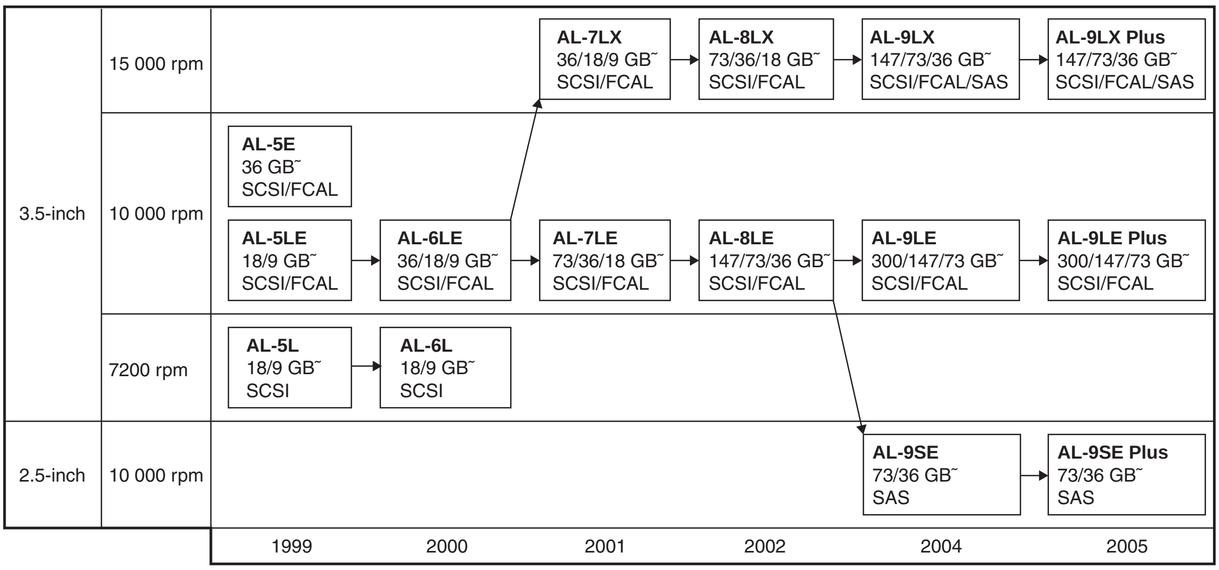


Figure 6
Evolution of AL series.

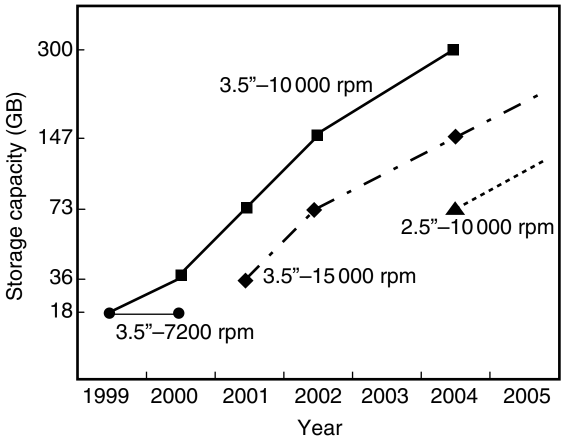


Figure 7
Increases in storage capacity of AL series for different rotational speeds.

2.5-inch, 10 000-rpm HDDs.

5. Overview of AL-9 series

The AL-9 series is Fujitsu's latest range of enterprise HDD products and consists of three product groups: AL-9LX (3.5-inch, 15 000 rpm), AL-9LE (3.5-inch, 10 000 rpm), and AL-9SE (2.5-inch, 10 000 rpm). The following gives an overview of the features of the AL-9 series and the principal technologies employed. **Table 1** lists the major specifications of the product groups above; **Figure 8** shows a mechanical overview of these products.

Mass production of the AL-9 series began in August 2004 and then in 2005, the AL-9 Plus series was introduced to comply with the RoHS (restriction of the use of certain hazardous substances in electrical and electronic equipment) directive, the EU regulations banning the use of harmful chemical substances.

5.1 AL-9LX & AL-9LE

The the AL-9LX and AL-9LE are 3.5-inch, 15 000-rpm and 10 000-rpm HDDs, respectively, that achieve high performance and high storage capacity using state-of-the-art technologies.

5.1.1 Features of the AL-9LX and AL-9LE

The features of the AL-9LX and AL-9LE are as follows:

1) Large capacity:
300 GB/147 GB/73 GB (AL-9LE)
147 GB/73 GB/36 GB (AL-9LX)
2) High speed seek:
(Read average seek time): 4.5 ms (AL-9LE),
3.3 ms (AL-9LX)
(Track-to-Track): 0.2 ms (Read),
0.4 ms (Write)
3) High data transfer rate (internal maximum):
132 MB/s (AL-9LE), 147 MB/s (AL-9LX)
4) FDB motor: employed in all models
5) Interface: 320-MB/s U320 SCSI,
2-Gb/s Dual Port FCAL,
3-Gb/s Dual Port SAS (AL-9LX)

5.1.2 Principal technologies adopted

1) Large capacity

The AL-9 series achieves high areal density recording by employing high-output GMR heads and low-noise multilayer recording media, coupled with improved signal processing in read channels by using such components as 32/34 MEEPRML[note 1)] and Media Noise Processors (MNPs), and 3-interleave ECC. The areal recording densities of the AL-9LE and AL-9 LX are 75 Gbit/in^2 and 59 Gbit/in^2, respectively. Therefore, with a maximum of four platters, the AL-9-LE has 300-GB capacity and the AL-9LX has 147-GB capacity.

2) High rotational speed

For the spindle motor, all AL-9LE and AL-9 LX models use an improved version of the FDB motor employed in the AL-8 series. The important technological refinements that have helped to achieve higher recording densities at higher rotational speeds are reduced RRO (Repeatable Run-Out) through the use of a Stacked Media Servo Track Writer (STW), reduced NRRO (Non-Repeatable Run-Out) through the use of 1.27-mm

note 1) 32/34 Modified Extended Partial Response Maximum Likelihood.

Table 1
Major specifications of AL-9 series.

	AL-9LE	AL-9LX	AL-9SE
Model	MAT3300/3147/3073	MAU3147/3073/3036	MAV2073/2036
(Plus series)	(MAW3300/3147/3073)	(MAX3147/3073/3036)	(MAY2073/2036)
Formfactor (inch)	3.5	3.5	2.5
Height (mm)	25.4 (1.0 inch)	25.4 (1.0 inch)	15 (0.59 inch)
Formatted capacity (GB)	300/147/73.5	147/73.5/36.7	73.5/36.7
Rotational speed (rpm)	10 025	15 000	10 025
Disk diameter (mm)	84	70	65
Number of platters	4/3/1	4/2/1	2/1
Number of heads	8/5/2	8/4/2	4/2
Media transfer rate (MB/s)	73.6 to 132	95.6 to 147	56.4 to 94.1
Areal density (Gbit/in^2)	75.4/60.3/75.4	58.9	70.2
Bit density (kBPI)	725	640	675
Track density (kTPI)	104/83.2/104	92.1	104
Seek time (average) (ms)	4.5 (Read)/5.0 (Write)	3.3 (Read)/3.8 (Write)	4.0 (Read)/4.5 (Write)
Track-to-track (ms)	0.2 (Read)/0.4 (Write)	0.2 (Read)/0.4 (Write)	0.2 (Read)/0.4 (Write)
Acoustic Noise at idle (Bel)	3.4	3.5	2.9
Power consumption at idle (W)	9.5 (10.5 with FCAL)	11.5 (13.5 with FCAL)	4.5
MTBF (Power on hour) (h)	1 200 000	1 200 000	1 400 000
Interface	U320/FCAL (2 Gb/s)	U320/FCAL (2 Gb/s)/SAS (3 Gb/s)	SAS (3 Gb/s)

Figure 8
Mechanical overview of AL-9 series (AL-9LE, AL-9LX, AL-9SE).

thick media and spoiler/shroud optimization, and greater positioning accuracy achieved through improved servo bandwidth and higher sampling frequency.

3) High transfer rate

The AL9LX achieves a maximum data transfer speed of about 150 MB/s in the outer zone. The long tail suspension used for this purpose significantly improves signal quality by adjusting the impedance of signal transmission lines from the preamp to the heads. Moreover, wiring distances have been reduced to minimize noise by optimizing the location of the Head Stack Assembly (HSA) within the Disk Enclosure (DE), and those of the Read Channel (RDC), and Hard Disk Controller (HDC) LSI on the Printed Circuit Board Assembly (PCBA).

4) High-speed access

Seek performance has been improved through the use of a high-rigidity suspension and high-performance actuators. The AL9-LX achieves the fastest access time, with an average seek time of 3.3 ms and a Track-to-Track seek time of 0.2 ms for read operations. Since small-stroke seek operations occupy a high percentage of actual operations as a result of reordering functions with command queuing, small-stroke seeks moving in less than a few hundred cylinders are speeded up. As for seek operations that do not require high-speed movement due to the result of reordering, the optimization of movement speeds has reduced noise as well as power consumption.

5) High-speed interface

The AL9-LX supports SAS interfaces having a maximum speed of 3 Gb/s in addition to the conventional parallel SCSI (U320: 320 MB/s) and FCAL interface (2 Gb/s). SAS will rapidly replace parallel SCSI in the next few years since the latter has reached the limit on increasing data transfer speed. SAS is compatible with the SCSI command set in the logical layer and has features not available in parallel SCSI, such as a dual port mechanism and excellent scalability.

6) Compliance with RoHS

The AL9 series has complied with the RoHS directive since the AL9-LX Plus and AL9-LE Plus models were introduced. In collaboration with parts suppliers and by implementing new manufacturing technology, the AL9 series now complies with the RoHS directive regarding the six harmful substances[note 2)] that are banned. For instance, ultrasonic bonding (USB) has been applied in HDD production lines to achieve complete lead-free connections within the DE. Moreover, gold plating has eliminated the possibility of whiskers on connectors.

5.2 AL-9SE

The AL9-SE represents a range of 2.5-inch, 10 000-rpm enterprise HDDs that has been newly added to the AL9 series product lineup. To achieve high performance and high reliability with a small form factor, a completely new design was devised based on the enterprise HDD technologies developed for the AL series. The AL9-SE actually achieves high performance, high reliability, and robustness equivalent to or better than those of 3.5-inch models, and has a high storage capacity of 73 GB. Like the AL9-LX and AL-9LE, the AL-9SE has complied with the RoHS directive since its Plus series (AL-9SE Plus) was introduced.

5.2.1 Features of AL-9SE

The AL-9SE has the following features:

1) Compactness and lightness: 69.85 mm (W) × 100 mm (D) × 15 mm (H), 0.22 kg
2) Large capacity: 73 GB/36 GB
3) High rotational speed: 10 025 rpm
4) High speed seek (average read seek time): 4.0 ms
5) Load/Unload mechanism: non-operating shock tolerance exceeding 400 G
6) Low acoustic noise: 2.9 Bel (in idle status)

note 2) 6 Substances regulated under the RoHS directive: lead (Pb), cadmium (Cd), hexavalent chromium (Cr^{6+}), mercury (Hg), polybrominated biphenyls (PBB), polybromo diphenyl ether (PBDE).

7) Low power consumption: 4.5 W (in idle status)
8) SAS interface: 3-Gb/s, Single Port (AL-9SE)/ Dual Port (AL-9SE Plus)

5.2.2 Principal technologies adopted

1) Large capacity

The AL-9SE employs common magnetic recording technologies and major key components of the AL-9LX and AL-9LE. Due to the use of 2.5-inch, smaller-diameter disks, the areal recording density is 70 Gbit/in^2. A maximum of two platters within a 15 mm-height SFF form factor can achieve a maximum capacity of 73 GB.

2) High rotational speed

A new type of FDB motor featuring an ultra-compact design, high rotational speed, and high reliability was developed for the AL-9SE. This motor has made longer service life possible, as well as low power consumption and low noise.

3) High-speed access

High-speed seek has been achieved through the development of a high-performance actuator and a compact, high-rigidity suspension. Although it was necessary to make a trade-off between high seek speed and power consumption and noise, the AL-9SE still provides high seek performance (i.e., average seek time of 4.0 ms, Track-to-Track seek time of 0.2 ms for read operations) through the advantages offered by smaller-diameter media.

4) High-speed interface

The features of SAS, such as its small number of signal lines and small-size connectors, make it the optimum interface for the small form factor HDD. With the AL-9SE, Fujitsu became one of the industry's leading HDD suppliers to pioneer SAS by initially introducing a single port SAS with the AL-9SE, followed by a dual port SAS on the AL-SE Plus. Both HDDs achieve a high data transfer speed of 3 Gb/s per port.

5) Compactness

Adopting the new 2.5-inch form factor in the AL-9SE provided several advantages, such as a volume ratio of 1/4, a weight ratio of 1/3, and a power consumption ratio of 1/2, with respect to the conventional 3.5-inch form factor. **Table 2** compares the features of the AL-9SE with a 10 000-rpm AL-9LE model having the same capacity.

6) High reliability

The smaller form factor results in a strict requirement for HDDs in terms of external shock tolerance due to the higher resonant frequencies of the components. The possibility of handling damage caused when installing HDDs in systems will also be greater than usual. In response to

Table 2
Comparison of AL-9SE and AL-9LE.

	AL-9LE (3.5”)	**AL-9SE (2.5”)**	Remarks
Capacity (GB)	73	**73**	
Rotational speed (rpm)	10025	**10025**	
Number of platters	1	**2**	
Number of heads	2	**4**	
Dimensions (W × D × H) (mm)	101.6 × 146 × 25.4	**69.85 × 100 × 15**	Volume ratio: 1/4
Weight (kg)	0.75	**0.22**	Weight ratio: 1/3
Power consumption at Idle (W)	9.5	**4.5**	Power consumption ratio: 1/2
Average seek time @Read (ms)	4.5	**4.0**	
Acoustic Noise at Idle (Bel)	3.4	**2.9**	
Operating shock (G)	65 @2 ms	**100 @1 ms**	
Non-operating shock (G)	225 @2 ms	**400 @1 ms**	Load/Unload mechanism
MTBF (Power on hour) (h)	1200000	**1400000**	

these considerations, a Load/Unload mechanism has been implemented to assure a non-operating shock tolerance of 400 G (1 ms) or greater.

5.2.3 Future development

The 2.5-inch form factor has been highly effective in reducing HDD installation space within the system enclosure as well as in reducing power consumption, heat generation, and noise. Since the 2.5-inch form factor represents an optimum solution for ultrahigh-performance subsystems with increased spindle densities, opportunities for using 2.5-inch HDDs should also rapidly expand in the future. Moreover, as in the case of 3.5-inch HDDs, there will be a strong market requirement to promptly add 15 000-rpm models to the lineup of products.

6. Conclusion

The HDDs used in high-performance servers, large-scale storage systems, and other enterprise applications will become increasingly important. Until now, the development of enterprise HDDs has responded to market needs by increasing capacity and pursuing higher performance and functionality, while at the same time improving reliability. From now on, it will become even more important and imperative to accurately appraise and promptly respond to changes in market needs, such as those for 2.5-inch HDDs and the increasing use of SAS. In this regard, it will be essential to accurately understand the HDD requirements in customer systems and pursue precise technological development necessary to satisfy these requirements. By capitalizing on its strengths in vertically integrated technological development, Fujitsu intends to continue developing leading-edge technologies and supplying high-quality HDD products.

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