White Paper

The Technical and Operational Values of Barium Ferrite Tape Media

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March 2014

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Introduction – Tape's Contemporary Relevance

While tape has sometimes (and at times even fairly) had a "bad rap" over the decades, the contemporary manifestation of the technology is not that of your grandfather's! Indeed, in recent years, numerous important technical advances have been implemented that yield dramatic improvements:

- Unprecedented cartridge capacities – which translate to excellent cost/TB
- Vastly improved bit error rates – which mean long-term data availability
- Much longer media life – which delivers reliability and improved TCO
- Faster sustained data rates than any previous tape *or* disk technology – which makes tape the optimum media for recovery purposes
- Linear tape file system (LTFS) – which allows tape data to be accessed similarly to disk

Tape's Changing Uses

Tape has been expanding its historical role—primarily as a backup solution—to a much broader set of workloads, including archive, fixed content, unstructured data, disaster recovery, business continuity, and long-term data retention. A burgeoning global list of government, compliance, and legal regulations now describes not only the way data should be managed and protected, but also the length of time that data is required to be stored.

For many applications and files, the lifetime for data preservation has become essentially infinite, further increasing the size, security needs, and management requirements of the digital archive. Meeting such huge and invariably less-active storage requirements with disk is financially prohibitive for most businesses, while the technological progress in tape media, drives, and libraries has once again positioned tape as the credible and optimal high-capacity storage solution for the foreseeable future.

Tape's Essential Value

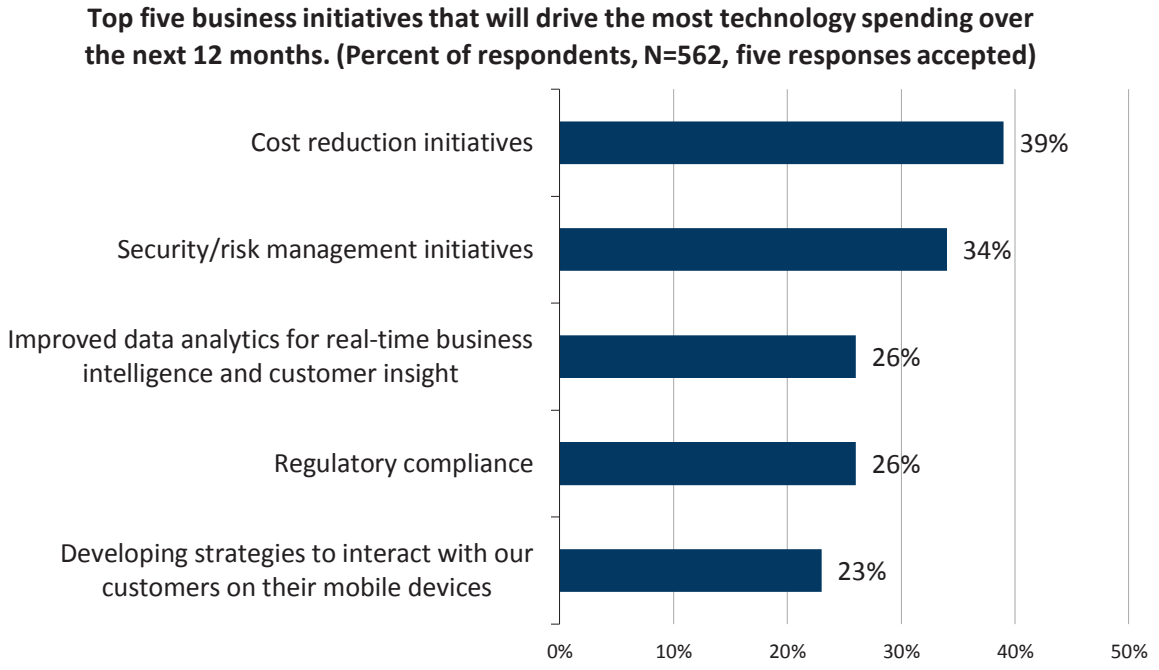
The essential value of tape is that it provides the lowest cost per gigabyte/terabyte/petabyte of storage. And, as ESG research shows (see Figure 1) one consistent driving motivation reported by IT users is the need to reduce costs.[1] Indeed, for the last five years (and more) of ESG's annual Spending Intentions Survey, cost reduction initiatives have been the number one most-cited business initiative impacting upcoming technology spending decisions.

Tape, therefore, clearly matters in the overall storage equation and indeed, in a more converged, virtualized, and software-defined world (the sum of which is more fluid data and easier, automated data movement), it is easy to actually see the role of tape expanding. While even on a straight CAPEX measurement, tape-based storage systems cost only a fraction of what comparable hard disk storage systems cost, it is in OPEX terms that tape truly shines.[2] Because tape cartridges in a library slot or on a shelf do not consume energy when they are not in use, tape is the greenest of all storage technologies and can be used to increase storage capacity with little, if any, increase in energy consumption. The TCO advantage for tape is expected to become more compelling with future technology developments as tape media capacities grow faster than disk capacities.

[1] Source: ESG Research Report, *2014 IT Spending Intentions Survey*, to be published February 2014.

[2] Source: ESG's TCO study (*A Comparative TCO Study: VTLs and Physical Tape,* February 2011) compared an LTO-5 tape library system with a low-cost SATA disk system for backup using deduplication (best case for disk) and showed that disk deduplication has a 2-4X higher TCO than the tape system for backup in several use cases over a five-year period. For archive data, the TCO for disk is considerably higher.

Figure 1. Top Five Business Initiatives Driving IT Spending Decisions Over the Next 12 Months



Source: Enterprise Strategy Group, 2014.

Why the Tape Media Matters

Tape media plays a crucial role in addressing today's growing storage requirements and is progressing faster than ever before. Tape media must be highly reliable, portable, and rugged enough to be moved without impacting reliability, while having a high capacity and very long life for archival applications. Modern tape drives include IBM's TS11xx product family, Oracle StorageTek's T10000x tape products, and the LTO product family.[3] Each of these drives uses advanced media that has a proven archival life of 30 years or more.

Increasing Capacity and Storage Reliability

In January 2010, scientists at IBM Research in Zurich recorded data onto a (then) new, advanced prototype Barium-Ferrite (BaFe) tape media developed by FUJIFILM Corporation at a density of 29.5 billion bits per square inch, which equated to the potential to yield a native (uncompressed) capacity of 35 TB on a single cartridge. As a result of this joint R&D effort, several new tape technologies were also developed including:

- Improved precision control of read-write head positioning
- More than a 25-fold increase in the number of tracks (compared to LTO-4 at the time)
- New detection methods to improve read accuracy
- A new low-friction read-write head

These enhancements represent a significant step toward not only achieving areal densities for tape of 100 billion bits per square inch and beyond, but also improving tape reliability.

[3] LTO refers to the technologies developed by the LTO Technology Provider Companies HP, IBM, and Quantum and supported by an ecosystem that produces compatible media and associated hardware and software products.

Comparative Reliability

As a result—and this can come as something of a surprise to many people involved in IT—the raw reliability of the media for today's enterprise and midrange tape systems—as measured by the published uncorrectable bit error rates from vendors—ranges *from one to three orders of magnitude higher* than that of even the best (Fibre Channel or SAS) disk media (see Table 1).

Table 1. Comparing the Raw Reliability of Tape and Disk Media

Media Type[4]	Technical: UBER (Uncorrectable Bit Error Rate) Range	Practical: What This Means in Plain English
Enterprise Tape	1 x $10E^{19}$ bits	Enterprise tape media (Barium Ferrite) has raw reliability levels that are *3 orders of magnitude* higher than its enterprise HDD cousins
Midrange Tape	Generally quoted at 1 x $10E^{17}$ bits	Mainstream midrange tape media (MP) has raw reliability that is *2 orders of magnitude* higher than enterprise SATA HDDs
Disk Drives (HDD)	Ranges from 1 x $10E^{14}$ bits for desktop SATA, to 1 x $10E^{15}$ bits for enterprise SATA, to 1 x $10E^{16}$ bits for enterprise class FC/SAS	The underlying reliability of the media used in all standard contemporary disk drives ranges from *1-6 orders of magnitude less* than contemporary tape drive media.

Source: Enterprise Strategy Group, constructed from vendors' specifications & ESG analysis, 2014.

Importance and Impact: A casual glance at these numbers might make them seem disingenuous—after all most disk systems *seem* fairly reliable in practice, don't they? That's true, but this perception applies to *systems*, rather than just the media. When evaluating such systems, the reliability [both perceived and real] comes in large part from the application of such tools as Error Correction Code and various levels of RAID. Since these tools can be—and indeed sometimes are—also used on tape systems, it is categorically reasonable to compare the underlying raw media reliabilities for two main reasons:

- The fact that tape media reliability exceeds that of disk media runs counter to much of the "received wisdom" in the IT industry; this can lead to IT professionals making sub-optimal choices in their media decisions.
- This is clearly a vital "suitability-attribute" in terms of the workloads for which tape is deployed; most tape is deployed for archive and backup purposes, which makes the maximum reliability of the underlying media (which, from an operational perspective, can be translated as guaranteeing data access) of paramount importance.

To drive the overall point home, the media reliability differences here are not at all marginal—they are significant. As one might expect, the latest enterprise tape media is considerably more reliable than the mainstream midrange media, but both offer multiple orders of magnitude better raw data reliability than disk drives. The numbers in Table 2[5] show the metrics for data usage, which puts the impact of the raw error rates into accessible terminology in order to emphasize the impact of the differences between media types. The calculations are based on 50 drives and show how long it would take (both as elapsed time, and as the number of full passes of a piece of media) to reach an uncorrectable bit error, as based on the vendors' published product specifications.

[4] For this media comparison, Enterprise Tape refers to Barium Ferrite tape media used in enterprise tape drives (IBM TS11xx and Oracle T10000x), and Midrange Tape refers to traditional MP formulation of LTO tape media.

[5] Source: the underlying spreadsheet calculations were developed in ESG discussions with tape drive developers and are extrapolations of published vendor specifications.

Table 2. The Impact of Raw Media Reliability

Media Type (50 Drives)	Time to Potential Error	Multiples of Unit Capacity (Full Passes) to Potential Error
Enterprise Tape	> 3 years	> 150,000
Disk Drives (HDD)	24 minutes to 40 hours (depending on class of drive)	~3 – 300 (depending on class of drive)

Source: Enterprise Strategy Group, constructed from vendors' published specifications & ESG analysis, 2014.

As a reminder, these differences matter because of the workloads for which tape is used. Of course, in daily operations there are many variables that can "affect your mileage." Everything from system degradation, to the tweaks that individual vendors claim to be able to make, and the slight differences in calculation methods that they certainly do make all the time! *However,* all such variance and debate is essentially irrelevant when one considers the ability of tape media to reduce the potential for hard errors by so much compared to disk media. Whatever the variances between vendors, their assumptions and models, none of these can overshadow the key point: all types of modern tape media have better raw reliability than any type of modern disk media.

Introduction to Barium Ferrite (BaFe)

BaFe is the key to unlocking the future of tape and represents an advanced media technology capable of pushing tape cartridge capacities to unprecedented levels. Fujifilm is the first media manufacturer to meet the challenge of delivering higher capacity and higher reliability with the development of its BaFe particle, which delivers greater storage capacity with lower noise and higher frequency characteristics than traditional metal particles. Magnetic tape consists of tiny microscopic "magnetic particles" uniformly dispersed and coated on the surface of the tape. Small groups of cells are then magnetized to create the data bits. Each cell is magnetized as either positive or negative and multiple bit combinations become data (just as digital data is made up of 1s and 0s).

Fujifilm's Nanocubic technology combines nano-scale particles with a unique coating process and advanced dispersion techniques to achieve an ultra-thin magnetic layer that produces higher resolution for recording digital data, together with ultra-low noise resulting in high signal-to-noise (SNR) ratios that are ideal for the Magneto-Resistive and Giant Magneto-Resistive heads that contemporary tape drives use. Nanocubic technology enables the production of nanometer-scale, ultra-thin coatings (one nanometer = one-billionth of a meter). In addition, nano-scale technology is employed to produce magnetic needle-shaped metal particles (MP) and hexagon-shaped BaFe particles that are only a few tens of nanometers in size, while a new high-molecular binder material and nano-dispersion technology are used to ensure uniform dispersion of the particles.

BaFe is a naturally stable crystalline particle that does not corrode or change chemically over time, making it *an optimal particle for data storage applications*. Due to their crystalline anisotropy (the property of generating magnetic power), the ultra-fine BaFe particles have higher magnetic properties for superior performance and high density recording. Because Fujifilm's new technology disperses the particles uniformly and controls disposition at nanometer levels, it has also improved the tape's running stability and reliability. Today, BaFe is used for LTO 6, the IBM TS1140, and the Oracle StorageTek T100000C/D enterprise-class tape drives.

Compared with a standard 3.5" HDD—which has an areal density approaching 600 Gb/in^2—the tape areal densities are not nearly as "crowded" yet, which, in colloquial terms, simply means that BaFe capacity has a lot of room to grow. Indeed, the perpendicular orientation of BaFe particles helps to ensure improved areal densities in future BaFe tape generations. Some key current comparisons are shown in Table 3.

Table 3. Comparing the Key Specifications of Tape Media and a 3.5" SAS Hard Disk Drive

Drive Type and Media	Capacity (native)	Data Transfer Rate	Channels/ head	Tracks	Areal Density
LTO-5 MP	1.5 TB	140 MB/sec	16	1,280	1.2 Gb/in^2
LTO-6 MP, BaFe	2.5 TB	160 MB/sec	16	2,176	2.2 Gb/in^2
TS1140 BaFe	4.0 TB	250 MB/sec	32	2,560	3.2 Gb/in^2
T10000D BaFe	8.0 TB	252 MB/sec	32	4,608	4.93 Gb/in^2
3.5" HDD SAS 7200 RPM	4.0 TB	175 MB/sec (sustained)	NA	NA	578 Gb/in^2

Source: Enterprise Strategy Group, constructed from vendors' published product specifications, 2014.

Fujifilm is developing BaFe technology to accelerate tape capacity growth and in 2011, the first two tape cartridges using BaFe were introduced: the IBM 3592 JC and the Oracle StorageTek T10000C. The roadmap progress of enterprise and LTO systems enabled by multiple generations of BaFe can very reasonably be expected to continue across future media and drives.

Barium Ferrite Advantages

For years, Metal Particulate (MP) was the primary tape media formulation. MP is mainly made of iron (Fe), meaning that it will oxidize over time and its magnetic property will therefore deteriorate. In order to slow that down, an additional outer layer (the passivation layer) is added around the main metal particle, essentially and intentionally trapping the oxidization in that layer. All previous generations of LTO cartridges prior to LTO-6 have only used the MP particles.

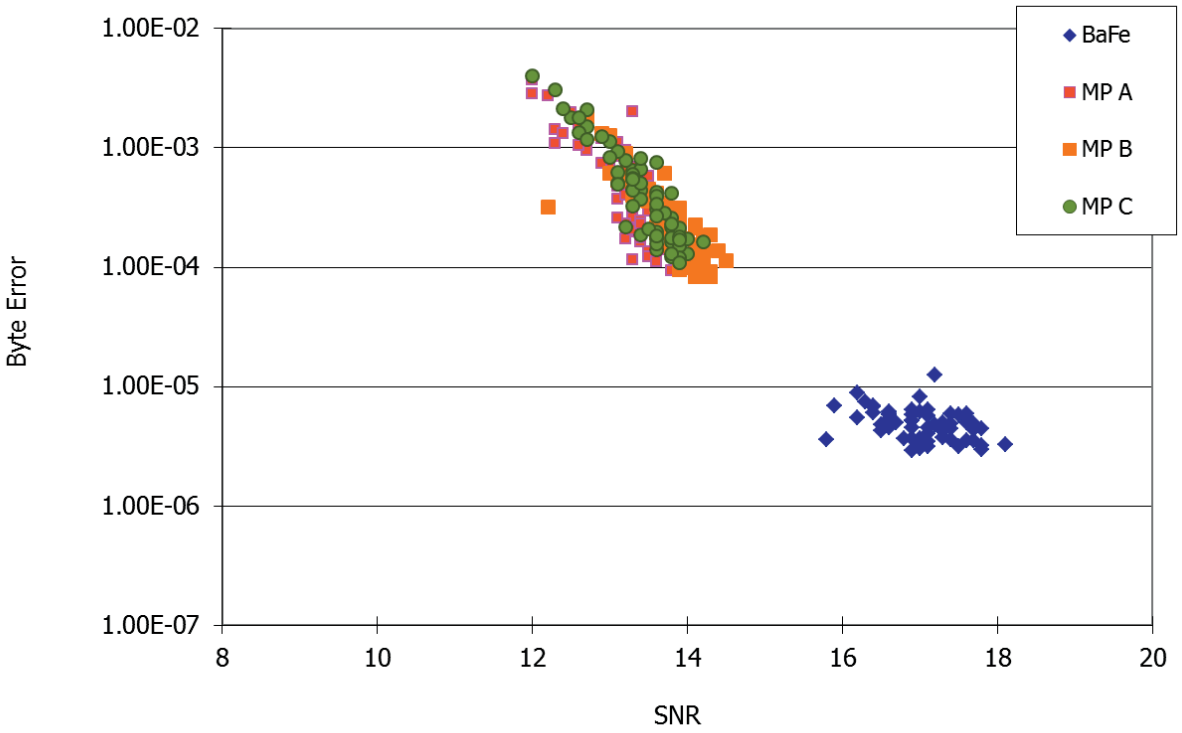
> ***Ed Childers, Manager, Tape Drive Development, IBM***
> *"The essence of Barium Ferrite media is that it is a superior technology that allows us, in turn, to provide higher quality solutions to our customers. Attributes such as its high signal-to-noise ratio make for a much better end-user value proposition; not only that, but our technology demonstrations have already shown that it will be the media of choice for several tape drive generations to come."*

While MP media was—and still is—perfectly fine to use up to the current generations of LTO drives, it is effectively "running out of steam" at this point; one of the key contributors to this is that the outer/passivation layer has become a higher percentage of the overall particle size, as it has not been technically feasible to reduce its scale as much as that of the "core" metal particle (size reductions obviously have been desirable to drive up density and capacity). This size constraint is in turn now preventing MP media from progressing as fast as the combined demands for linear density, overall capacity and high SNR demand. In comparison, BaFe particles are not only smaller and more stable (themselves both good things in this technology area, of course!) but are actually inherently an oxide, and therefore they do not lose their magnetic property due to oxidation.

Better Signal Means Less Errors

Furthermore, the smaller particles used in BaFe—a result of their crystal structure with excellent magnetic properties relative to their size—mean more particles will exist on a given area of the tape, which of course improves the signal-to-noise (SNR) ratio, which contributes to the significantly lower error rates compared to MP media (the details of this are shown in the data in Figure 2). While both MP and BaFe are capable of meeting the fundamental specifications of the current LTO-6 format in terms of capacity and transfer rates, BaFe offers better reliability and future scalability, which means that it will inevitably be preferred over MP for future tape drive/media generations; this of course, also makes it a more attractive and compelling media for all users today. We can find that advantage of reliability in the fact that every system manufacturer has adopted BaFe LTO6 cartridges.

Figure 2. Comparative Error Rates of BaFe and MP Media



Source: Enterprise Strategy Group, constructed from vendor data, 2014.

Areal Density and Capacity Growth

The amount of data that can be placed onto a given area of media is the areal density. The scenarios in Figure 3 are from the vendor-neutral INSIC group and suggest that the annual tape areal density growth rates will either maintain or exceed traditional 30% values, while annual HDD areal density growth rates will not maintain their traditional 40% values using vertical recording and will likely slow toward just 10% per annum.[6]

In plain English, these scenarios mean two things:

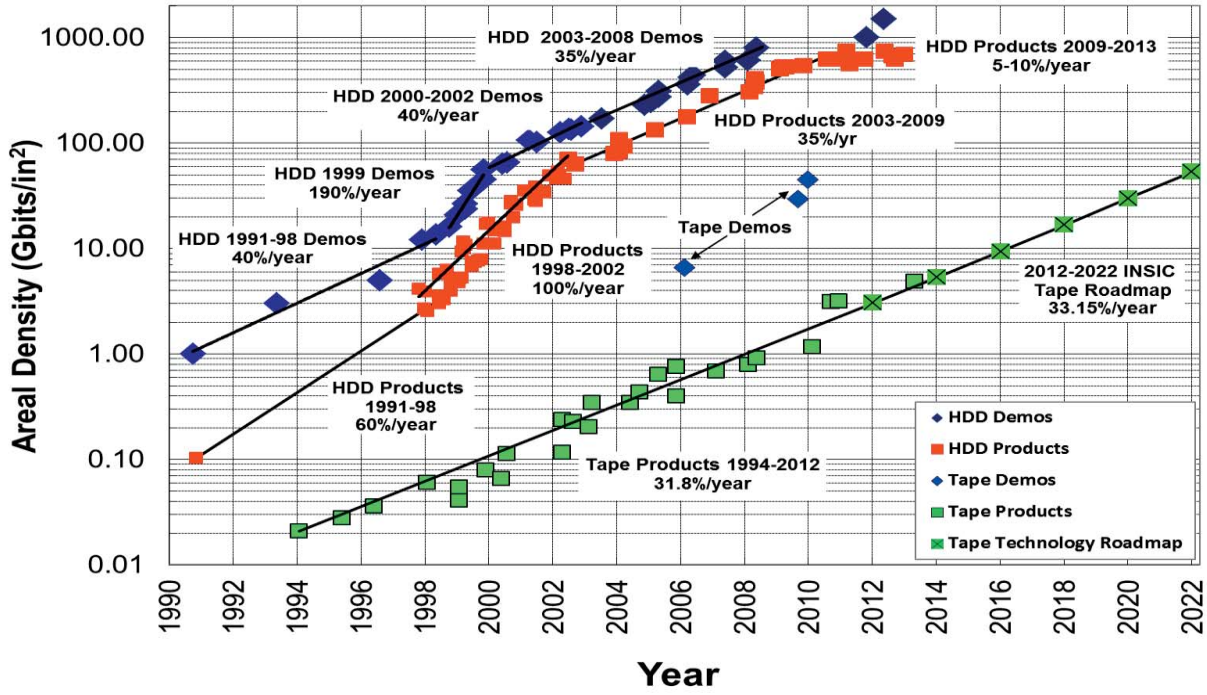
1) The surface area available to increase HDD capacity is becoming crowded, and HDD areal density growth is slowing while tape cartridges have a much larger area to work with. The net forward impact is a sustained volumetric and total capacity storage advantage for tape technology. Tape cartridge native capacities exceeding 100 TB are within realistic reach given these strides in areal density.

Robert Raymond, Director, Hardware Development, Oracle Tape Engineering
"The primary advantage of Barium Ferrite is that, using its specifically shaped and dispersed magnetic particles, users can enjoy the highest possible areal densities and capacities. This helps reduce overall costs—not just per-gigabyte-stored, but also less data center footprint. Furthermore, its excellent chemical stability, with low susceptibility to corrosion and oxidation, makes it an excellent archival media."

[6] Source: Information Storage Industry Consortium, *Magnetic Tape Storage Roadmap,* October 2013 (used with permission).

2) Better areal density means more data on a given tape, and more data stored means a lower cost per stored TB (this assumes that the BaFe media and MP media are somewhat similarly priced in terms of a given length of tape—which they are for all intents and purposes). And of course, more densely packed storage also means less floor space is needed to store a given number of TB or PB, which is a further financial saving.

Figure 3. Historical and Projected Areal Densities Across Disk and Tape Technologies



Source: INSIC (used with permission).

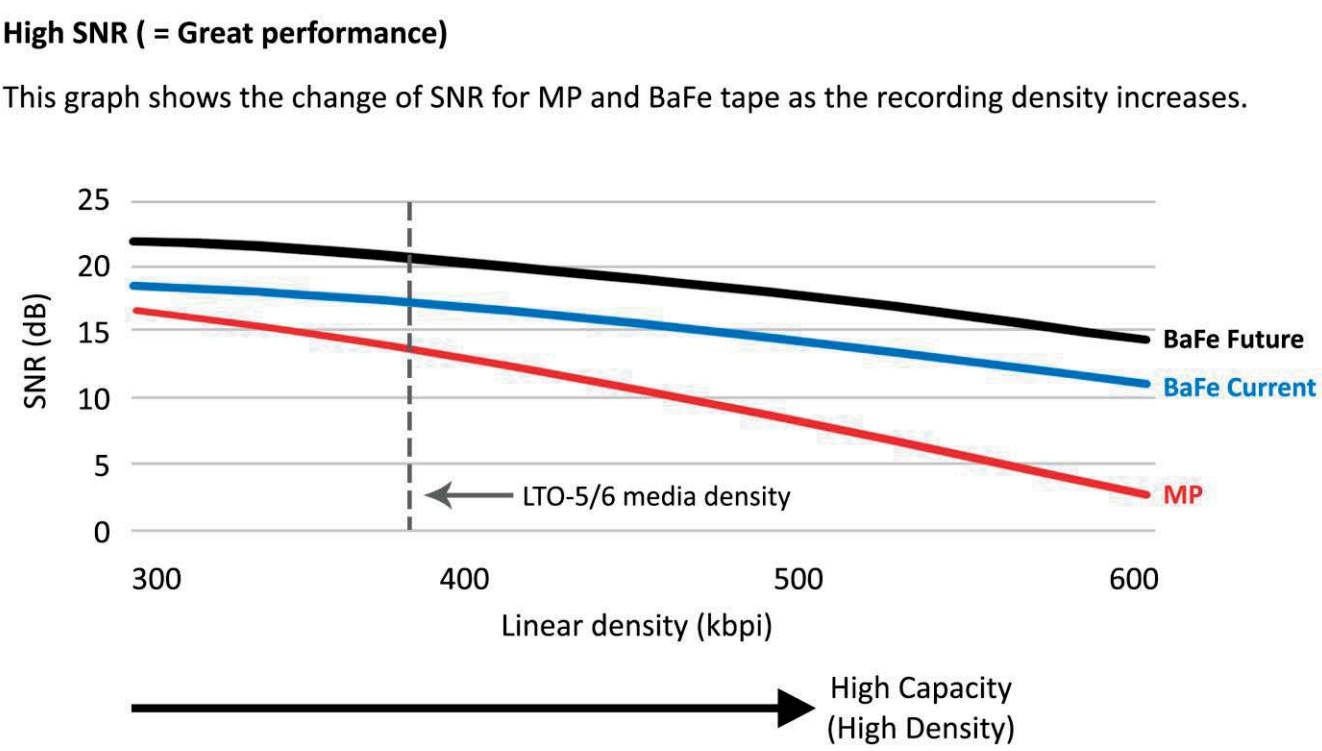
Improved Performance

Signal-to-noise ratio (SNR) is the ratio between output signal (strength) and noise, and is a key metric for the performance of tape media. BaFe tape has a thin and uniform magnetic layer. This enables less output fluctuation, which in turn results in less noise and maintains a strong tape signal even as natural tape drive head wear occurs. The higher SNR of BaFe compared with MP (see Figure 4) leads to the improved media performance and better bit error rate (BER) compared with MP. The stronger SNR (a better data signal, in plain English) means more robust read/write ability even in the event of higher system noise.

John Moore, Vice President, LTO Engineering, Quantum

"Barium Ferrite media simply allows more data to be put on tape. Whereas the preceding, and indeed overlapping, technology of MP media requires a protective ceramic 'shell' (that is, extra bulk) to prevent oxidation and magnetic decay, Barium Ferrite particles are already chemically stable and so need no such protective layer…they are thus inherently smaller and hence capable of delivering higher signal and improved signal-to-noise ratio."

Figure 4. Signal-to-noise Ratios for MP and BaFe Tape Media



Source: Enterprise Strategy Group and Fujifilm, 2014.

Recording Stability, Long-term Reliability, and 'Archive-ability'

Accelerated aging tests and modelling show that BaFe media can be used effectively for more than 30 years. While this is not new for tape media per se, the longevity of BaFe media is combined with other advantages.

Coercivity: Coercivity, measured in Oersteds, is the measure of resistance of a ferromagnetic or ferroelectric material to withstand an external magnetic or electric field that could cause demagnetization. High coercivity is a key requirement for recording stability and "archive-ability." A higher coercivity is necessary for storage products because, as the bits get more tightly packed, magnetic forces between them become more intense. As a result, they exert stronger demagnetizing tendencies on each other, which need to be resisted through increased coercivity. What is notable with BaFe particles is that their crystalline anisotropy allows for coercivity to be maintained at a very high level despite the much smaller media particle sizes (see Table 4).

Table 4. Comparing Size, Volume, and Coercivity of Media Particles

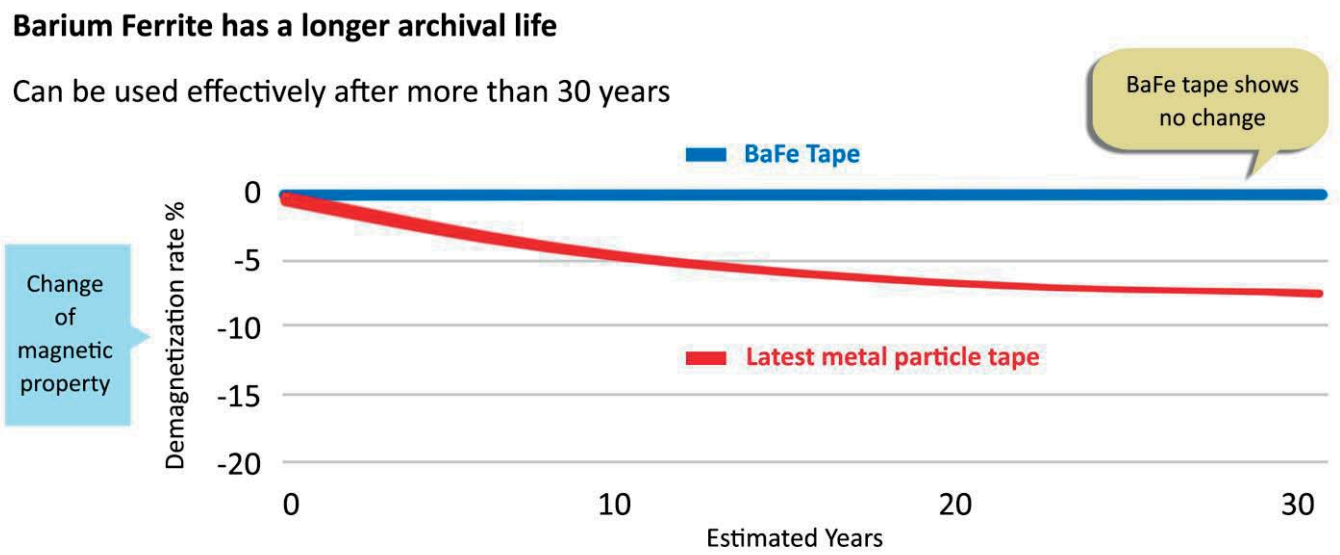
Media Particle Sizes	MP Prototype	BaFe Current	BaFe Future
Size across (nanometers)	~20 nm	21 nm	19.5 nm
Volume	~900 nm^3	2100 nm^3	1600 nm^3
Coercivity (Oersteds)	~1570 Oe	2280 Oe	2550 Oe

Source: Enterprise Strategy Group, constructed from vendors' product specifications, 2014.

Archiving: The main archival-life testing for retained magnetization uses conditions that, effectively, create an acceleration of time by adjusting the environmental conditions. Hence, each day at 60 degrees Celsius (140 degrees Fahrenheit) temperature and 90% humidity is the equivalent of one year in regular ambient conditions. In the harsh "accelerated life" conditions, the changes in magnetic property of both BaFe and MP media were measured and

compared. As can be seen in Figure 5, the results showed no demagnetization for BaFe particles, whereas there was some demagnetization for MP particles.

Figure 5. Accelerated Lifecycle Tests



Source: Enterprise Strategy Group and Fujifilm, 2014.

> ***Matt Starr, Chief Technology Officer, Spectra Logic***
> *"Because Barium Ferrite is pre-oxidized, its shelf life is better, which makes it a better particle for the long-term retention of information; moreover, it is a smaller particle which means more particles in each bit that we write, and therefore a stronger bit: a stronger 1 or a stronger 0. The "go-forward" tape media is almost certain to be based on a barium particle as it has extensive roadmap-potential."*

Delivering System Value with Tape Drives

One other benefit of BaFe is crucial: it is in the interaction of the media and the tape drives—more specifically the tape heads—with which the media interacts.

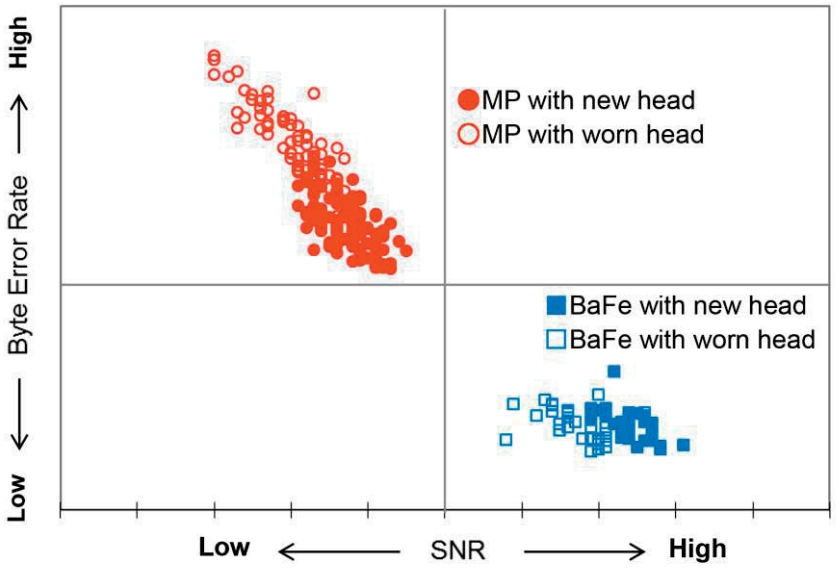
It is the inevitable nature of tape heads to wear gradually as they are used. As head wear occurs, it has the potential to impair the ability to read data cells on the media; however, the high SNR that is inherent with BaFe media means that it is able to maintain a strong signal even as this natural head wear occurs. This means two things:

1) System and application performance is not impaired or compromised
2) Head life can be extended, reducing costs and operational interruptions

In other words, this is a tape drive *system* benefit of the BaFe media, as compared to simply an inherent benefit of the media itself. The data discussed earlier in this paper was comparing the expected error rates that are inherent in the *media* itself; in contrast, the data covered here is comparing both the SNR and the error rates of new and worn tape heads *in concert* with the different media types. As the data shows (see Figure 6), not only does BaFe media exhibit a higher SNR with both new or worn heads when compared to MP media, but as a result of the maintained signal strength, it does not suffer any meaningful increase in error rates as tape drive heads wear.[7]

[7] This test was conducted with an LTO6 drive.

Figure 6. Comparative SNR and Error Rates of BaFe and MP Media with New and Worn Tape Drive Heads



Source: Enterprise Strategy Group and Fujifilm, 2014.

BaFe Is the Tape Media of the Future

The range of improvements that BaFe media offers (including higher output, better SNR, longer archival life, and smaller particle size for future scale) means that there can be little debate that it represents the optimum tape media – not only for today but for the foreseeable future. Its high specifications and abilities are already serving the needs of the IBM and Oracle enterprise products. In addition, it is used for LTO 6, and it is poised to deliver the capacity boosts required by the LTO specification roadmap.

There are a couple of other contemporary notable tape capabilities, where the specific abilities of BaFe media can contribute to an improving overall value proposition for tape in IT operations:

Simplified Data Access and Interchange with LTFS: To improve the access and interchange capabilities of tape, a file system specification for LTO called linear tape file system (LTFS) became available with LTO-5 in 2010 and has changed the rules for tape access. LTFS provides an easy way to archive data to tape without the need for other backup software. The metadata of each cartridge, once mounted, is cached in server memory. Metadata operations, such as browser directory and filename search, do not require physical tape movement. LTFS allows tape data to be accessed in a manner similar to disk or other removable media, and provides the ability to drag, drop, and share data without regard to platform. Even with tape management software, file access was not always intuitive because it often required users to know which cartridge volume contained the specific files they needed. The faster tape file access capability provided by LTFS becomes more important as tape cartridge capacities and the number of files per tape steadily increase. With

Peter Faulhaber, President, Fujifilm Recording Media U.S.A., Inc.
"Fujifilm has advanced the development of Barium Ferrite particles to provide superior quality tape media to support the growing data storage requirements corporations are faced with today. Tape media is the best choice for archival storage; tape is both cost effective and reliable. Fujifilm's BaFe technology takes the reliability of tape to the next level and is capable of meeting the existing tape hardware roadmaps and beyond. Simply put, Barium Ferrite is the future of tape."

LTFS, archiving and restoring data using tape is much easier than before, especially in tape library applications. LTFS becomes increasingly important as BaFe pushes tape capacities to much higher levels. Expect LTFS and its future iterations to provide even greater access capabilities for tape.

- **Intelligent Data Management Software and Appliances Boost Tape Efficiency:** Tape appliances, analytic software, and robotic libraries are available that improve management insight, performance, and overall tape functionality when integrated with tape systems. In addition, these capabilities can optimize cartridge utilization and improve media lifecycle management of higher capacity tape media formats (as promised by expected BaFe technology extensions in the future). Leading edge tape library suppliers offer proactive tape management software that tracks, manages, and reports status on tape library usage and media health from file creation to end of life. These tools identify any potential tape media related errors and media degradation, eliminating unscheduled downtime and increasing the reliability and availability of tape operations.

The Bigger Truth

Today's reality is a data tape industry that has made considerable progress over the last decade to push tape capacity, reliability, and media life to new levels. Tape is a highly relevant media whether for meeting tight backup windows (excellent compression and streaming abilities support this) or providing long-term archive of persistent data (excellent reliability and tools like LTFS support this).

Neither the current enterprise tape drives, nor the expected future iterations of both those and the LTO format could exist without a new suitable tape media to run on—where "suitable" means extremely high capacity, combined with superior handling and reliability attributes…all of which combine to produce the storage-leading TCO per GB that has always been the foundational hallmark value-proposition of tape. Pioneered by Fujifilm, that new, and future, media is Barium Ferrite; indeed, the advantages of BaFe media will become even more evident in—and are prerequisites for—future LTO and enterprise tape formats.

The evidence (increasing data capacities and retention needs are not being met by equivalent budget increases; and an increasing software ability to manage data placement intelligently over its life) strongly suggests that tape will retain a role wherever high volumes of less active data need to be dealt with economically, whether onsite or in the cloud. With BaFe as the key enabler, tape is proving its capability to support significant future roadmap enhancements. Today's modern tape technology is nothing like the tape of the past—and BaFe has shown itself to be the optimal contemporary tape media…and the tape media of the future.

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