Spectra Logic

Tape Drive Technology Comparison

MAMMOTH
DLT AND SUPER DLT
LTO
AIT

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NOVEMBER 2001

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CONTENTS

SPECTRA LOGIC

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INTRODUCTION

The explosive growth of data in the world around us is staggering today's computing environment. Application advancements, hard disk capacity doublings, network bandwidth, and connectivity improvements are all contributing to the management challenges felt by today's information technology managers. This growth presents particularly interesting challenges to tape backup technology, since protecting the data on today's rapidly growing storage subsystems is an absolute requirement.

Data is typically thought of and measured by its physical capacity. This physical capacity has fueled tremendous growth in the primary storage industry (hard drives and hard-drive-based subsystems). The successes of large primary disk suppliers such as IBM, EMC and Network Appliance have been the result. One often overlooked piece of the storage boom is the effect that this explosion has had on the market for secondary storage, or removable media storage.

Of the removable storage types, tape has continued to evolve through the years, and it is still the hands-down leader in the cost-for-capacity category. This fact has created an ever growing need for larger and higher-performance tape drives and automation subsystems. To effectively select a tape technology in today's crowded tape marketplace, it is important for end users to understand the underlying technology and some of the history of tape. Then, end users must apply some common feature-and-benefit analysis and some individualized needs analysis to ensure that a tape technology choice does not leave the business hanging as time goes by. Roadmaps end, technology improvements can be delayed or never realized, companies falter, and new technologies can be introduced which out-date the older technologies. Any of these happenings can leave an end user in a precarious position when they affect the tape technology in which the end user has invested.

This white paper provides a simple and understandable look at today's most prevalent mid-range tape technologies. It looks at the history and evolution of each technology and examines how each technology accomplishes the advances and features necessary to compete in the mid-range tape marketplace today. This paper does not discuss a number of very expensive tape technologies, as they are typically not cost competitive in the mid-range space. By the same token, many low-end tape technologies are excluded from discussion, primarily because of the types and sizes of the customers that they target. All of the mid-range tape technologies studied in this paper are available in stand-alone and automated library offerings. However, regardless of the offering, the tape drive technology specifications remain the same.

This paper covers the following information regarding mid-range tape drive technologies:

- Technology evolution
- Recording methods
- Performance
- Reliability
- Integration and maintenance
- Technology roadmaps

In each of these sections, this paper examines the four leading mid-range tape technologies: Exabyte Mammoth, Quantum DLT and Super DLT, HP/IBM/Seagate Linear Tape Open (LTO), and Sony Advanced Intelligent Tape (AIT). These four tape drive technologies employ distinctly different recording formats and exhibit different performance characteristics. Therefore, investing in one of these popular technologies calls for a complete understanding of their respective strengths and weaknesses.

THE EVOLUTION OF FOUR MID-RANGE TAPE DRIVE TECHNOLOGIES

Exabyte Mammoth

Exabyte introduced the 8mm helical-scan tape drive in 1985, setting a new standard for mid-range tape drives of that era. The early Exabyte tape drives offered compelling cost, capacity and value propositions to the users of the older linear tape drives, such as the IBM 3480 and 3490 models. The original Exabyte 8mm drive mechanical sub-assembly was designed and manufactured by Sony. Exabyte supplied the interface electronics, firmware, and cosmetics to create a final product. Two generations of full-high and one generation of half-high tape drives were developed under this Sony-Exabyte partnership. Exabyte later chose to develop and manufacture its own scanner and mechanism for the first-generation Mammoth drive and to terminate its technological relationship with Sony. Exabyte does, however, continue to rely on Sony for its Mammoth Advanced Metal Evaporated (AME) media.

Quantum DLT and Super DLT

Quantum Corporation originally purchased Digital Linear Tape (DLT) technology from Digital Equipment Corporation in 1994, and Quantum is now the primary manufacturer of DLT drives. In 1998, Quantum licensed the right to manufacture DLT drives to Tandberg Data. The early product line included the DLT 2000, 4000, 7000, and 8000 products. Also in 1999, Quantum announced the next generation of DLT technology, called Super DLT. The first Super DLT product began production shipments in early 2001. DLT made a promise of backward compatibility for previous DLT users, but initial Super DLT shipments were not backward compatible. Another version of the Super DLT drive was later announced, which will provide this feature. Super DLT has a publicly announced roadmap promising another four generations of Super DLT tape technology.

LTO

Linear Tape Open technology is a family of open tape standards developed in a joint venture by Hewlett Packard (HP), IBM, and Seagate. That group created LTO technology in 1998 as an effort to provide more choices to users in the midst of the present complex array of storage options. LTO is an open format technology, which means that users have multiple sources of product and media. Also, because they license manufacturing to other vendors, LTO enables compatibility between different vendors' offerings. LTO technology is currently produced in two formats: Accelis and Ultrium. The two formats share common components such as track layout, read-write heads, and servo technology, but other than that, they are quite different. Accelis is the fast-access implementation, and Ultrium is the high-capacity implementation. For the purposes of this paper, only the Ultrium format will be discussed in detail.

Sony AIT

Sony, continuing its role as a leading innovator in tape technology, began producing the Advanced Intelligent Tape (AIT) drive in 1996. Sony's AIT drives and media have been designed and manufactured entirely by Sony. Although the 8 mm helical scan recording method is used, the AIT recording format was specifically designed for computer applications and is incompatible with the early 8mm drives from Exabyte. The AIT-1 drive was the first generation of a technology family positioned to double capacity and transfer rates every two years. Since its introduction, three new AIT products have been released: an extended-length tape for the AIT-1 drive, the AIT-2 drive, and the new AIT-3 drive, which has lived up to the AIT promise of doubling capacity and transfer rates.

RECORDING METHODS

Linear Serpentine Recording

All DLT and LTO tape products write linear serpentine data tracks parallel to the edge of the tape (Figure 1). In these technologies, a half-inch tape moves linearly past a head assembly that houses the carefully aligned read and write heads. To create the serpentine pattern on the tape, the head assembly moves up or down to precise positions at the ends of the tape. Once the head assembly is in position, the tape motion is resumed and another data track is written parallel to and in between the previously written tracks. Both DLT and LTO technologies position the read heads slightly behind the write heads to accomplish a read-while-write-verify. Older DLT and LTO technologies use the edge of the tape or a pre-written servo-track as a tracking reference during read and write operations. The new Super DLT technology, however, uses an optical-assist servo technology, called Pivotal Optical Servo, to align its heads to the proper tracks.

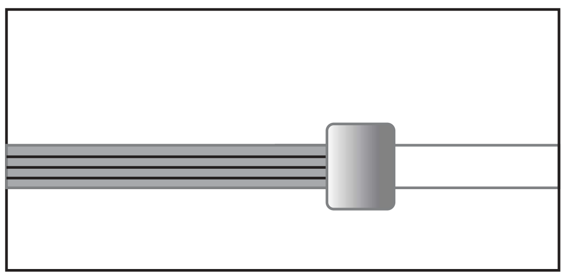

Figure 1. *Linear serpentine recording.*

The Use of Azimuth to Increase Linear Capacity

Azimuth is defined as the trajectory of an angle measured in degrees going clockwise from a base point. In many tape and disk applications, azimuth has been used through time to increase storage densities. When using azimuth, tracks can be pushed together on a tape, eliminating the need for the guard bands that used to be required between adjacent tracks. The guard bands were eliminated, for example, in DLT's transition from the DLT 4000 to the DLT 7000-8000 technologies (see Figure 2 on page 6).

The DLT 4000 used normal linear recording, in which the head assembly operated in one position perpendicular to the tape, writing data blocks in a true linear pattern. The DLT 7000 and DLT 8000 incorporated a modified linear serpentine method called Symmetrical Phase Recording (SPR). The SPR method allows the head assembly to rotate into three different positions, thereby allowing data blocks to be written in a herringbone or SPR pattern, as shown in

Figure 2 below. This method yields a higher track density and higher data capacity, eliminating the wasted space for guard bands. A third vertical head position (zero azimuth) allows the DLT 7000 and DLT 8000 drives to read DLT 4000 tapes.

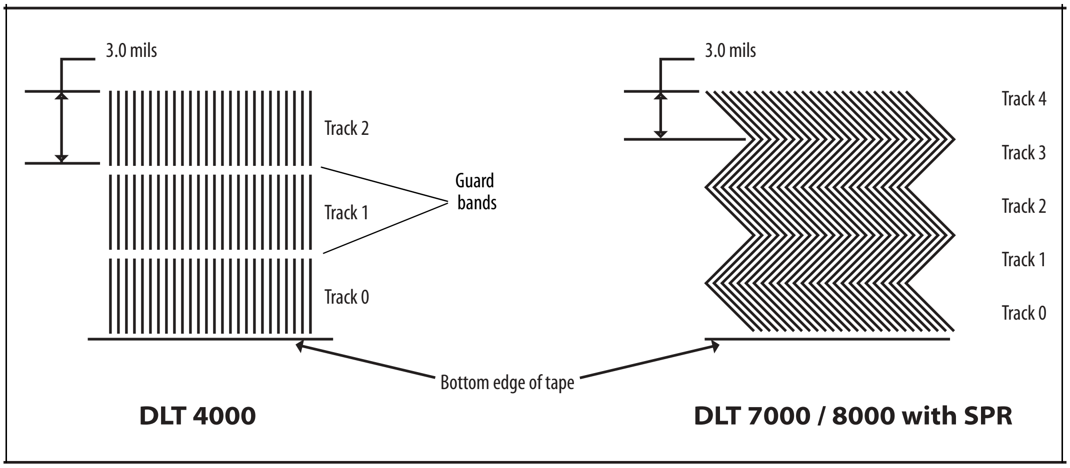

Figure 2. *Logical diagram of normal linear and SPR linear recording.*

Helical Scan

Sony AIT and Exabyte Mammoth employ a helical scan recording method in which data tracks are written at an angle with respect to the edge of an 8 mm tape. This is achieved by wrapping magnetic tape partially around an angled, rotating drum. The read and write heads are precisely aligned in the drum and protrude very slightly from its smooth outer surface. As the tape is moved past the rotating drum, the heads create an angled data track on the tape (Figure 3).

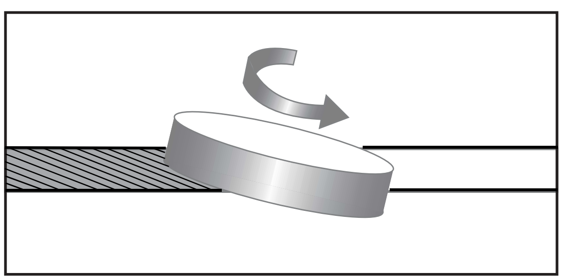

Figure 3. *Helical-scan recording.*

Read heads are positioned just behind the write heads, allowing read-while-write-verify, which ensures the data integrity of each data stripe. A special servo head on the drum and track on the tape are used for precise tracking during subsequent read operations. All helical-scan tape drives use azimuth to maximize the use of the tape media. Rather than moving the head assembly itself like linear devices do, helical recording creates azimuth by mounting the heads at angles in respect to each other.

TAPE DRIVE PERFORMANCE

Tape Loading and Cartridge Handling

In all tape drive systems, the tape must be pulled from the cartridge, guided through the tape path, and then pulled across the read-write head assembly. Linear and helical tape technologies differ significantly in their methods of tape handling and loading, but in every case, tapes must be handled properly to avoid high error rates, tape damage, and—in the worst case—loss of data.

Linear Drive Mechanisms

When the tape cartridge is inserted into a linear tape drive, a load mechanism inside the drive engages with a positioning tab at the beginning of the tape, which pulls the tape out of the cartridge and onto a take-up hub inside the drive compartment. As the read or write operation is performed, the tape is spooled between the take-up hub inside the drive and the cartridge supply reel inside the media cartridge. This is one reason why linear tape drives are much larger than helical scan drives, which employ a dual-spool cartridge design.

It is very important that linear tape cartridges not be dropped or roughly handled because the tape inside may slacken or shift on the spool. This may cause problems with loading the tape or may cause edge damage on the media, since the leader may fail to engage when inserted into the tape drive. If this leader-latching problem occurs, the tape cartridge is typically rendered useless, and the drive may even require repair, which is particularly problematic in automated tape library environments.

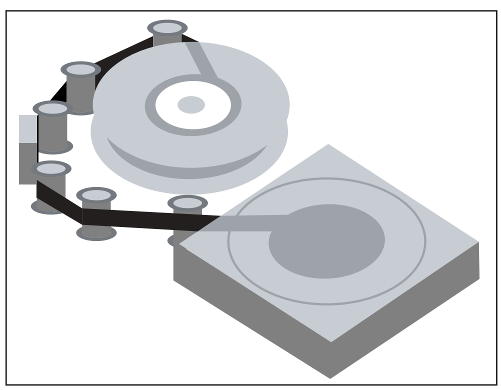

Figure 4. *Diagram of a linear tape drive.*

Helical-Scan Drive Mechanisms

Sony AIT and Exabyte Mammoth drives employ a more common method of tape loading. When the tape cartridge is inserted, drive motors engage the cartridge hubs and work with tape loading guides to position tape into the tape path. As the read or write operation is performed, the tape is spooled from one cartridge hub to the other. Because of this, Sony AIT and Mammoth tape cartridges are much less sensitive to rough handling and dropping. For best results, users should follow the manufacturer's recommendations for storage and handling of data cartridges.

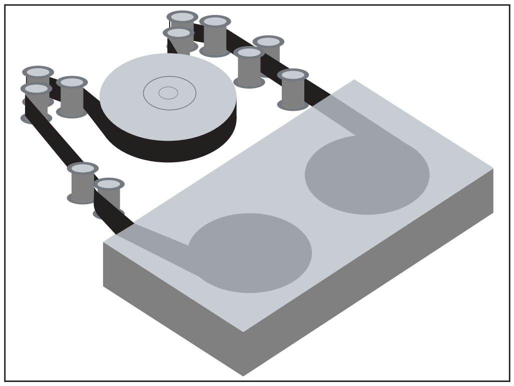

Figure 5. *Diagram of a helical-scan drive.*

Tape Tension and Speed Control

In all tape drives, the tape must be precisely moved through the tape path and across the heads during read or write operations. Also, the relative speed between the tape and the heads must be precisely controlled.

AIT and pre-Mammoth Exabyte tape drives employ traditional servo-driven capstan-and-pinch-roller designs to control tape speed. These designs use a capstan, or a controlled motorized cylinder, to pinch the tape against a freewheeling roller, pulling the tape through the tape path at a regulated speed. The take-up and supply hubs are used to spool and unwind the tape, but the precise tape speed is controlled at the capstan point.

Exabyte Mammoth drives employ an entirely new capstan-less design in which the tape speed is completely controlled by closed-loop, servo-driven take-up and supply hubs. The speed of the hubs is engineered to be constantly and precisely varied as the diameter of the two spools changes. For instance, the take-up hub speed must decrease steadily as the tape spool gets larger in order to maintain a constant tape speed across the heads. The goal of the capstan-less design is to reduce tape stress caused by the capstan-and-pinch-roller system. However, Mammoth field studies have not proven this method to significantly improve reliability.

Linear recording technology controls tape speed with a system that is very similar to that of Mammoth tape drives. Tape speed is controlled using a servo mechanism and pick-up and take-up spools. These linear mechanisms employ a very tight and positive control of the spool-to-deck mechanism, which forces the spool gears into the corresponding deck gears.

In all tape handling systems, tape tension is required to ensure that the tape is held firmly against the head assembly as it traverses the tape path. This tension leads to tape-head wear. In general, the tape tension in linear drives is over twice that of helical scan drives. However, other factors such as head material, media composition, and cleaning practices will also have an effect on tape-head wear.

Tape Speed and Stress

Linear drives move tape at a relatively fast rate, typically over 150 inches per second (ips). The helical scan drives use a much slower tape speed of less than one ips through the tape path and past the rapidly rotating drum assembly. Interestingly, the relative tape speed is nearly equal in both helical-scan and linear technologies.

Tape stress is a function of many system variables, some of which include tape speed, tape path control mechanisms (usually guide rollers), capstan pressure, and media contamination. It is important to understand how each drive technology minimizes this tape stress. Linear tape drives utilize a straighter tape path but a much higher tape speed, making the guide-roller system critical to minimize edge wear on the media. On the other hand, helical scan drives use a much slower tape speed but a more complex tape path.

Data Streaming and Start/Stop Motion

A tape drive's ability to continuously read or write data, or "stream" data, is a key performance and reliability differentiator. A drive's performance will suffer dramatically if the drive is not supplied with data at a rate sufficient to keep it streaming. In cases where these conditions are not met, the drive will need to stop the forward tape motion, reverse the position, bring the tape back to speed, and then restart the write operation.

Linear technologies, with higher tape speeds, do not operate well in start-stop mode. Each start-stop operation requires the mechanism to stop the tape from greater than 150 ips, rewind well past the last data written, ramp the speed back to greater than 150 ips, and then resume writing. The amount of time spent performing a stop-rewind-start motion dramatically impacts the overall tape system's throughput. In an attempt to minimize this, high-performance linear technologies employ powerful reel motor systems. The reel-motor system results in linear drives having larger physical footprints and higher power consumption ratings than helical-scan devices.

Helical-scan drives, in addition to being smaller and using less energy, can perform the stop-rewind-start sequences very quickly. This is owing to their slower tape speeds and their constantly rotating drum mechanisms. While continued stop-start motion is detrimental to any drive, the reliability impact is greater on devices with higher tape speeds because of the mechanical stress placed on the system and the media.

All four of these tape drive technologies use data buffering techniques to minimize the need to perform stop-start activities. Linear technologies must use larger buffers since the performance and reliability penalty for a stop-start operation is so much higher than with helical-scan products. Mammoth and AIT drives will typically out-perform DLT and LTO drives in applications where drive streaming is not possible.

Media Load Time and File Access Time

Media load and file access times are important factors to consider as per-tape capacities rise or when tape drives are integrated into robotic tape libraries. Media load time is defined as the amount of time between cartridge insertion and the drive becoming ready for host system commands. File access time is defined as the time between when the drive receives a host-system command to read a file and the time when the drive begins to read the data.

File access times are typically expressed as averages, since the requested file might be located in the middle of the tape or at either end. Times are usually specified as the time required to reach the middle. Drive vendors typically state specifications for both media load and file access. The specifications for the four mid-range tape technologies are shown in the following table.

Media Load and File Access Time *		
Tape Drive	**Media Load Time**	**Average File Access Time**
Exabyte Mammoth	20 seconds	55 seconds
Exabyte Mammoth-2	17 seconds	60 seconds
Quantum DLT 8000	40 seconds	60 seconds
Quantum Super DLT	40 seconds	70 seconds
HP LTO Surestore Ultrium 230	15 seconds	71 seconds
IBM LTO 3580 Ultrium	15 seconds	65 seconds
Seagate Viper 200 LTO Ultrium	10 seconds	76 seconds
Sony AIT-1	10 seconds	27 seconds
Sony AIT-2	10 seconds	27 seconds
Sony AIT-3	10 seconds	27 seconds

** Times obtained from drive manufacturers' published information.*

The Sony AIT drives offer a much faster media load time and file access time, making these technologies an obvious choice for applications requiring fast data retrieval. The AIT time advantage is due in part to the unique Memory In Cassette (MIC) feature, which consists of an electrically erasable programmable read-only memory chip, called Flash EEPROM, built into the Sony AME tape cartridge. The flash memory stores information previously stored in a hidden file written before a tape's Logical Beginning Of Tape (LBOT). Through the use of the MIC feature, Sony's AIT drives reduce wear and tear on mechanical components during the initial load process and offer faster file access. MIC technology is now being used in today's LTO tape drives.

Data Capacity

Data capacity is measured by the amount of data that can be recorded on a single tape cartridge. Tape manufacturers maximize capacity by increasing the bit density on a given area of tape or by increasing the length of the tape in the cartridge. Hardware data compression is also used to increase capacity, and any valid tape technology comparison must show both native and compressed values. Each manufacturer uses a different data compression algorithm resulting in different compression ratios:

Data Compression *		
Tape Type	**Algorithm**	**Ratio**
Exabyte Mammoth	IDRC	2:1
Exabyte Mammoth-2	ALDC	2.5:1
Quantum DLT	DLZ	2:1
Quantum Super DLT	DLZ	2:1
HP/IBM/Seagate LTO	ALDC	2:1
Sony AIT	ALDC	2.6:1

** Data compression obtained from drive manufacturers' published information.*

Native and compressed capacities for each type of tape are shown in the table below. The comparisons made here are based on the maximum tape lengths available at the time of this writing.

Capacity		
Media Type	**Native Capacity**	**Compressed Capacity**
Exabyte Mammoth	20 GB	40 GB
Exabyte Mammoth-2	60 GB	150 GB
Quantum DLT 8000	40 GB	80 GB
Quantum Super DLT	110 GB	220 GB
HP LTO Surestore Ultrium 230	100 GB	200 GB
IBM LTO 3580 Ultrium	100 GB	200 GB
Seagate LTO Viper 200 Ultrium	100 GB	200 GB
Sony AIT-1 (Extended Length)	35 GB	91 GB
Sony AIT-2	50 GB	130 GB
Sony AIT-3	100 GB	260 GB

** Tape capacities obtained from drive manufacturers' published information.*

Data Transfer Rate

Data transfer rate is defined as the speed at which data is written to tape from the drive's internal buffer. This is usually measured in megabytes per second (MB/sec.). If the data transfer from the host system to the drive is significantly slower than the drive's transfer rate (after compression), a great deal of start-stop tape motion will occur while the drive waits for more data. Start-stop activities—sometimes referred to as shoe-shining because the tape goes back and forth across the head—will adversely impact the drive's throughput performance and can dramatically increase wear on the drive's mechanical subsystem. Therefore, it is important to keep the tape drive's cache buffer supplied with data for drive streaming. Buffer sizes are selected by the manufacturers to minimize start-stop activities. However, larger buffer sizes cannot eliminate start-stops in situations where there exists a performance mismatch between the host system and the drive.

As in capacity figures, all transfer rate comparisons must be studied using both native and compressed figures. Current drive transfer rates are shown in the table below. More detailed information about compression can be found in the section on Data Capacity on page 9.

Data Transfer Rates		
Drive Type	**Native**	**Compressed**
Exabyte Mammoth	3 MB/sec.	6 MB/sec.
Exabyte Mammoth-2	12 MB/sec.	30 MB/sec.
Quantum DLT 8000	6 MB/sec.	12 MB/sec.
Quantum Super DLT	11 MB/sec.	22 MB/sec.
HP LTO Surestore Ultrium 230	15 MB/sec.	30 MB/sec.
IBM LTO 3580 Ultrium	15 MB/sec.	30 MB/sec.
Seagate LTO Viper 200 Ultrium	16 MB/sec.	32 MB/sec.
Sony AIT-1 (Extended Length)	3 MB/sec.	7.8 MB/sec.
Sony AIT-2	6 MB/sec.	15.6 MB/sec.
Sony AIT-3	12 MB/sec.	31.2 MB/sec.

** Data transfer rates obtained from drive manufacturers' published information.*

RELIABILITY

In general, tape drive reliability can mean many things to many people. Tape drive vendors have notoriously slanted tape technology specifications in order to lure users into using to their technology. Following are two sets of reliability specifications often used in mid-range tape technology competition.

Mean Time Between Failure (MTBF)

One method of measuring tape drive reliability is specified by Mean Time Between Failure (MTBF). This is a statistical value relating to how long, on average, the drive mechanism will operate without failure. In reality, drive reliability varies greatly and cannot be accurately predicted from a manufacturer's MTBF specification. Environmental conditions, cleaning frequency, and duty cycle can significantly affect actual drive reliability. Add to this the fact that manufacturers usually do not include head life in the MTBF specification, and that the manufacturer's duty cycle assumptions vary. Tape drive manufacturers often add a disclaimer to the MTBF specification that the figures should only be used for general comparison purposes. Head life specifications (in hours) are subject to some of the same interpretation problems as MTBF, but, when combined with other reliability specifications, they offer a good comparison of performance in high duty-cycle environments. The table below shows how reliability specifications compare.

MTBF and Head Life Statistics *

Tape Drive	MTBF	Head Life
Exabyte Mammoth	250,000 hours @ 20% duty cycle	30,000 hours
Exabyte Mammoth-2	300,000 hours @ 20% duty cycle	50,000 hours
Quantum DLT 8000	250,000 hours @ 100% duty cycle	50,000 hours
Quantum Super DLT	250,000 hours @ 100% duty cycle	30,000 hours
HP LTO Surestore Ultrium 230	250,000 hours @ 100% duty cycle	**
IBM LTO 3580 Ultrium	250,000 hours @ 100% duty cycle	60,000 hours
Seagate LTO Viper 200 Ultrium	250,000 hours @ 100% duty cycle	**
Sony AIT-1	250,000 hours @ 40% duty cycle	50,000 hours
Sony AIT-2	250,000 hours @ 40% duty cycle	50,000 hours
Sony AIT-3	400,000 hours @ 100% duty cycle	50,000 hours

** Rates obtained from drive manufacturers' published information.*
*** Information not provided by manufacturer.*

Annual Failure Rate (AFR)

An excellent real-world indicator of a drive's reliability is the Annual Failure Rate (AFR) of a drive technology's field population. As in MTBF calculations, the user's results are averaged regardless of environmental conditions, cleaning frequency, and duty cycle, which can significantly affect actual drive reliability. Therefore, these numbers should be used only for general comparison purposes.

Vendors calculate AFR numbers based on how many failed drives they have returned to the factory from the installed base. The vendor then averages those numbers over each year for that tape technology. LTO tape technologies are so new that they have not yet been able to produce any AFR data.

Tape Drive Annual Failure Rates	
Drive Type	**Approximate AFR**
Exabyte Mammoth	2.5%
Quantum DLT	4.5%
HP/IBM/Seagate LTO	**
Sony AIT	1.5%

*** Technology too new to be quantified.*

Data Integrity

Data integrity is specified as the bit error rate (BER), which gives the number of permanent errors per total number of bits written. Mammoth, DLT, AIT, and LTO drives all incorporate a read-while-write-verify error detection, a cyclic redundancy check (CRC), and an error correction code (ECC) algorithm to ensure a BER of 10^{17}, or 1 error in 100 trillion bits. The Sony AIT drive is the only product that incorporates a third-level error correction code (in addition to first and second level) for increased data integrity.

MEDIA TYPES

Two basic types of media are used in today's mid-range tape drives: Metal Particle (MP) and Advanced Metal Evaporated (AME). MP technology is used in DLT, LTO, first-generation Exabyte drives, as well as many other tape technologies, like video tape technology. AME technology is used for Mammoth and AIT media. Both media types contain a base film and a recording layer of magnetic metal material. MP tape is a relatively old technology and has evolved to support ever-increasing bit densities. Sony's new AME media, on the other hand, has key features that significantly improve its recording characteristics and its head-to-tape interface reliability, making it the most advanced media type being used today.

The MP recording layer is composed of magnetic material mixed with a binder and other additives, such as lubricants. AME media's recording layer is made entirely of magnetic cobalt material. The highly metallic surface of AME media allows higher recording densities and improved signal-to-noise ratios. AME media also employs a very smooth diamond-like carbon (DLC) coating, which significantly reduces drive-head wear and head contamination.

Media Reliability

Media reliability is often summarized with pass specifications and use specifications. However, media experts and real-world users agree that media pass and use specifications are largely theoretical and generated primarily for marketing purposes. Even Quantum has stated, "The relevance of the media use spec is under review" (DLT Forum, 17 August 1999). The best way to judge media's durability is to evaluate its formulation. The smoother and more pure the media, the less friction is generated between the tape and head, resulting in longer-lasting media.

For a comparison of the stated specifications of media uses and passes in today's mid-range tape technologies, a clarification of terms is required. Note the distinction between the terms "passes" and "uses." For purposes of comparison here, one "use" is defined as the filling of a tape to capacity, and a "pass" is defined as the running of the tape over the head in one direction.

The media-use specification is the more valid way to compare the drives. This is because the pass specifications are not comparable; there are too many differences between helical-scan and linear technologies. In helical-scan devices, there are only two passes required for one use. In linear devices, multiple passes are required for one use.

A single use of a DLT tape, for example, involves numerous tape passes over the read-write heads. Specifically, in a DLT 8000 device, the head can write four channels at once, and the tape can accept 208 channels, requiring the tape to be passed over the head 52 times to fill a tape. Helical drives, like Mammoth and AIT, require only one pass to fill a tape and one to rewind it, for a total of two. To determine the number of uses a tape may endure, the listed pass-specification must be divided by the number of passes necessary to fill a tape. For example, the DLT 8000 media-use number can be calculated by dividing 1 million passes by 52. This equals 19,230 (Quantum lists 15,000 in their specifications). AIT's 15,000 and Mammoth's 10,000 media-use numbers are deduced by dividing 30,000 and 20,000 passes by two, respectively. Therefore, based purely on specifications, the media used by all of the drives are approximately equal in durability.

Media Use Specifications *		
Drive Type	**Media Type**	**Media Uses**
Exabyte Mammoth	AME	10,000
Quantum DLT	MP	15,000
Quantum Super DLT	MP	17,850
HP/IBM/Seagate Ultrium LTO	MP	**
Sony AIT	AME	15,000

** Rates obtained from drive manufacturers' published information.*
*** Information not provided by manufacturer.*

Media and Backward Compatibility

Exabyte originally designed Mammoth-1 drives to read both AME and MP media as well as to be compatible with their existing MP 8 mm tapes. This backward compatibility, however, forces special read-write head requirements to read both AME and MP media. It also necessitates special cleaning practices by the user. For example, if an MP tape is read by the Mammoth drive, the drive will not accept another tape until a cleaning cartridge is inserted. Cleaning is required because the MP media binder chemistry is prone to leave debris on the heads and in the tape path. This raises a reliability question for Mammoth drives reading MP tapes on a consistent basis. Exabyte has not published any specifications or test reports that quantify reliability when using the Mammoth drive in this mode. The implications of cleaning are even less appealing when using the drive with a mixed media set in a tape library environment where backup software does not recognize the difference in media types. It is perhaps more realistic for Mammoth users to transition to AME media and avoid the problems associated with using MP media.

As tape technologies evolve, a drive manufacturer must weigh the size of its installed base and the willingness of that base to switch to a new media type as the manufacturer introduces new tape drives. In general, new tape drives utilize new media types to take advantage of the latest head and media components. Unfortunately, comparison algorithms and media types have been continued long past their usable life just to extend the installed base's backward read (and sometimes write) capabilities.

Sony's third generation AIT product, AIT-3, is the first tape drive to double the transfer rates of previous-generation media. For example, an AIT-1 cartridge in an AIT-3 drive will achieve double the transfer rate of that same cartridge in an AIT-1 drive. (That transfer rate is higher than an AIT-2 cartridge in an AIT-2 drive, but still not as high as an AIT-3 cartridge in an AIT-3 drive.) However, an AIT-2 cartridge in an AIT-3 drive will duplicate the transfer rate available for AIT-3 cartridges in AIT-3 drives.

Other technologies have always forced the previous generation speeds when using the older media. So, while it is appealing to be able to read the older tape with the newer drives, most customers have ended up transitioning their media pool over to the newer tapes. Backup windows become unpredictable when new and old media are mixed inside an automated tape library. However, tape library manufacturers like Spectra Logic are now providing solutions in which a user can logically partition old and new media in one tape library. Logical partitioning such as this can help to leverage the end user's original investment in the older tapes.

INTEGRATION AND MAINTENANCE

Drive Size and Form Factor

The size of a tape drive is important for ease of integration into tape libraries, servers, and other host systems. Tape drive size is designated by a form factor, which is often indicated using industry standard width, height, and depth measurements.

- Widths are measured into either a 5-1/4-inch or 3-1/2-inch form factor. Sony's AIT drives are the only 3-1/2-inch units. All others require 5-1/4-inch bays.
- Height is measured as either a full-height or half-height form factor of 5-1/4-inches. AIT, Mammoth, and IBM LTO drives are half-height products. DLT, HP LTO, and Seagate LTO drives are full-height products.
- Depths of tape drives can vary. Since no standards were set early on, some vendors have produced drives which are deep. See the table below for mid-range tape drive measurements.

Physical Dimensions of Mid-Range Tape Drives *			
Drive Type	**Width**	**Height**	**Depth**
Exabyte Mammoth	5.75 in.	1.63 in.	8.00 in.
Exabyte Mammoth-2	5.75 in.	1.63 in.	8.00 in.
Quantum DLT 8000	6.88 in.	6.48 in.	12.80 in.
Quantum Super DLT	6.90 in.	6.30 in.	12.80 in.
HP LTO Surestore Ultrium 230	8.00 in.	5.00 in.	12.00 in.
IBM LTO 3580 Ultrium	6.74 in.	5.75 in.	13.11 in.
Seagate Viper 200 Ultrium LTO	5.88 in.	3.39 in.	8.31 in.
Sony AIT-2	7.44 in.	2.28 in.	6.10 in.
Sony AIT-3	7.44 in.	2.28 in.	6.10 in.

** Dimensions obtained from drive manufacturers' published information.*

Notice how compact the helical scan technology is; this allows libraries integrating AIT and Mammoth technology to hold more drives in less space.

Drive size or form factor is unfortunately not an area that can be improved upon for some drive technologies. The mechanical nature of DLT technology and the larger reel motors required to support the faster tape speed, for example, make it very difficult to further reduce the DLT drive's form factor. Currently, the non-standard length of Quantum DLT products necessitates special design considerations when integrating DLT libraries, servers, and system cabinets.

Media Size and Storage Density

Media size is just as important as drive form factor, and for largely the same reason: saving space. Simply put, using smaller cartridges for data storage takes up less physical space. If the tapes are being used in a library environment, their smaller size allows for more tapes to fit into a library at any given time, lessening the manpower needed to replace them quite so often. Also, whether in a library or in a stand-alone drive environment, the smaller tapes take up less space outside the drive or library for on-site or off-site storage. See the media size comparisons in the table below.

Physical Dimensions of Mid-Range Media				
Media Type	**Length**	**Width**	**Height**	**Cubic Space**
Exabyte Mammoth	9.50 cm (3.74 in.)	6.20 cm (2.44 in.)	1.50 cm (0.59 in.)	88.35 cu. cm (5.39 cu. in.)
Quantum DLT	10.41 cm (4.10 in.)	10.41 cm (4.10 in.)	2.54 cm (1.00 in.)	275.25 cu. cm (16.81 cu. in.)
HP/IBM/Seagate LTO	10.21 cm (4.02 in.)	10.54 cm (4.15 in.)	2.15 cm (0.85 in.)	231.37 cu. cm (14.18 cu. in.)
Sony AIT	9.50 cm (3.74 in.)	6.20 cm (2.44 in.)	1.50 cm (0.59 in.)	88.35 cu. cm (5.39 cu. in.)

Again, notice how compact the helical scan technology is. Taking this compact size into account with the great amount of data stored in that little amount of space, this technology integrates very well into automated libraries designed for storage density.

Storage density is defined as the amount of data capacity in a given amount of physical space. This is an important consideration in all data storage environments, from an on-site storage space to an off-site colocation center. Businesses of all sizes can appreciate that space is money, so saving space means saving money.

To emphasize the difference in storage densities of the different tape technologies, see the table below, which shows how much space is required for each type of drive to store one terabyte (TB) of data. Considering that most businesses are concerned with taking up less space, the smaller numbers are better.

Storage Density			
Media Type	**Size of Tape Cassette**	**Tapes Required for 1 TB ***	**Space Required for 1 TB ***
Exabyte Mammoth	88.35 cu. cm (5.39 cu. in.)	25	2,208.75 cu. cm (134.79 cu. in.)
Exabyte Mammoth-2	88.35 cu. cm (5.39 cu. in.)	7	618.45 cu. cm (37.73 cu. in.)
Quantum DLT 8000	275.25 cu. cm (16.81 cu. in.)	13	3,578.25 cu. cm (218.53 cu. in.)
Quantum Super DLT	275.25 cu. cm (16.81 cu. in.)	5	1,376.25 cu. cm (84.05 cu. in.)
HP LTO Surestore Ultrium 230	231.37 cu. cm (14.18 cu. in.)	5	1,156.85 cu. cm (70.90 cu. in.)
IBM LTO 3580 Ultrium	231.37 cu. cm (14.18 cu. in.)	5	1,156.85 cu. cm (70.90 cu. in.)
Seagate LTO Viper 200 Ultrium	231.37 cu. cm (14.18 cu. in.)	5	1,156.85 cu. cm (70.90 cu. in.)
Sony AIT-2	88.35 cu. cm (5.39 cu. in.)	8	706.80 cu. cm (43.12 cu. in.)
Sony AIT-3	88.35 cu. cm (5.39 cu. in.)	4	353.4 cu. cm (21.56 cu. in.)

** Compressed.*

Drive Cleaning

As tape technologies advance, the recording density on each square millimeter of the tape increases, the distance between the head and tape decreases, and the physical head gap shrinks. Dust, media particles, and other contaminants can enter the head-to-tape interface area and cause high error rates which slow performance, decrease capacity per tape, and eventually lead to drive failure. Tape drive manufacturers have traditionally addressed these issues by specifying periodic cleaning with a fabric or rough media cleaning cartridges. All of the drives examined here have an LED cleaning light on the front of the drive, which flashes when the drive needs to be cleaned. In addition, Exabyte specifies that a cleaning cartridge be loaded into the Mammoth drive every 72 tape-motion hours. Quantum DLT drives have no recommended cleaning interval other than when the cleaning LED flashes.

Sony has taken a different approach to keeping the AIT drive's tape path and heads clean. First, the AIT drive does not rely on external fans in the library or the system cabinet to cool the AIT drive and components; those types of fans force airborne dust through the drive and the critical head-tape interface. AIT drive cooling is achieved via an internal, variable-speed fan that cools *only* the drive circuitry and base plate without pulling air through the tape path. Second, the AME media formulation and the DLC coating significantly reduce media surface debris that can clog heads. These features allow Sony AIT drives to operate with virtually no manual cleaning, eliminating maintenance problems and significantly reducing the drive's overall operating costs. Finally, a built-in head-cleaning wheel is automatically activated by an error-rate-monitoring device to ensure a clean head-to-tape interface and maximum performance. (Occasional cleaning of AIT read and write heads with approved Sony cleaning media may be required for excessive head contamination.)

Power Requirements

Tape drive power requirements are important when integrating the drive into libraries, servers, and system enclosures. As costs have been cut from servers and enclosures, vendors have often specified a power supply with minimal margin over the system's current consumption, not providing sufficient power to support the higher requirements of linear technology devices.

Heat is a by-product of power, and as the drive's power requirement increases, more heat dissipation and cooling is required. DLT and LTO drives require significantly more power and generate much more heat than Mammoth and AIT drives.

Tape Drive Power Requirements

Tape Drive	Operating Power Requirement
Exabyte Mammoth	15 watts
Exabyte Mammoth-2	16 watts
Quantum DLT 8000	28 watts
Quantum Super DLT	26 watts
HP LTO Surestore Ultrium 230	**
IBM LTO 3580 Ultrium	**
Seagate Viper 200 Ultrium LTO	25 watts
AIT-2	12 watts
AIT-3	18 watts

** Rates obtained from drive manufacturers' published information.*
*** Information not provided by manufacturer.*

Application-specific issues such as form factor, power supply requirements, and heat dissipation should all be examined in detail before selecting a mid-range tape drive technology.

TECHNOLOGY ROADMAPS

When choosing a tape drive technology, an end user should consider the migration path of the technology. A future migration path should offer higher performance and capacity while ensuring backward-read compatibility with previously written tapes. With typical corporate data volume growing at 60 percent per year, a user would not want to buy into a technology near the end of its life cycle and then be stuck with the lower performance and lower capacity of an older technology. For a look at the past and the proposed future of the different mid-range tape technologies, see the roadmaps compared at the end of this section. (See the table below for drive performance roadmaps and the table on page 25 for drive capacity roadmaps.)

Roadmaps of Drive Performance (Native Transfer Rates) *								
Drive Type	**1998**	**1999**	**2000**	**2001**	**2003**	**2005**	**2006**	**2007**
AIT	AIT-1-XL 3 MB/sec.	AIT-2 6 MB/sec.	-	AIT-3 12 MB/sec.	AIT-4 24 MB/sec.	AIT-5 48 MB/sec.	-	AIT-6 96MB/sec.
DLT	DLT 7000 5 MB/sec.	DLT 8000 6 MB/sec.	-	Super DLT 220 11 MB/sec.	Super DLT 320 16 MB/sec.	Super DLT 640 32 MB/sec.	Super DLT 1280 50 MB/sec.	Super DLT 2400 100 MB/sec.
Mammoth	Mammoth 3 MB/sec.	Mammoth 3 MB/sec.	Mammoth-2 12 MB/sec.	**	**	**	**	**
HP LTO	-	-	-	Surestore Ultrium 230 15 MB/sec.	**	**	**	**
IBM LTO	-	-	-	3580 Ultrium 15 MB/sec.	**	**	**	**
Seagate LTO	-	-	-	Viper 200 Ultrium 16 MB/sec.	**	**	**	**

** Highest data transfer rates of tape drive technologies as publicly stated by drive vendors.*
*** These tape drive manufacturers have not yet provided roadmaps for their technologies.*

Roadmaps of Drive Capacity (Native) *								
Drive Type	**1998**	**1999**	**2000**	**2001**	**2003**	**2005**	**2006**	**2007**
AIT	AIT-1-XL 35 GB	AIT-2 50 GB	-	AIT-3 100 GB	AIT-4 200 GB	AIT-5 400 GB	-	AIT-6 800 GB
DLT	DLT 7000 35 GB	DLT 8000 40 GB	-	Super DLT 220 110 GB	Super DLT 320 160 GB	Super DLT 640 320 GB	Super DLT 1280 640 GB	Super DLT 2400 1.2 TB
Mammoth	Mammoth 20 GB	Mammoth 20 GB	Mammoth-2 60 GB	**	**	**	**	**
HP LTO	-	-	-	Surestore Ultrium 230 100 GB	**	**	**	**
IBM LTO	-	-	-	3580 Ultrium 100 GB	**	**	**	**
Seagate LTO	-	-	-	Viper 200 Ultrium 100 GB	**	**	**	**

** Highest native capacities of tape drive technologies as publicly stated by drive vendors.*
*** These tape drive manufacturers have not yet provided roadmaps for their technologies.*

Historically, tape vendors have struggled to continue along their roadmaps. These challenges have stemmed from a wide variety of causes, including financial difficulties owing to loss of marketshare, prices decreasing, and product development delays. Product development problems have arisen from a number of sources. Sony stands alone as having full ownership control over its deck manufacturing, head technology, and media; several companies, however, have been very dependent upon other companies to release their next product.

Three generations have historically been the industry norm for tape drive evolution. Evolving semiconductor technologies, compression algorithms, heads, and media processes have made it very difficult for drive vendors to extend the older technologies past three generations while remaining competitive with newer drive products and backward compatible with the existing installed base. This typically leaves engineers with the problem concerning backward compatibility. Often times, backward compatibility issues make it difficult to remain competitive with other technologies of the time. In the early years of DLT technology, the capacity and transfer rate between DLT generations doubled. However, now that it's mature, the jump from DLT 7000 to 8000 yielded an incremental increase of only 5 GB in capacity and 1 MB/sec. in transfer rate.

Quantum Corporation recently launched its next generation DLT product: Super DLT. Super DLT technology incorporates more channels, new thin film M-R heads, a new optical servo system, and advanced media formulations. This new DLT product required significant engineering innovation. The major challenges that created on-schedule delivery difficulties include the new servo positioning architecture, a new head design, new media formulations, and much higher internal data rates than the previous DLT architecture. Additionally, pressure to maintain backward read and write compatibility only increased the engineering complexity. The first Super DLT drives did not offer backward compatibility to previous DLT generations.

With AIT, Sony remains in the forefront of all mid-range tape technologies, holding the highest capacity and performance specifications for the last several years. Sony has continued to drive the cost of AIT drives down, offering users the best cost-for-performance figures in this class. The December 2001 release of AIT-3 marks the third generation of Sony's AIT technology. Sony has published a roadmap which extends through AIT-6, expecting to double capacity and performance every two years.

Exabyte's Mammoth drive had experienced some lengthy production delays but is shipping in volume quantities today. Exabyte's Mammoth technology showcased numerous industry firsts and was the company's first attempt at designing and manufacturing a deck mechanism and head assemblies without Sony's expertise. During the production delays, Exabyte allowed Quantum's DLT and Sony's AIT to capture Mammoth's previous generation customers as the customers' needs increased when no new products were being offered by Exabyte. The company's financial woes were only continuing to grow, and Exabyte very recently made the decision to merge with Ecrix Corporation.

In today's marketplace, companies that deliver solid products on schedule have gained market share and have become standards. Exabyte delivered a number of products from 1987-1992, and gathered more than 80 percent of the mid-range market share. Those products included the EXB-8200, EXB-8500, EXB-8200C, EXB-8500C, EXB-8205, EXB-8505, and EXB-8505XL. Exabyte owes its key success to those initial products, which offered higher performance at a moderate price while playing in a market with very little competition. However, Exabyte's inability to deliver Mammoth until nearly three years after announcing the product opened the door for other technologies.

Quantum's DLT drives were able to deliver better throughput at a time when storage capacities were exploding. The DLT 2000, DLT 2000XT, and DLT 4000 drives were able to offer better capacity, performance, and reliability than the first Exabyte products, allowing them to capture the market share previously owned by Exabyte. Again, delivering a product in a landscape with little competition allowed Quantum to gain more than 80 percent of the market between 1992 and 1996. Availability and engineering delays for DLT 7000 and follow-up DLT products have now opened the door for newer technologies.

Since 1996, Sony AIT technology seems to have picked up where the other two tape drive technologies left off. If Sony can continue to deliver on its promise to double capacity and performance every two years, AIT appears to be positioned to become the next mid-range tape standard.

The newest entry in the mid-range tape technology market is the new LTO format available from HP, Seagate, and IBM. It is a a barely emerging technology competing in a market with other more-established technologies, yet it seems to be gaining fast acceptance. As time goes by, it may very well last and develop a roadmap for a bright future all its own.

CONCLUSION

The mid-range tape market is currently dominated by Sony's AIT drives, Quantum's DLT and Super DLT drives, Exabyte's Mammoth drives, and, as of very recently, HP/IBM/Seagate's LTO drives. Of the mid-range drives discussed here, the Sony AIT and Exabyte Mammoth drives offer incredible capacity and transfer rates, fastest media load and file seek times, smallest form factors, lowest power requirements, easiest maintenance, and equal or better reliability and data integrity specifications.

Only time will tell, however, which of these manufacturers will meet the demands of the growing mid-range storage marketplace. Regardless of the future, understanding the core technologies discussed in this white paper will better equip users to make intelligent business decisions right now. The competition has been heated for years, and now the releases of new linear technology ensure plenty more competition in the mid-range tape drive market for years to come. Such competition is good, and the end user almost always emerges the winner, getting more and better technology for less money.

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