Tape Drive Technology Comparison

Sony AIT • Exabyte Mammoth • Quantum DLT

By Roger Pozak
Boulder, CO
(303) 786-7970
roger_pozak@mail.sel.sony.com
Updated April 1999

Introduction

Tape drives have become the preferred device for backing up hard disk data files, storing data and protecting against data loss. This white paper examines three leading mid-range tape drives technologies available today: Sony AIT, Exabyte Mammoth and Quantum DLT. These three technologies employ distinctly different recording formats and exhibit different performance characteristics. Therefore, choosing among and investing in one of these technologies calls for a complete understanding of their respective strengths and weaknesses.

Evolution of Three Midrange Tape Drive Technologies

Exabyte introduced the 8mm helical scan tape drive in 1985. The 8mm drive mechanical sub-assembly was designed and manufactured by Sony while Exabyte supplied the electronics, firmware, cosmetics and marketing expertise. Today, Exabyte's Mammoth drive is designed and manufactured entirely by Exabyte.

Sony, long a leading innovator in tape technology, produces the AIT (Advance Intelligent Tape) drives. The AIT drive is designed and manufactured entirely by Sony. Although the 8mm helical scan recording method is used, the AIT recording format is new and incompatible with 8mm drives from Exabyte.

Quantum Corporation is the manufacturer of DLT (Digital Linear Tape) drives. Quantum purchased the DLT technology from Digital Equipment Corporation in 1994 and has successfully developed and marketed several generations of DLT drive technology including the current DLT-7000 product.

Helical Scan vs Linear Serpentine Recording

Sony AIT and Exabyte Mammoth employ a *helical scan* recording style in which data tracks are written at an angle with respect to the edge of the tape. This is achieved by wrapping 8mm wide magnetic tape partially around an angled, rapidly 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 over the angled, rotating drum, the *write* heads create a helical data track pattern on the tape (Fig.1). The *read* heads are positioned just behind the write heads so that "read after write verify" is achieved which ensures data integrity. A *servo* head writes servo data on the tape to be used for precise track following during subsequent read operations.

Quantum DLT drives write *linear serpentine* data tracks parallel to the edge of the tape (Fig 1). The ½" wide tape moves linearly over the head assembly which houses the precisely aligned read and write heads. To write linear serpentine data tracks, tape motion is halted while the head assembly moves incrementally up or down to precise positions with respect to the edge of the tape. Tape motion is resumed and data tracks are written parallel to and in-between previously written tracks. As with AIT and Mammoth, the DLT read heads are positioned slightly behind the write heads so that read after write verify is accomplished. In addition, DLT uses the edge of tape as a tracking reference instead of written servo data.

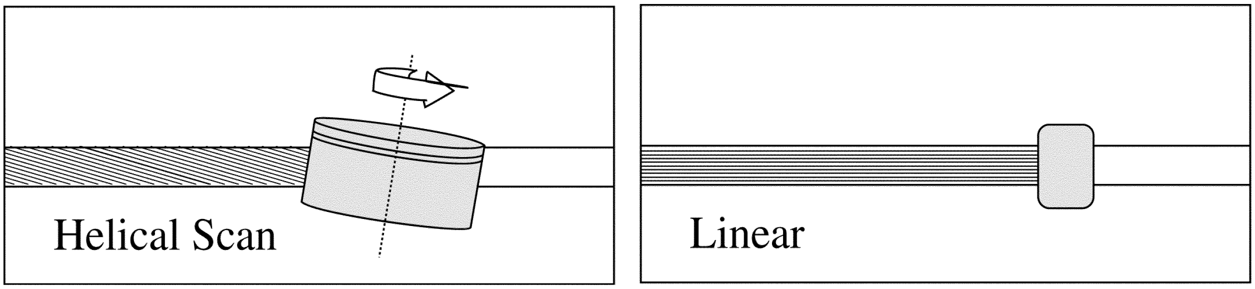

Fig. 1 - Helical Scan vs Linear Recording

Differences Between DLT-4000 and DLT-7000 Recording Formats

To achieve higher data capacity, DLT-7000 incorporates a modified linear serpentine method called SPR (Symmetrical Phase Recording) which differs from the DLT-4000 data recording method. The DLT-7000 head assembly rotates into three positions allowing data blocks to be written in a herringbone or SPR pattern. The SPR recording method gives a higher track density and higher data capacity than the DLT-4000 (Fig 2). The vertical head position allows the DLT-7000 to read DLT-4000 tapes.

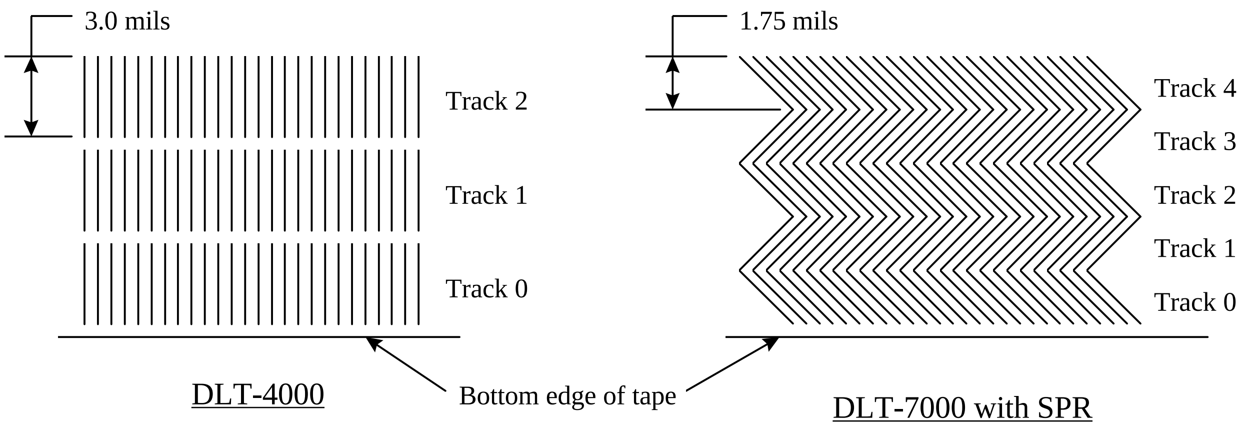

Fig 2 - Logical Diagram of Normal Linear (DLT-4000) and SPR Linear (DLT-7000) Recording

Tape Loading

In every midrange tape drive, the tape must be delicately pulled from the cartridge, placed over the head/drum assembly, and guided through the tape path across the read and write heads at precise speeds. Tape technologies differ significantly in tape loading.

The DLT method of tape loading is most unique. When the DLT cartridge is inserted, the drive's leader latching device engages a leader at the beginning of the tape, pulls the tape out of the cartridge, through the tape path, and onto a take-up hub inside the drive. As the read or write operation is performed the tape is actually spooled on and off a hub *inside* the DLT drive. This is why DLT drives are physically much larger and require more power than other drives. It is very important that DLT tape cartridges not be dropped or roughly handled because the tape inside may slacken and the leader may mis-engage or break when the cartridge is inserted into the tape drive. If mis-engagement or leader breakage occurs, the DLT tape cartridge is rendered useless and the drive may require significant repair.

Sony AIT and Exabyte Mammoth drives employ a more common method of tape loading. When the 8mm cartridge is inserted, the drive motors engage with the cartridge hubs working in concert with tape loading guides to unload tape from the cartridge and into the tape path. As the read or write operation is performed, tape is spooled from one cartridge hub to the other and through the drive's tape path. Sony AIT and Mammoth tape cartridges are less sensitive to rough handling than DLT cartridges, but since the recorded data can be worth thousands of dollars, it is prudent to handle all cartridges carefully.

Tape Speed Control

The AIT drive and DLT drives employ a traditional servo driven capstan and pinch roller device which precisely controls tape speed while moving tape over the head assembly. The take-up and supply hubs act simply for spooling and un-spooling the tape while keeping the tape under precise tension.

Mammoth employs an entirely new "capstan-less" design in which the tape speed is completely controlled by closed loop, servo driven take-up and supply hubs. This is a quite an engineering feat, as the speed of the hubs must be constantly and precisely varied as the diameter of the tape spool 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 and tape debris caused by the capstan and pinch roller.

The DLT drive moves tape at 160 ips over the read/write heads and through the tape path during read/write operations. The AIT and Mammoth drives use a much slower tape speed of about 1 ips while the head/drum assembly rotates at a high RPM (Mammoth at 5,660 rpm and AIT at 4,500 rpm). Interestingly, the relative speed between the heads and the tape is nearly equal in all three technologies.

Tape Tension and Handling

The tape tension of Mammoth and AIT is less than half that of DLT. Lower tape tension reduces the phenomenon of *head wear* which is the gradual wearing out of the drive's read and write heads, but head material, media composition and cleaning practices have a much greater effect on head wear than tape tension. The slower moving and lower tension AIT and Mammoth tape may be less likely to undergo high speed stress during start/stop motion, but the DLT tape path has fewer rollers and guides which reduces stress points. There is no data or other evidence indicating any of these three technologies offers a gentle tape handling advantage, but head life specifications vary significantly as noted in the *reliability* section of this paper.

Data Streaming and Start/Stop Motion

Start/Stop motion impacts the drive's performance and causes additional wear and tear if data is not supplied to the drive at a rate sufficient to keep it *streaming*. This is a common occurrence since most LAN networks can only move data at about 1 or 2 MB/sec. A DLT drive must stop the tape, rewind well past the last file mark, wind up to 160 ips, and resume reading or writing all of which takes a considerable amount of time. Mammoth and Sony AIT drives can perform the stop/rewind/start sequence very quickly due to the slower tape speed. All three technologies employ a large data buffer to minimize the effects of slow network data speeds, but the Mammoth and AIT drives out-perform DLT drives in applications where significant start/stop motion occurs.

Data Capacity

Tape drive capacity is measured by the amount of data that can be recorded on a single tape cartridge. Tape drive manufacturers increase capacity by increasing the track density on a given section of tape or by increasing the physical length of the tape in the cartridge. The comparisons made here are based on the maximum tape lengths available today.

Hardware data compression is also used to increase capacity, and any comparison must show both *native* and *compressed* values. Each manufacturer uses a different data compression algorithm resulting in different compression ratios:

— Exabyte Mammoth uses IDRC compression that gives a typical 2:1 ratio.
— Quantum DLT uses DLZ compression that gives a typical 2:1 ratio.
— Sony AIT uses ALDC compression that gives a typical 2.6:1 ratio.

Native and compressed capacities for each drive are shown in Fig. 3.

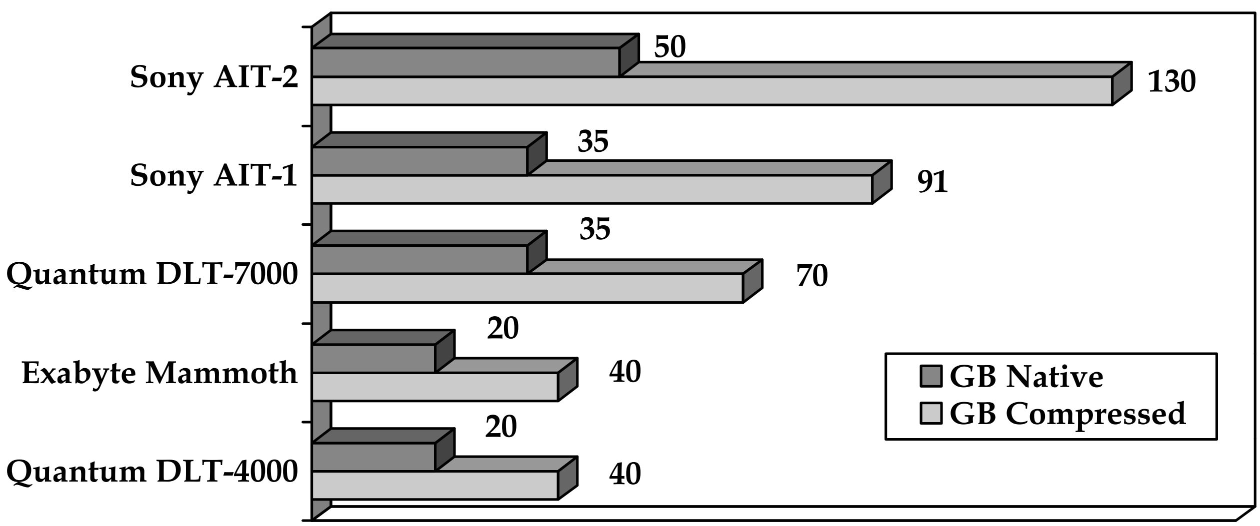

Fig. 3 - Current Product Capacities in Gigabytes per Cartridge

It is important to note that Sony specifies the AIT drive's ALDC compression at only 2:1. IBM uses the same compression method in their high-end tape drives and they rate ALDC at 3:1. Independent tests conclude an average of 2.6:1 compression can be expected with the AIT drive, so the author uses 2.6:1 here.

Data Transfer Rate

Data transfer rate is defined here as the speed at which data is written to tape from the drive's cache buffer. This is usually measured in MB/sec. As noted earlier, if the data transfer from the host system to the drive is significantly slower than the drive's transfer rate, a great deal of start/stop tape motion occurs while the drive waits for more data. Excessive start/stop motion stresses the drive and the tape and adversely affects performance; therefore, it is preferable to keep the tape drive's cache buffer supplied with data to allow data streaming. As with capacity, transfer rate comparisons must take into account compression ratios. Current drives are shown in Fig. 4.

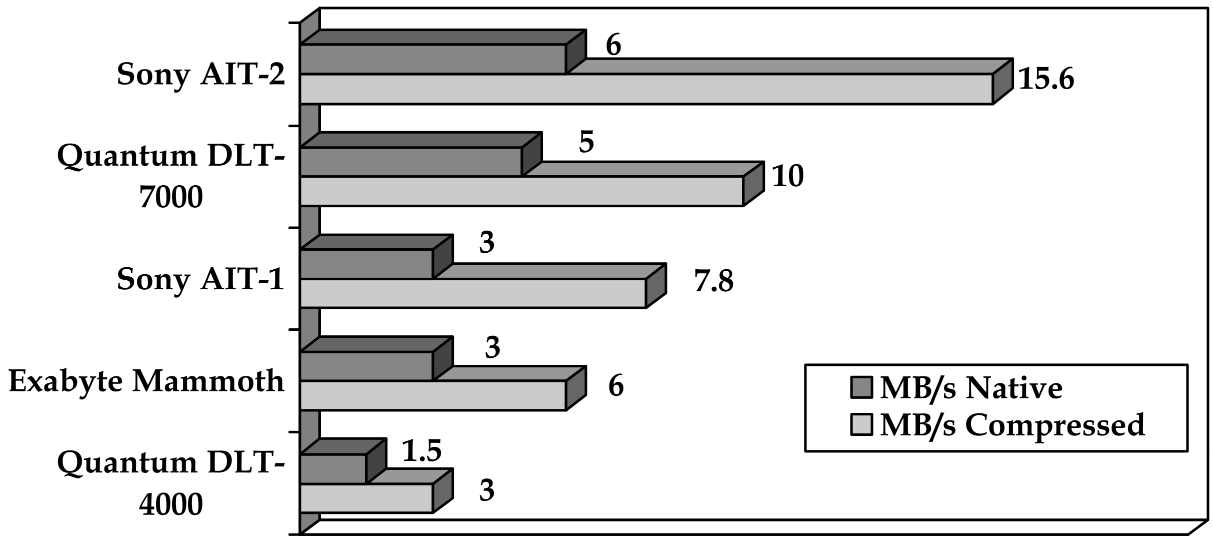

Fig. 4 - Current Product Transfer Rates in MB/sec

Media Load Time & File Access Time

Media load and file access times become important performance factors to consider when tape drives are integrated into robotic tape libraries. Media load time is defined as the amount of time between cartridge insertion and when the drive becomes "ready" for host system commands such as reading or writing data. File access time is defined as the time between the drive receiving a host system command to read a file and the time the drive begins to read the data. Media load and file access specifications for our three technologies is shown in the table below:

Product	Media Load Time	Average File Access Time
Sony AIT-1 & MIC	<7 sec	27 sec
Sony AIT-2 & MIC	<7 sec	37 sec
Exabyte Mammoth	<20 sec	55 sec
Quantum DLT-7000	40 sec	60 sec
Quantum DLT-4000	45 sec	68 sec

The Sony AIT drive offers a faster media load time and file access time than Mammoth, DLT-4000 and DLT-7000 making the Sony AIT drive a good choice for applications requiring fast data archive and retrieval. The Sony AIT file access time advantage is due in part to the unique Memory In Cartridge (MIC) feature which consists of a 16KB flash EEPROM memory chip built into Sony AME tape cartridge. The flash memory holds the tape's entire data structure, history, and other user-defined information which is read directly by the Sony AIT drive

— other tape drives must rewind to the beginning of tape to retrieve this information. Therefore, the MIC feature reduces wear and tear on the drive's mechanical components. The MIC feature also enables the host software to create multiple *partitions* and perform *multi-point load/unload* to allow better volume stacking and data management.

Reliability

Tape drive reliability is often specified by MTBF (Mean Time Between Failure). This is a statistical value relating to how long, on average, a drive will operate without failure. In reality, tape drive reliability varies greatly and cannot be accurately predicted from the manufacturer's MTBF specification. Operating environmental conditions, cleaning frequency, duty cycle, and even data patterns can have great effects on actual drive reliability. Manufacturers usually do not include head life in the MTBF specification, and duty cycle assumptions vary while actual duty cycles are10% to 80% in a typical backup application. As a result, tape drive manufacturers often add a disclaimer to the MTBF specification. Manufacturers also change the MTBF and duty cycle specifications regularly as in-house reliability testing dictates.

Head life specifications (in hours) offer a more "apples to apples" comparison. AFR (Annual Failure Rate) is an excellent way to compare technologies because this shows the actual field failure rates in real-world conditions (please see the author's white paper *Rating Tape Drive Technologies*).

The following chart shows how our three tape drive manufacturer's reliability specifications and actual annual failure rates compare.

Product	MTBF	Head Life	AFR*
Sony AIT-1	250,000 Hrs @ 40% duty cycle	50,000 hrs	2.2%
Exabyte Mammoth	250,000 Hrs @ 10% duty cycle	35,000 hrs	3.1%
Quantum DLT-7000	300,000 Hrs @ 100% duty cycle	30,000 hrs	4.5%
Quantum DLT-4000	80,000 Hrs @ 100% duty cycle	10,000 hrs	4.5%

The AIT drive offers the highest head life and lowest annual failure rate. Cleaning per the manufacturer's recommendations, using high quality data tapes, and keeping the drive "streaming" maximizes the reliability of any tape drive.

Data Integrity Specifications

Data integrity is specified as the Bit Error Rate (BER) which gives the number of permanent errors per bits written. The Exabyte Mammoth, Quantum DLT, and Sony AIT drives all incorporate read-after-write verify error detection, a Cyclic Redundancy Check (CRC) and an Error Correction Code (ECC) algorithm to ensure an extremely high BER of 10^{-17} — or 1 error in 1,000,000,000,000,000,000 bits.

It is important for users to consider *data archive integrity* which includes all of the possible problems that may occur after the data is written to tape and the cartridge is stored for future use. For example, if the DLT tape leader latching mechanism malfunctions, data archive integrity will be greatly reduced because the stored data cannot be retrieved. Other causes of data archive integrity problems include wear-out of the beginning of tape area and bad spots on poor quality media.

Media Types

Two basic types of media are used: MP (Metal Particle) technology is used in DLT-4000 & DLT-7000, and AME (Advanced Metal Evaporated) technology is used in Mammoth and Sony AIT. The relatively new AME media technology has key features that significantly improve 8mm drive reliability.

*Sources include published data by Quantum Corp., statement from Exabyte Corp., and actual data from Sony Corp

The MP recording layer is composed of about 45% magnetic material mixed with a binder and other additives, while the AME media recording layer is 90% to 100% magnetic cobalt material. The highly metallic surface of AME media allows higher recording densities with 50% lower tape tension than MP. This significantly reduces drive head wear and head contamination due to tape debris. The AME media also contains a smooth, protective diamond-like carbon coating on the recording surface, a lubricant, and a protective back coating. These unique features further reduce drive head wear and increase the number of passes AME can withstand without degradation.

Note the term *passes* is used here rather than *uses* because one use may involve numerous tape passes over the read/write heads as the drive searches, reads, writes, and rewinds the tape. Helical scan recording (Mammoth & AIT) allows the entire tape to be written in as little as one pass. Linear Serpentine recording (DLT) requires a minimum of 56 passes to fill an entire tape with data. In reality, all tape drives put many passes on a tape in a typical backup application, and no data or other evidence exists showing one technology having an advantage over the other in terms of media uses.

Media Compatibility

DLT-4000 and DLT-7000 use the same MP tape cartridge and are read compatible with each other. The AME media use and compatibility is as follows:

- There is one AME tape cartridge specifically designed for the Sony AIT drive, and there is another for Exabyte's Mammoth drive.
- The Sony AIT drive accepts only AME media made for the AIT drive and rejects all other 8mm tape cartridges including Mammoth AME. Likewise, Mammoth drive rejects all AIT AME cartridges.
- Exabyte's Mammoth drive reads both AME and 8mm MP media but does not write to the MP media.

It is interesting to note that Exabyte's Mammoth drive actually reads *both* AME and MP media. Exabyte designed Mammoth to read both media types so that it would be read compatible with existing MP 8mm tapes. This compatibility feature forced special read/write head material design requirements and necessitates special cleaning practices by the user. For example, if an 8mm MP tape is read by the Mammoth drive it will not accept another tape thereafter unless a cleaning cartridge is inserted. This raises a question as to how many times a Mammoth drive can read an MP tape without suffering permanent damage. The implications are even more unappealing with respect to tape libraries in which tapes are read many times. It is perhaps more realistic for Mammoth users to transition to the AME media and avoid the implications of using MP media.

Drive Cleaning

As recording technologies advance the recording density on tape increases. Dust, media particles and other contaminants can enter the head/tape interface area and cause high error rates that slow performance, decrease capacity per tape, and eventually cause a drive failure. Tape drive manufacturers have traditionally addressed this issue with periodic cleaning via a cleaning cartridge that is loaded into the drive just like a data cartridge. Most tape drives have a cleaning light on the front of the drive that flashes when the drive needs to be cleaned. 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. The AIT drive cooling is achieved via an *internal*, variable speed fan that cools the PCBA and base plate without inducing airborne dust into the tape path. A built-in head cleaning wheel is automatically activated by an error rate monitoring device to ensure a clean head/tape interface. Finally, the AME media formulation significantly reduces tape debris that can clog heads. These features allow the Sony AIT drive to operate with virtually no cleaning thereby eliminating maintenance problems and reducing operating costs. The Mammoth drive also exploits the benefits of AME media and has an internal cleaning device.

Drive Size & Form Factor

The physical 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* that indicates the width of the drive and assumes standard height and length. The Sony AIT drive is the most compact with a 3 ½" form factor. The Exabyte Mammoth is next in size with a 5 ¼" *half height* form factor. The Quantum DLT products are largest with a 5 ¼" *full height* form factor and a non-standard 9" length. The non-standard length of the Quantum DLT products necessitates special design considerations for DLT libraries, servers and system cabinets.

Power Requirements

Tape drive power requirements are important when integrating the drive into libraries, servers and system enclosures. Heat is a by-product of power, and as the power requirement increases, more heat dissipation and cooling is required. As indicated by the following chart, Quantum DLT drives require significantly more power and generate much more heat than Exabyte Mammoth and Sony AIT.

Product	Power Requirement
Sony AIT	12 watts
Exabyte Mammoth	15 watts
Quantum DLT-4000	27 watts
Quantum DLT-7000	37 watts

The Importance of Future Product Migration Paths

When choosing among tape drive technologies, it is wise to consider the planned future or *migration path* of the technology. The migration path should offer higher performance and capacity while ensuring backwards read compatibility with previously written tapes. With typical corporate data volume growing at 60% per year, a user would not want to buy into a tape technology at the end of its life cycle and face costly technology change issues in order to maintain pace with data storage growth.

Migration paths are compared in Fig. 5. Capacities, transfer rates and ship dates are based on manufacturer's published figures or the author's estimate where the manufacturer's data is not available. Products shipping today are noted in dark print, while products not yet shipping are noted in light print. Please note that tape drive manufacturer's schedules for future products often slip by as much as a year or two.

The DLT-7000 and Mammoth are third generation technologies. Historically, the third generation of a tape technology is near the end of providing backwards read compatibility with previous generations. The fourth or fifth generation typically involves significant technology changes that preclude backward compatibility with one or more previous generations. Quantum Corporation has noted that incorporating more channels, thin film M-R heads, optically assisted servo tracking, and advanced media formulations will evolve the DLT technology beyond the DLT-7000 to "Super DLT," but details regarding ship dates and backward compatibility issues are not clear as of this writing. Exabyte has announced Mammoth-2 offering higher capacities and performance, but details regarding backward compatibility are not clear as of this writing. Sony AIT-1 is the first of several announced generations of AIT that provide backward compatibility. Two lengths of media for AIT-1 are now available, so buyers have a choice of 25 GB or 35 GB native capacities today. Initial shipments of AIT-2 drives began in January 1999, so it appears this technology roadmap is on track.

Native Transfer Rate Migration Paths

	1998	1999	2000	2001	2003
Sony AIT	**3MB/s**	**6MB/s**	---	12MB/s	24MB/s
DLT	**5MB/s**	10MB/s	---	---	---
Mammoth	**3MB/s**	12MB/s	---	20MB/s	---

Native Capacity Migration Paths

	1998	1999	2000	2001	2003
Sony AIT	**35GB**	**50GB**	---	100GB	200GB
DLT	**35GB**	100GB	---	---	---
Mammoth	**20GB**	60GB	---	200GB	---

Fig. 5 - Future Technology Migration Paths

As a final note on future products, Hewlett Packard, IBM and Seagate have jointly announced the Accelis (25GB & 10MB/s) and Ultrium (100GB & 10MB/s) Linear Tape Open (LTO) technologies. This was a *technology announcement* only and not a product shipment announcement, so general availability of these tape drives may be a year or more away if shipped at all. LTO is an attempt to develop an "open" standard for midrange tape drives in which technology may be licensed to several manufacturers. Several other technology announcements were made in 1998 by companies including Ecrix, OnStream, Benchmark and StorageTek. The feasibility of these technologies is uncertain given the size of existing manufacturers and number of existing products already serving the market.

Summary

The mid-range market is currently dominated by Exabyte Mammoth, Quantum DLT-4000 and DLT-7000, and Sony's AIT-1 and AIT-2 drives. The Sony AIT-2 drive offers the highest capacity, fastest performance, smallest form factor, and highest field reliability. In terms of future product generations Quantum has announced a drive technology beyond DLT-7000 called Super DLT. This new technology promises double transfer rate and nearly triple capacity of DLT-7000 and is planned to ship in late 1999. Exabyte has announced Mammoth 2 with triple capacity and quadruple transfer rate of Mammoth 1. Mammoth 2 is planned for mid-1999 shipments. Sony has published a migration path for the AIT technology that doubles performance and capacity every two years through 2003. Only time will tell which of these manufacturers can meet the demands of the growing mid-range network storage market.

About the author: Roger Pozak has worked in the tape drive industry for the past 10 years. He has held positions in engineering, marketing and sales at companies including Philips LMSI, Exabyte, Spectra Logic and Sony Electronics and holds degrees in engineering and business from Michigan State University and the University of Colorado. Today he works and lives in Boulder Colorado. This and other white papers written by Roger Pozak including "Rating Tape Drive Technologies" are available by calling (303) 786-8947. Electronic copies are available.