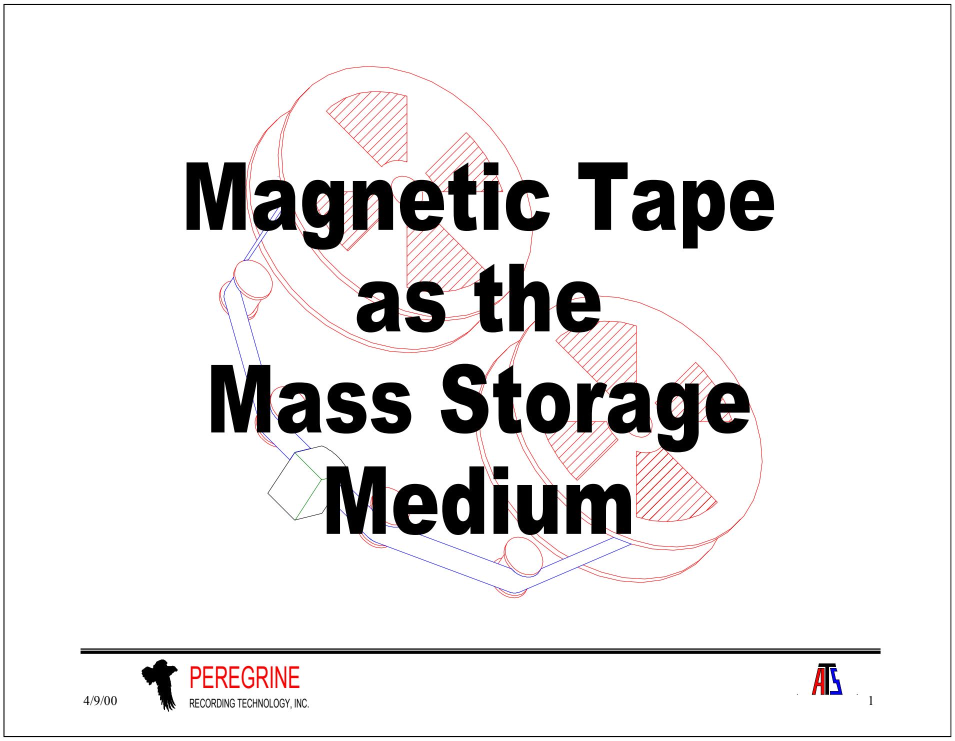

For at least three decades the demise of magnetic tape has been predicted. The prediction is probably true, the question is when? Today, the tape market continues to grow at a 15-20 percent rate. Quantum has captured a billion dollar market for itself without diminishing the traditional “big iron” market. This has led to a consortium led by IBM, Seagate, and HP in developing a new open standard, LTO as competition.

What will replace tape. In the 1970’s and 1980’s it was magnetic disk. In the 1990’s it was optical disk. Will it be some form of Holography or some totally new format. Historically, what has been required is that the new technology must be 10 times cheaper per bit for the same “performance” or have 10 times the “performance” for the same cost.

Next Decade's Competition

1. Magnetic Tape – Most Likely Candidate for the next decade.
2. "Optical" Tape
   - WORM
   - Phase Change
   - Optically Assisted Magnetic
3. Magnetic Disk
4. 3D, i.e., Holographic, 2-electron, etc.
5. Other ?

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As the steamship replaced the sailing ship and the car replaced the horse, some magnetic tape will be replaced as the medium of mass storage - probably not this decade because Magnetic tape has the potential to increase its volumetric density by a factor of 100X or more and to achieve a transfer rate of 1 Gb/sec or more. Magnetic tape remains a moving target. The gestation period from the initial entering of a technology in the marketplace to dominance is five years or longer. Witness the introduction of MR head technology or thin film disk technology.

The most likely candidate of the "exotic" candidates is Optical Tape. It is the only such technology to emerge from the lab into production. This first effort is a WORM, and, hence, most likely be a niche market. Re-recordable phase change is the next step in this evolution. It has not, however, reached production. Finally, there is Magneto-optic tape. A variant on magnetic recording! These technologies, however, fall into the same category as optical disk that is forever trying to catch up with magnetic disk.

Magnetic Disk cannot compete on a long-term archival basis with tape. The cost ratio between disk and tape is likely to remain. Additionally, there are other problems of reliability associated with inactive long-term storage.

Each year, for at least 10 years, Holographic technology promises the new "breakthrough" that will make it viable. There are many challenges still to be overcome and by the time it comes to fruition, tape storage will be very dense.

Mass-Store Metrics

1. Magnetic Disk Drive Cost/bit
2. Total Volumetric Density
   - Not Areal Density
   - Archival Storage Density
3. Thru-put

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The common metric for all storage is the cost/bit of disk drives which continues to fall at a rate of almost 50 percent per year. Any mass storage technology must be at a fraction of the cost of disk drive storage at the time of its introduction.

The areal density of disks is 100 times that of tape! However, the usable surface area of the 3480 form factor cartridge is nearly 1000 times that of a comparable disk and approximately 10 times the data capacity can be stored in the same volume.

Although the "burst rate" of a high performance disk drive can be quite high, especially the new 15,000 rpm drives, the sustained data rate is much much lower. The data rate of most tape systems is constrained by the thru-put of the system. Except for specialized cases (very high cost), present systems cannot keep a 20 MB/sec tape system streaming.

Technology Replacement Rules

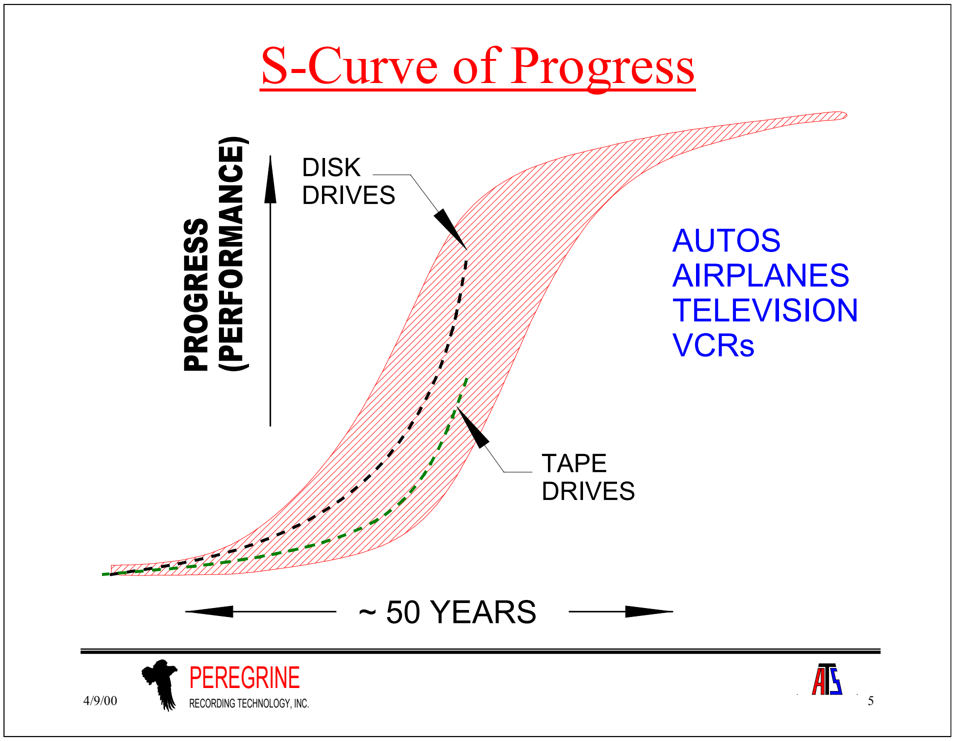
10 times the performance for the same cost

Or

1/10th the cost for the same performance

(excludes really good marketing)

The economic barrier is as great as the technology barrier . To be successful, a new technology must in reality (not by future projection) be ten times cheaper or have ten times the performance of the technology it is replacing. The instances of marketing overcoming this barrier are few and far between, particularly under the scrutiny of sharp-eyed accountants and engineers.



Will the rate of areal density increase, hence, the cost/bit for magnetic disk slow down? Technologies have a history of rapid growth in performance for a period of 50 years or so. Then they slow down, following the classic “S-curve”. As IBM could not ultimately overtake the US economy when it was growing at 15 percent per year versus the 3-5 percent for the US, the increase in areal density must also slow down. Exactly where in the S-curve region is disk drive growth is unknown, but signs abound that it will soon become much more difficult to sustain the present growth. Disk drive technology is almost 50 years old.

Because disk drive technology has been so vigorously pursued relative to tape technology it is much nearer to the knee of its performance curve (areal density). It is hard to imagine that in the next five years the technology could be at 3 TB/in^2. This would amount to a 100X increase in areal density.

Tape Density Migration

100 kbpi → 300 kbpi*

750 tpi → 20,000 tpi*

3000 lpi → 5000 lpi

75 Mb/in^2 → 6.0 Gb/in^2*

28GB/in^3 → 3.8TB/in^3

* National Storage Industry Consortium (NSIC) goal

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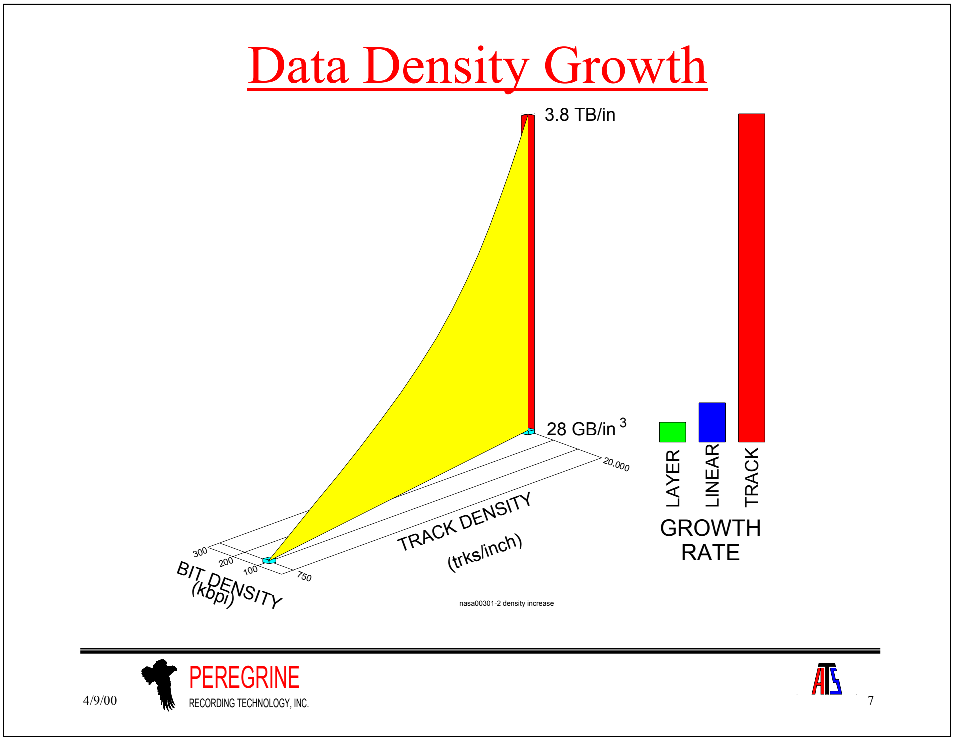
It has been claimed that tape bit density can grow by 100X. How will this happen. The National Storage Industry Consortium (NSIC) drew together, several years ago, a group of experts from industry and academia to plot a migration path for magnetic tape. They arrived at 6 Gb/in^2. They did not account for increasing the number of layers. A recent proposal to NIST, with a detailed plan, has adopted NSIC's goals and added the layer density increase to arrive at almost four $terabytes/in^3$. This would yield more than 12 TB in a 3480 form factor cartridge.



As can be seen from figure. 7, most of this increase comes from increasing track density. The current limits to the track density are:

•Substrate Instability

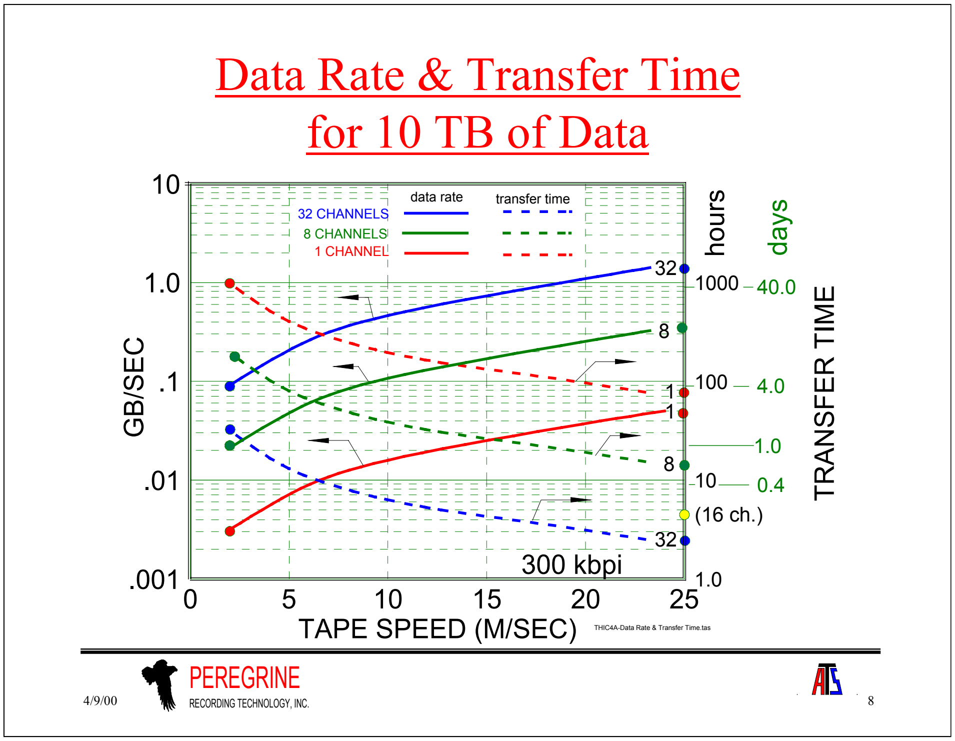
•Tracking

•Mechanical Misalignments

•Mechanical Tolerances

•Media defects

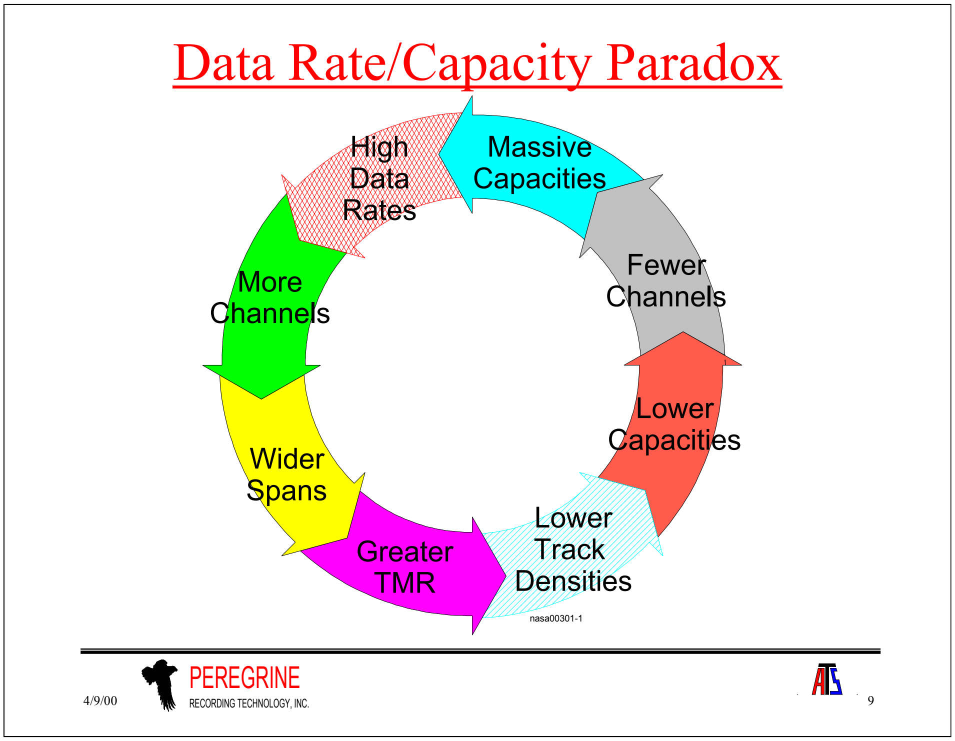
•Media Intrinsic SNR



A significant problem for both disk and tape is how to transfer all the data in a reasonable time. Suppose for a moment that a cartridge is filled with 10 TB of data. Even at a high tape speed of 25 meters/sec, multiple channels are required. A single channel device, operating at 100 percent efficiency would take nearly **four days** to transfer the data.

It is for this reason that multi-channel devices are likely to predominate in this market. Even though helical scan devices offer a 25 – 50 percent areal density advantage (currently it is nearly 300 percent) through the use of azimuth recording, they are hampered by the limited number of heads that they can simultaneously employ. Further, to enhance reliability, the tape wrap is only 90 degrees, hence, the alternating read and write elements reduce the duty cycle to 50 percent. Ironically, the data rate records are held by multi-element (32-64) large drum helical scan devices, but they cost $250,000 or more to be in the Gb/sec range. The current "low-cost" commercially derived devices have small drums (approximately 25 mm). Projecting that they can be spun at 15,000 rpm (and this is somewhat unlikely), their head-to-tape-surface speed is 19 meter/sec.

Because of this limitation, the high performance tape system of the future is likely to be a multi-channel linear system.



Multiple channels on today's substrates offers significant challenge to reaching the high track densities projected by NSIC. The paradox is that for reasonable transfer times of massive capacities, a high data rate is needed. Many data channels are required, in addition to moving the tape at high speed. This necessitates a wider span between the servo tracking elements and the farthest data element. This increases the track misregistration (TMR), limiting the track density. The lower track density requires fewer channels to transfer the data available in the same amount of time. Fewer channels means a shorter span, allowing the increase in track density and, hence, capacity.

Density Key for Tape

Track Density

- Dimensionally Stable Substrate
- Closely Spaced Channels
- Low “noise” media
  - Maintain intrinsic SNR
  - Reduced surface roughness
- Mech. Alignment & Tolerance Compensation

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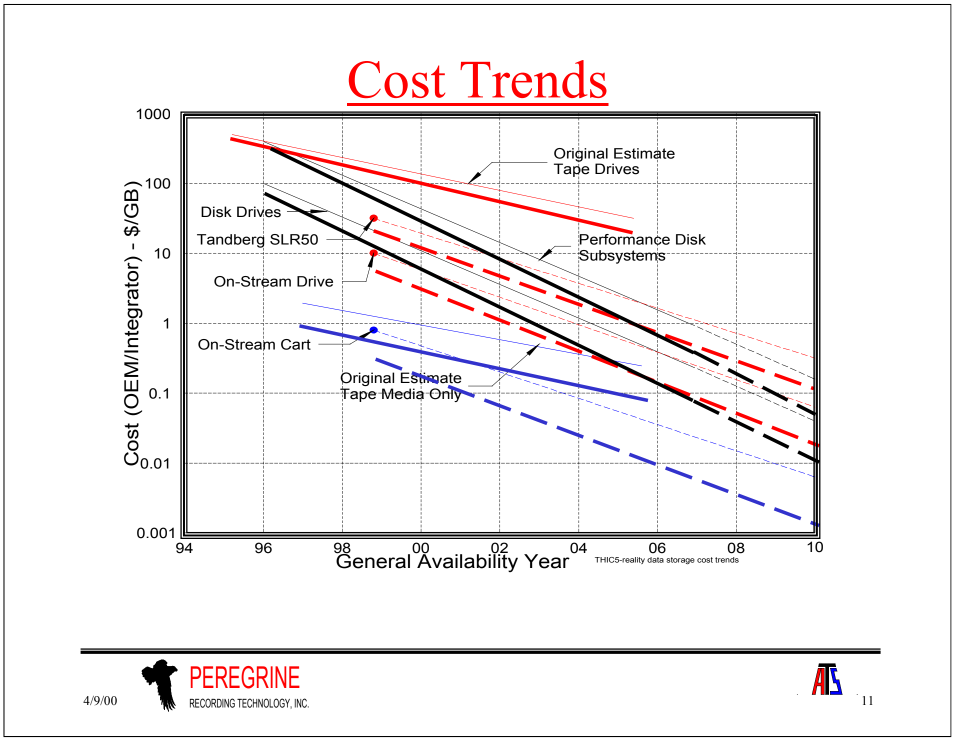
The NSIC program projects a 25X increase in track density. The keys to achieving this are to find a dimensionally stable substrate across the environmental extremes the cartridge is likely to experience and to reduce the multi-channel element span by placing the elements closer together.

The first goal is to reduce the dw/w from the current 1000 ppm to 100-200 ppm through the development of new substrate material.

The second goal is to reduce the write element-to-element spacing from 300-400 um to 30- 40 um, reducing the span by a factor of 10. Currently, thin film tape write elements are based on disk drive write elements where space is not such a premium. Disk write elements employ a pancake configuration of 7-15 turns.

For these narrow tracks the media SNR must be improved. This requires smaller magnetic particles (without superseding the superparamagnetic limit) and surface roughness, both contributors to media noise.

Finally, the mechanical tolerances the occur in manufacture and assembly must be compensated. Two approaches are to put the reading, writing, and servoing in the same gap or build a second degree of freedom in the tracking mechanism.



The current evolutionary path for tape does show that the cost/bit for a disk drive will soon fall below that of tape. With the aggressive volumetric density increase proposed here, this will not happen. Tape capacity and, hence, cost/bit will keep up with disk drives.

Further, this will provide a considerable barrier to the introduction of any new technology in mass storage systems.

Magnetic Tape Summary

Terabytes per Cubic Inch

One Cent per Gigabyte

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The net result is that the mass storage targets are to achieve 3-4 terabytes per cubic inch at a cost of one penny per gigabyte.