1995117707

N95- 24127

43462

p. 15

Influence of Technology on Magnetic Tape Storage Device Characteristics

John J. Gniewek and Stephen M. Vogel
IBM Corporation
9000 S. Rita Road
Tucson, Arizona 85744
(602) 799-2390
Fax: (602) 799-3665
jgniewek@vnet.ibm.com
svogel@vnet.ibm.com

Introduction

There are available today many data storage devices that serve the diverse application requirements of the consumer, professional entertainment, and computer data processing industries. Storage technologies include semiconductors, several varieties of optical disk, optical tape, magnetic disk, and many varieties of magnetic tape. In some cases, devices are developed with specific characteristics to meet specific application requirements. In other cases, an existing storage device is modified and adapted to a different application. For magnetic tape storage devices, examples of the former case are 3480/3490 and QIC device types developed for the high end and low end segments of the data processing industry respectively, VHS, Beta, and 8 mm formats developed for consumer video applications, and D-1, D-2, D-3 formats developed for professional video applications. Examples of modified and adapted devices include 4 mm, 8 mm, 12.7 mm and 19 mm computer data storage devices derived from consumer and professional audio and video applications.

With the conversion of the consumer and professional entertainment industries from analog to digital storage and signal processing, there have been increasing references to the "convergence" of the computer data processing and entertainment industry technologies. There has yet to be seen, however, any evidence of convergence of data storage device types. There are several reasons for this. The diversity of application requirements results in varying degrees of importance for each of the tape storage device characteristics listed in Table 1.

Table 1
Tape Storage Device Characteristics

- Reliability
  - Data Reliability
  - Device Reliability
- Procurement Cost
- Operating and Maintenance Cost
- Access Time to Data
- Data Rate
- Automation Compatibility
- Capacity
  - Cartridge Capacity
  - Automation Capacity
- Write/Read Ratio
- Form Factor

This diversity of requirements has continually reinforced the need for an economical storage hierarchy. Continuing advances in technology have enabled the development of new devices with enhanced capabilities. The acceptance of new devices is tempered, however, by the investment most users have in existing tape storage volumes. For removable tape storage systems, this therefore presents a dilemma. Significant (perhaps 5-10X) rather than incremental improvements in storage cost-performance assessments must be offered to make the conversion to a new system attractive. However, in order to obtain order of magnitude improvements, it is usually necessary to introduce significant changes in the technology components that may prevent direct device compatibility with previous devices in an economical manner. In this respect, removable media storage systems which often hold large quantities of archival data are unique compared to other storage devices and components such as semiconductor memory or magnetic disk storage.

This paper discusses the device attributes that may be obtained by using advanced technology components in an embodiment that is deemed most suitable for computer data storage applications requiring high reliability, flexibility of data processing operations, economical storage costs, economical maintenance and operations costs, and data rate parity with other members of the storage hierarchy.

Storage Hierarchy

Storage hierarchies exist primarily for economical reasons. In the extreme limit of unbounded advances in the price/performance characteristics of semiconductor memory or hard disk storage and electronic data transfer network technology, it might be concluded that the need for tape storage devices and removable tape media would almost entirely disappear. In almost all cases hard disk device characteristics would be preferred. In actual fact, however, in spite of the advances in both semiconductor and hard disk capabilities, there are five basic reasons why tape storage will remain an important member of the computer data storage hierarchy.

1) Magnetic tape storage will remain significantly less expensive than hard disk storage. While lower cost per storage will be a continuing trend for all technologies, it is expected that the cost ratios will remain intact.

2) The volumetric density of tape storage relative to other storage technologies will, for fundamental reasons, always be a large ratio.

3) With each advance in technology, the demand for data storage increases. Improved storage devices enable new applications that previously were not economical and this, in turn, leads to increased demand for additional storage.

4) Software-managed automated removable media storage libraries continue to evolve and will be common for all applications. With this in place, optimally-designed tape storage devices will provide a continuum of storage characteristics along with semiconductor memory, hard disk and optical disk storage.

5) Although significant advances in electronic data transfer communication networks can be expected in the next decade, because of band width limitations and telecommunication costs, data interchange via physical transport of removable media volumes will remain the most economical procedure for many applications.

Tape Storage Device Attributes

Because of the wide diversity of application requirements, there will undoubtedly continue to be several types of devices required in order to meet all needs economically. The best a user could hope for would be to reduce the number of types of devices that need to be supported. Setting this as a design goal, the development objective becomes one of utilizing advanced technology components in a design(s) that attempts to provide: 1) the greatest flexibility of uses; 2) at an affordable price; 3) without compromising reliability objectives and at 4) performance matched to system requirements.

The IBM 3480 technology introduced in 1985 has become the industry standard for high performance computer data storage users. The 3480 and the 3490 and 3490E follow-on devices have developed a well-deserved reputation for providing highly reliable operations. Those attributes, high performance and high reliability, were responsible for its widespread industry acceptance. In providing the technology base for the next generation of tape storage devices, it is desirable to build upon the strengths of the 3480/3490 class of devices and enhance those factors that are necessary to achieve the development objectives described earlier.

Analysis of the 3480/3490 device design reveals several key design features that contribute to the performance and reliability reputation that has been achieved. These features are as follows:

1) An enclosed Cartridge System Tape (CST) that prevents accumulation of handling damage, fingerprints, airborne debris, etc.

2) A gentle tape path and tape guiding system that minimizes or eliminates mechanical tape damage.

3) An 18 track linear recording technology using thin film ferrite heads with magneto-resistive (MR) read elements. The 3490E utilizes serpentine linear recording at 2X track density with second generation MR read elements and enhanced Error Correction Code (ECC). The format is arranged such that when writing full tapes, no tape rewind is required.

4) An ECC that utilizes the advantages of multiple track recording in a track format that minimizes the probability of concurrent track errors due to media defects.

5) A Head-Tape-Interface (HTI) that operates at low pressures ensuring low head wear rates, yet provides the closely controlled spacing required for data reliability.

6) A tape media with mechanically and chemically stable polymer binder system, magnetic particles and substrate that minimizes debris generation and provides stable tape motion.

7) Reel-to-Reel servo control for precise tension and velocity control. In combination with the fixed head design and an electronic buffer, both start-stop and streaming data recording/reading are supported without performance or reliability penalties.

These are laudable design features proven in almost 10 years of field operation. Incremental improvements have been introduced during this time as the cartridge capacity increased from 200 MB to 400 MB to 800 MB, uncompressed. Additionally, IDRC compression was introduced along with channel data rate enhancements and cost reductions. The ability to use lossless data compression, such as IDRC, provides benefits to both effective capacity and effective data rate. Because data compression ratios can be highly variable, it is very possible that the storage device can be driven into start-stop mode if the channel data rate becomes the gating factor. Hence, to get full benefit of data compression features it is highly desirable to have a storage device that operates in both start-stop and streaming modes.

As a result of numerous discussions with numerous customers, the following items were identified as desired improvements to the attributes of 3490E tape transports. This listing is from a diverse group of applications and is not to be interpreted that all items correspond to a single application. Using the 3490E experience as a base, an assessment was made of how advanced technology components could enable the achievement of the desired improvements listed in Table 2.

Table 2
Desired Improvements Relative to 3490E Technology

1) Higher Capacity
2) Higher Data Rate
3) Lower Cost
4) Smaller Form Factor
5) Maintain or Improve Reliability
6) Higher Drive Utilization
7) No Increase in Rewind Time
8) Faster Access to Data
9) Automation Compatible
10) Preservation of Automation Investment
11) Growth Path for Future Product Enhancement

Technology Factors

In discussing the influence of technology on magnetic tape storage device characteristics, it will be helpful to analyze the end objectives from the viewpoint of <u>both</u> the user parameters <u>and</u> the technologist/developer parameters. To this end, it is necessary to provide a translation between device functional parameters and base technology parameters. Such an analysis enables the developers of new devices utilizing new technology components to prioritize the required development activity in a manner that considers the interdependence of the various technology components. Table 3 illustrates this point.

Table 3
Translation Between End User Functional Parameters and Developer Technology Parameters

End User Parameters	Developer Parameters	Primary Technology Components
• Capacity (GB)	• Bit Areal Density (bit/mm^2) - Track Density (#/mm) - Linear Density (bit/mm) • Media Length • Recording Code	• Media • Heads • Head Positioning System
• Data Rate (MB/sec)	• Linear Density (bit/mm) • Head/Tape Velocity (m/sec) • Number of Concurrent Channels	• Heads • Media • Tape Path/Control
• Reliability a) Data Reliability (MBBE)[a]	• SNR Margin • Media Defect Level • ECC Design • Device ERP • HTI Stability	• Heads • Media •Tape Path/Control • Signal Processing Techniques/ Electronics
b) Device Reliability (MTBF)[b]	• Mechanical Design • Electrical Design	
• Access Time to Data	• Load/Thread Time • Search Time - Search Speed - Media Length	• Cartridge Loader Design • Cartridge Design • Tape Path/Control • Media
• Drive Utilization	• Load/Thread Time • Search Time • Read/Write Time • Rewind Time • Unload Time	• Cartridge Loader Design • Cartridge Design • Tape Path/Control • Media

(a) MBBE - Mean Bytes Between Error
(b) MTBF - Mean Time Between Failure

The End User Parameters - Capacity, Data Rate, and Reliability - need no elaboration. Access Time to Data and Drive Utilization, however, have importance beyond the obvious. These attributes serve as key elements in optimizing the price-performance of the complete storage subsystem, i.e. automation plus storage devices plus media. Different applications will provide different weighting factors to each of the sub-elements under these parameters. In the final analysis, a device with higher throughput (for whatever reason - data rate, search speed, load/unload time, etc.) requires fewer devices to achieve a given function. If there is not a cost penalty for such devices, this would then result in a lower total subsystem cost, hence a better price-performance rating. Applications such as "digital libraries" and network-attached HSM servers will be the major beneficiaries of such characteristics.

Technology Prototypes

In what follows, we will explain the methodology of the technology development process which began with choices for the various technology components, evolved with the assessment of their interoperability, and culminated with building and testing of prototype devices used both to validate the chosen operating points and to serve as an input to the product development decisions.

Technology Components

With reference to Table 3, there are a number of technology components that must be assessed and evaluated both on a stand-alone basis and in an integrated interactive environment. We identify the following as the key technology elements.

A) Media
B) Heads
C) Tape Path
D) Servo Systems
E) ECC
F) Device Electronics

A brief discussion of the factors involved in assessing the merits of each of the technology components is covered in the next section. In the following section we describe the technology elements to be incorporated into two different technology prototype devices and their resultant device characteristics. Finally, these characteristics are compared against the Desired Improvements listed in Table 2.

A) Media

The laws of physics determine the ultimate areal density that a recording medium can support. Numerous other factors influence the practical limits. Factors determining the ultimate recording density are identical for both disk and tape recording media. Practical limits, however, are significantly different due to significant differences in the other factors, such as track guiding, fly height, defect mapping stability, etc.

Because capacity and data rate are directly dependent upon the areal density capability of the recording medium, choice of the recording medium is of prime importance. Numerous investigations have assessed the recording density capability of various types of media [1] [2] [3]. It is generally agreed that a thin film medium of a few hundred Angstroms thickness with coercivity of ~1000 Oe provides superior areal density capability compared to any single-layer particulate recording medium. Thin film is the recording medium benchmark against which particulate medium improvements are measured. Indeed, current high performance high density hard disk recorders almost exclusively utilize thin film media. For saturate recording, which is used in thin film disk recorders, the areal density capability is proportional to $H_c/(M_r t)$, where H_c is the coercive force of the medium, M_r is the remanent magnetization, and t is the media thickness [4]. Particulate tape media generally are utilized in a non-saturate recording mode where the coating thickness is usually greater than the recording depth. The effective recording depth is determined by the gap length of the recording head and the media coercivity. In this case, effective areal density can still be considered to be proportional to H_c/M_r. This explains the trend from ~350 Oe iron oxide recording media in the 1960s and 1970s to 550 Oe chromium oxide media and 900 Oe cobalt doped iron oxide media in the 1980s to 1500 Oe metal particle (MP) media in the 1990s. In addition to the increasing use of MP media, smaller quantities of barium ferrite media have appeared in floppy disk applications as well as thin film metal evaporated (ME) media for consumer video applications.

It should be cautioned that within a given media type, there are many variations possible, including many varieties of particle size, shape, and chemical composition, polymer chemical composition, mixing and coating processes, etc. In other words, all media of a given generic name type, e.g. MP, are not equivalent.

Another law of physics indicates that one parameter affecting the media signal-to-noise ratio (SNR) is the number of particles (n) in the recording volume in a manner such that SNR ~ [5]. This indicates that SNR can be improved through use of a medium with a larger number of smaller particles. Numerous other practical factors influence the final choice of particle size to be used.

Finally, it is realized that volumetric density is directly affected by the substrate [6]. Thinner substrates provide a higher volumetric density, however this desirable attribute must be balanced with durability and tape guiding issues, the latter factor obviously being dependent upon the tape path and the tape transport system.

B) Heads

Writing and reading data is accomplished via an intimate compatible relationship between the magnetic recording media and the magnetic recording/reading head. There are numerous design parameters that the head design engineer has at his disposal for optimizing the performance for a given type media. The head indeed plays a central role in providing a suitable transfer function between the write/read electronic circuits and the writing and reading of magnetic flux transitions in the recording media. In addition to the function of writing and reading of data, head design involves factors which influence a stable Head-Tape Interface (HTI) which is necessary for data reliability and tribology factors involving wear (of both head and media) and friction. For advanced recording systems, new media and head technology components are developed together to allow for intelligent design trade-offs and optimized system performance.

Write heads utilize an inductive coil of various designs coupled with a suitable magnetic pole tip material and write gap design that provides sufficient magnetic field strength to efficiently write flux reversals in the recording medium. IBM 3480/3490 technology utilizes a nickel-zinc ferrite (~3000 Gauss) material for the recording head pole pieces. While this is suitable for efficiently writing chromium oxide (H_C ~550 Oe) media used in 3480/3490 systems, this material is not capable of adequately writing 1500 Oe MP media. The ability to write higher coercivity media to get the benefits of higher areal density recording capability therefore requires the development of a new head design employing higher saturation magnetization pole tip material. A generic class of Metal-In-Gap (MIG) head designs has evolved for this reason. Most have been developed for rotary head type recorders. The ability to utilize MIG-type designs in a 3480/3490-like embodiment, i.e. stationary head, multi-track longitudinal recording, requires some unique features in both materials and fabrication processes.

Read heads may employ either inductive or magnetoresistive (MR) read elements. For inductive read elements, the signal amplitude is proportional to N d /dt, where N is the number of turns and d /dt is the rate of flux change. The rate of flux change is, in turn, proportional to the relative head-tape velocity. All rotary head recorders utilize inductive read heads. Unlike inductive heads, magnetoresistive heads provide a signal amplitude that is velocity independent. Furthermore, MR elements can be designed to provide high output signals with little required real estate or process complexity required for thin film inductive heads with a large number of turns. This is particularly important for 3490-like recording technology that employs 18 read and 18 write elements in each of the 2 modules required to make a recording head. The MR design enables a simplified thin film semiconductor-like process capable of fabricating the 36 elements per module economically. As track densities increase, the benefits of the MR design become indispensable. MR read elements were introduced in the 3480 product in 1985. A second generation improved MR design was introduced in 1991 with the double track density 3490E design. A new inductive thin film write head with third generation MR read head design was developed for the technology prototype devices described here.

C) Tape Path / Tape Transport

Magnetic tape storage recorders are electro-mechanical devices. The reliability of electro-mechanical devices is usually gated by the mechanical components. Hence, in order to achieve high reliability in a high performance computer data storage device, special attention must be paid to the mechanical portion of the tape path/tape transport design. Some of the requirements expected of the tape transport are reviewed in [7]. Suffice it to say that a reliable tape transport requires accurate velocity, tension, and tape guiding control while maintaining HTI stability and without damaging the media under repeated accesses in both write/read and high speed search/rewind modes. Features built into longitudinal recording stationary head devices enable highly reliable streaming or start-stop operations. These features include economical electronic buffers of sufficient size to totally mask the acceleration/deceleration times of tape movement.

For advanced operating point devices employing higher track densities, it is necessary to further improve the tape guiding envelope and, for interchange applications, the accuracy of the initial alignment of the head to the recorded tracks. As the advanced media and head components allow ever narrower tracks, the mechanical registration tolerances become the dominant issue limiting track density. At some point it becomes economically advantageous to introduce a head servo capability in lieu of ever more precise (and expensive) mechanical tolerances required to achieve the goal of increased track density and hence capacity.

D) Servo Systems

Servo systems of varying function are utilized in high performance tape storage devices. These functions include velocity and tension control in reel-to-reel driven transports such as 3480/3490 type, and synchronization of scanner speed with tape velocity for accurate tracking in various rotary head recorders. The use of a reel-to-reel tape transport servo system also enables a simple means of obtaining high-speed search capability.

While hard disk storage devices have employed active head positioning servo systems for many years as a means of reducing misregistration tolerances between the head and the written track, such active head positioning servo systems have yet to be employed in longitudinal recording format tape storage devices. Based on the discussion in the previous section, the ability to utilize head positioning servo systems in combination with accurate guiding tape transports, enables the attainment of higher track densities (hence higher capacities) without having to resort to longer length media and concomitant increases in search/rewind times.

E) Error Correction Code (ECC)

Error Correction Codes are employed to provide an uplift to the data reliability achievable from practically available media quality and device performance. Raw bit errors can be a result of a variety of causes, including a) local media defects such as coating contaminants, b) global media defects such as damaged edges, creases, adherent debris, c) adherent head contamination, d) transient non-adherent particulate debris at the head/tape interface, e) clocking errors due to velocity transients, and f) electronic noise.

The different types of error sources usually have a distinctive signature of raw errors which includes parameters such as error length, error reproducibility, error coincidence across multiple tracks, etc. The measured raw bit errors are of course critically dependent upon the data channels employed and the optimization of equalization and detection schemes for the variety of defect signals experienced.

In order to meet some end user data reliability target, the developer must first characterize and specify the media quality in terms of both average bit error rate (*ber*) and error distribution (error lengths and coincidence) as input to deciding which ECC scheme will meet the required objectives. It is meaningless to talk in terms of an average *ber* only without addressing the defect spatial and temporal distribution. A robust recorder design must also allow for possible increases in errors during either storage or heavy use of the media in order to achieve the desired performance objectives. Many claims that are made about corrected *ber* in various product advertisements do not define what is or is not included in the claim, frequently leading to "apples and oranges" comparisons.

The effectiveness of the ECC is intimately connected with the spatial distribution of the data format written on tape. Multi-track recording heads enable a more robust ECC since data is distributed laterally across the width of tape as well as linearly (temporally) along the length of tape. In systems utilizing a large number of concurrent channels, ECC robustness is enabled by reducing the probability of encountering extended concurrent defects of duration sufficient to defeat the ECC. This is extremely important for reliable data recovery from marginally recorded or degraded archive media. 3480/3490 devices utilize 18 concurrent channels. Data recovery is possible with 1 or 2 data read-back channels completely disabled. Obviously this would not be possible in 2 channel recording systems.

Thus multi-track recording formats can be used advantageously for enhancing data reliability. It is also apparent that performance (i.e. data rate) enhancements result from the use of multi-track formats. This ability to obtain both reliability and performance enhancements is what has been touted for RAID disk technology. In effect, tape storage devices have been utilizing these concepts for many years with the paradigm shift that the "Inexpensive Device" is the recording element in the multi-track head rather than a complete device. Indeed, because of the differences of tape devices compared to disk devices in achieving device synchronization and the stability of defects, we believe it is more practical to consider RAID type benefits for tape devices as occurring at the multi-track head level rather than schemes employing multiple devices. There is of course a cost associated with the benefits obtained by the use of multi-track recording technology. This includes a more expensive head and the additional cost of the additional read/write channel electronics.

F) Device Electronics

The increased density and decreased cost per circuit for semiconductor chips during the past decade has been nothing short of phenomenal. There is no indication that this progress will not continue. The power of using advanced recording media and heads combined with the advanced semiconductor components enables significant recording device performance improvements while maintaining simple mechanical components (i.e. high mechanical reliability at low maintenance costs) and similar or reduced acquisition costs. These concurrent technology advancement trends have strongly influenced the decisions involved in the design, assembly and testing of the technology prototype devices.

Technology Prototype Devices

I) Technology Component Selection

Based on the analyses in the previous sections, the technology development team selected and developed the following technology components for incorporation into technology prototype devices.

A) Media - MP (1500 Oe class)

- Metal particle type chosen for optimal balance to meet both SNR and archival stability requirements
- Polymer binder system - uniquely developed to meet stringent performance/reliability requirements

B) Heads - multi-track linear recording

- Third generation magnetoresistive (MR) read elements
- Inductive thin film write elements
- New thin film shield/write pole tips materials/design needed to meet write performance and head-wear lifetime requirements

C) Tape Path - varies by technology prototype design

D) Servo Systems

- Reel-to-reel servo for velocity/tension control
- Active head positioning actuator/servo

E) ECC - Reed-Solomon

- Enhanced and scaled with areal density increases

F) Device Electronics - per performance and form factor objectives of technology prototype

Upon reviewing the eleven items listed as Desired Improvements in Table 2, it became apparent that a single prototype design would not be able to address all the items on the list. Therefore it was decided to build and test two different designs utilizing a common advanced technology base. In combination, the two different designs are able to address all eleven items.

II) Technology Prototype I

Of paramount importance in the selection criteria for the Prototype I design was preservation of automation investment. This requirement translated into the use of a 3480 CST type cartridge for compatibility with the IBM 3494 and 3495 tape libraries. Use of a CST type cartridge would thereby provide for coexistence of 3490 and an advanced function drive type to enable both investment protection and migration capability to new technology.

Following this decision, it was decided to utilize the basic 3490 tape path since this design has been proven with approximately ten years of field experience since the introduction of 3480 in 1985. To obtain maximum benefit of the field experience, it was further decided to utilize approximately the same media thickness, and hence media length, as is utilized in the 3490E extended length cartridge. This ensures similar media mechanical properties favoring the establishment of a stable and reliable HTI with minimal development effort. Since the stated objectives were to increase capacity, including track density, early investigations were made to understand the various factors controlling the tape guiding envelope. The result of this has been to introduce into the tape path design subtle improvements to both the 3490 tape path and cartridge design that are designed to reduce the tape guiding excursions and therefore enable higher track densities.

Many media types were investigated with compatible read-write head designs to assess their storage capacity capability. Possible extensions of the 550 Oe chromium oxide media used in 3480/3490 devices were judged not to be of sufficient magnitude to lead to an attractive design point. MP media provided the best overall capability, but led to the requirement of being able to develop a compatible read-write head design capable of meeting all functional requirements including low wear and long operational lifetime. This was a major development checkpoint that, once achieved, committed the prototype design to MP media. Head and media were then co-developed to optimize their combined performance.

With continued co-development of head and MP media technology components, it was assessed that greater than an order of magnitude areal density improvement, relative to 3490E technology, could be obtained without an active head positioning actuator/servo technology. However, in order to provide for future capacity enhancements using the same cartridge, and to provide means to ensure data integrity and protect against neighboring track overwrite encroachment at high track densities, it was decided to incorporate servo tracks written on tape and to incorporate an active head positioning servo system. Such a system is new to linear tape recording systems, but borrows from the extensive technology developed for disk systems. The utilization of an active head positioning system reduces track misregistration (TMR) errors without the need for expensive, high precision mechanical components, and therefore enables the attainment of higher track densities.

Given these choices and the appropriate ECC and channel electronic circuitry, a design target of 10GB cartridge capacity with 9MB/sec data rate was established [8]. The 12.5X (relative to 800MB 3490E technology) capacity increase is obtained by operating at approximately 4X track density and 3X linear density. All values are uncompressed. It is judged that enhancement of the chosen technology components would provide for additional 2X-4X multipliers to both data rate and capacity without compromise of data reliability. Should the constraint of using the same media be removed, it is possible that even greater enhancements could be achieved.

Performance and capacity enhancements could always be obtained by reducing operating margins that relate to robustness of the system data reliability. The design point chosen for Prototype I and the expected possible extensions utilize the new technology components in a manner that does not compromise data reliability.

A comparison of the Prototype I design point to the list of eleven desired improvements indicates that seven of the eleven objectives are achieved. They are listed in Table 4.

Table 4
Prototype I
Functions Achieved Compared to Design Objectives

1)	Higher Capacity	10GB (0.8GB)
2)	Higher Data Rate	9MB/sec (3MB/sec)
5)	Maintain/Improve Reliability	Yes
7)	No increase in Rewind Time	Yes
9)	Automation Compatible	Yes
10)	Preservation of Automation Investment	Yes
11)	Growth Path	Yes

III) Technology Prototype II

Items 3, 4, 6, and 8 that were not achieved by the Prototype I design became key focal points in defining the design objectives for Technology Prototype II. The design was based on most of the same base technology elements, including the media and head, that were used in the Prototype I design. The major change that was made in the Prototype II design point involved the design of a new tape cartridge and tape path. Such changes were deemed necessary to achieve the design goals of items 3, 6, and 8. Several of the design objectives set for Prototype II are similar to those set in an earlier development effort [9].

For many of the emerging data storage applications involving network hierarchical storage management (HSM), digital libraries, and "parking garages on the information superhighway," current tape storage devices have several deficiencies. Key among the missing attributes is fast access time for data retrieval. There are two aspects to obtaining fast access time to data. The first is what may be termed the human factors aspect gauging user satisfaction against system response time. The second factor involves the price-performance aspects of a storage subsystem. A fast-response tape device with short rewind time leads to higher device utilization, i.e. the throughput rate per device is higher. This leads to fewer devices needed to perform the storage subsystem function and hence to overall lower storage subsystem costs.

Any tape storage device will still have orders of magnitude slower response time compared to a disk storage device, however the storage cost for tape will have a couple orders of magnitude advantage. This is enough incentive to employ a hierarchical storage system. The Prototype II design was developed to provide significant advantage over existing devices for these applications.

For both form factor reasons as well as access time and drive utilization reasons, it was desirable to have a high areal density recording technology. This would enable high capacity on a shorter length of media. Hence MP media, compatible head technology and active head positioning actuator/servo become the key enablers of such a prototype design. The next key design factor was the selection of a 2-reel cartridge with a self-contained tape path. This provided the ability to improve access time and drive utilization by not having to extract the tape from the cartridge in order to engage the head. Of equal importance, this design has the added benefit of improved mechanical reliability. By defining the Logical Beginning of Tape (LBOT) at the Physical Middle of Tape (PMOT) additional improvements are achieved in both access time and drive utilization.

A 5 1/4" form factor compliance was set as a goal, thereby setting an upper limit for the cartridge size. Other aspects of the objectives criteria refined the constraints on cartridge size further. Factors affecting ECC design, available electronic circuitry and data format were common with the Prototype I decisions.

Table 5 summarizes which of the desired objectives listed in Table 2 were achieved in the Prototype II design using the technology components previously described.

Table 5
<u>Prototype II</u>
Functions Achieved Compared to Design Objectives

1)	Higher Capacity	Yes 5GB (0.8GB)
2)	Higher Data Rate	No[a] 2.2MB/sec (3MB/sec)
3)	Lower Cost	Yes
4)	Smaller Form Factor	Yes
5)	Maintain/Improve Reliability	Yes
6)	Higher Drive Utilization	Yes
7)	No Increase in Rewind Time	Substantial Reduction 8 sec (30-50 sec)
8)	Faster Access to Data	Yes 8-10 sec (30-50 sec)
9)	Automation Compatible	Yes
10)	Preservation of Automation Investment	No[b]
11)	Growth Path for Future Enhancements	Yes

(a) Design is family compatible with higher data rate capabilities.

(b) Drive/Cartridge design enables compatibility with new high speed automation systems.

Conclusions

Advanced technology elements indeed enable advanced tape storage device capabilities. How such technology elements are utilized in particular device embodiments is highly dependent upon the application solutions that are targeted. The functions achieved in the Prototype I design were targeted to provide evolutionary, albeit saltatory, performance extensions to the 3480/3490 type products for their historical tape processing applications. Functions achieved in the Prototype II design are directed to providing solutions for a) cost-effective, lower performance historical applications and b) the putative new emerging applications. Both designs utilize a common technology base. This divergence in device designs is not unique in the storage industry. In the disk storage business, utilization of new technology capabilities has resulted in smaller disk files with higher capacity than their predecessor larger size disk products. The very reasons that provided those decisions for disk products, as opposed to simply increasing capacity on a large disk, will serve to guide the future direction of expected new tape storage devices. More than ever before, it is necessary to incorporate into the device design objectives, the performance objectives of the total storage subsystem rather than treating the device by itself.

Acknowledgements

The activity described here clearly represents the result of a development team effort composed of diverse technical skills. The authors acknowledge the contributions of these development team members, too numerous to credit individually, that contributed to the design, assembly and testing of the two prototypes.

References

1. Inaba, Hiroo, et al, "The Advantage of the Thin Magnetic Layer of a Metal Particulate Tape," *IEEE Trans on Magnetics*, **29** (1993) 3607.

2. Speliotis, Dennis E, "Double Layer Particulate Magnetic Recording Tapes," *IEEE Trans on Magnetics*, **29** (1993) 3613.

3. Williams, Peter, "Recent Developments in Particulate Recording Media," *IEEE Trans on Magnetics*, **24** (1988) 1876.

4. Middleton, Barry K, "The Recording and Reproducing Processes," in *Magnetic Recording, Volume I: Technology*, C. Denis Mee and Eric D Daniel, ed. (New York: McGraw-Hill, 1987).

5. Jorgensen, Finn. *The Complete Handbook of Magnetic Recording*, p220. (Blue Ridge Summit, PA: TAB Professional and Reference Books, 1980).

6. Goerlitz, W and Ito, A, "Substrates for Flexible Magnetic Recording Media: The Role of Base Films for Modern Performance requirements," *J Mag & Mag Mat*, **120** (1993) 76.

7. Cannon, Max R and Seger, Paul J, "Data Storage on Tape," in *Magnetic Recording, Volume II: Computer Data Storage*, C Denis Mee and Eric D Daniel, ed. (New York: McGraw-Hill, 1987).

8. Graves, David, "Capacity and Data Rate Advances in IBM Longitudinal Magnetic Tape Recording Technology," IEEE Symposium on Mass Storage, France (1994).

9. Doyle, William D, "A High Capacity, High Performance, Small Form Factor Magnetic Tape Storage Subsystem," *IEEE Trans on Magnetics*, **26** (1990) 2152.