Magnetic Tape as the Mass Storage Medium

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Magnetic Tape as the Mass Storage Medium
Outline

- Density/Capacity
- Cost
- Performance (Data Rate)
- Key Technologies
- Summary
Mass-Store Metrics

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

Today
100 kbpi
750 tpi
3000 lpi
  75 Mb/in²
  28 Gb/in³
Density Migration

**Today**
- 100 kbpi → 300 kbpi
- 750 tpi → 20 ktpi
- 3000 lpi → 3000 lpi
- 75 Mb/in\(^2\) → 6.0 Gb/in\(^3\)
- 28 Gb/in\(^3\) → 3.8 TB/in\(^3\)
  (2 b/um\(^3\))
# Technology Objectives

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>track density</strong></td>
<td>tpi</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>linear density</strong></td>
<td>bpi</td>
<td>300,000</td>
</tr>
<tr>
<td><strong>areal density</strong></td>
<td>Gb/in²</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>layer density</strong></td>
<td>lpi</td>
<td>5,000</td>
</tr>
<tr>
<td><strong>vol density</strong></td>
<td>TB/in³</td>
<td>3.80</td>
</tr>
<tr>
<td><strong>tape width</strong></td>
<td>inches</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>tape length</strong></td>
<td>feet</td>
<td>5512</td>
</tr>
<tr>
<td><strong>total area</strong></td>
<td>ft²</td>
<td>230</td>
</tr>
<tr>
<td><strong>volume</strong></td>
<td>in³</td>
<td>4.71</td>
</tr>
<tr>
<td><strong>user efficiency</strong></td>
<td>%</td>
<td>70%</td>
</tr>
<tr>
<td><strong>CAPACITY</strong></td>
<td>TB</td>
<td>12.53</td>
</tr>
</tbody>
</table>

**LTO Cartridge:**

- **tape width:** 0.50 inches
- **tape length:** 5512 feet
- **total area:** 230 ft²
- **volume:** 4.71 in³
- **user efficiency:** 70%
- **CAPACITY:** 12.53 TB
Data Density Growth

- Bit Density (kdbpi)
- Track Density (trks/inch)
- Layer Growth Rate
- Linear Growth Rate
- Track Growth Rate

3.8 TB/in
28 GB/in³

nasa00301-2 density increase
Tape Density Migration

![Graph showing relationship between track density (tpi) and linear density (kbpi). The graph includes points labeled ATS, LTC, 3420, 3480, 3490, and 3570, 3590, 3490E. The x-axis represents linear density (kbpi) ranging from 1 to 1000, and the y-axis represents track density (tpi) ranging from 1 to 30,000. The data points are connected by lines indicating the migration path.](THIC6-DensityMigrationPath.tas)
Areal Density Trends

Gb/in² vs. General Availability Year

- 1970: 3420 Gb/in²
- 1980: 3480 Gb/in²
- 1990: 3590 Gb/in²
- 2000: 3570 Gb/in²

HDD trend line
Areal Density Trends

General Availability Year

Gbps/in²


HDD

ATS

LTO

3570 3590

3490E

3480

3420
Cost Trends
Cost Trends

![Graph showing cost trends over time for different storage technologies.

- Tape Drives
- Disk Drives
- Performance Disk Subsystems
- On-Stream Drive
- On-Stream Cart
- Tape Media Only

Cost (OEM/Integrator) - $(/GB)

General Availability Year: 94, 96, 98, 00, 02, 04, 06, 08, 10

THIC-0627-3A Costs(1)
Cost Trends
FOR THE SAME READ TRACK WIDTH & PERFORMANCE, AZIMUTH RECORDING CURRENTLY HAS A 2:1 ADVANTAGE IN TRACK DENSITY. AS THE TRACK DENSITY INCREASES FASTER THAN THE LINEAR DENSITY AND THE TAPE SUBSTRATE DIMENSIONAL STABILITY IMPROVES THAT ADVANTAGE WILL SHRINK TOWARDS A 1:1 RATIO.
Recording Methods

Linear

Helical

tape motion

write fwd.
read fwd.

tape motion

read rvrs
write rvrs

Head Structure

nasa00301d-heads
Data Rate vs. Speed and No. of Elements

Graph showing data rate in Mb/sec vs. head-to-media speed in m/s and ips. The graph includes lines for Linear (1) and Helical (2) with points indicating data rates for different speeds:

- Linear (1): 32 GB/sec at 1.00 m/s, 16 GB/sec at 0.75 m/s, 8 GB/sec at 0.50 m/s, 4 GB/sec at 0.25 m/s, 2 GB/sec at 0.125 m/s.
- Helical (2): 2 GB/sec at 0.125 m/s.

Assumes 300 kbpi, 3820 RPM at 19100 RPM* for 25 mm hub.

Legend:
- Thin green line: 32
- Red line: 16
- Blue line: 8

* 25 mm hub

THICKK-0627-5 Data Rate
Data Rate & Transfer Time for 10 TB of Data
Transfer Time vs. Data Rate

Data Rate (MB/sec)

ASSUMES 100 % DUTY CYCLE

10 TB

1 TB

100 GB
Argument for Linear Systems

![Graph showing cost vs. data rate for different recording technologies. The graph compares linear and helical recording systems, with data points for Mammuth & DVC (6 MB/s), D5, D6, and Linear recording systems. The x-axis represents data rate (MB/Sec), while the y-axis represents price ($000).]
Head Plan View

THIC-0627-8 Head Layouts

TAPE MOTION

TWO PLANAR COIL ELEMENTS

200 UM < 5 UM

400 UM

TWO PLANAR COIL ELEMENTS
Data Rate/Capacity Paradox

- More Channels
- Wider Spans
- Greater TMR
- Lower Track Densities
- Smaller Capacity
- Lower Data Rate
- Fewer Channels
- Smaller Span
- Smaller TMR
- Higher Track Densities
- Higher Data Rate
- Massive 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
Read/Write Separation

SUBSTRATE (500 - 750 um)

~30 um TRACK (CURRENT)

1.27 um TRACK (20,000 tpi)

MECHANICAL & PHOTOLITHOGRAPHIC OFFSETS

OFFSET & WEAVE

SKEW & AZIMUTH

10X

20ktpi

Same Gap R/W

THIC-0627-9 R-W Separation
Data Density Growth

BIT DENSITY (kbpi) vs. TRACK DENSITY (trks/inch)

- 28 GB/in³
- 3.8 TB/in

GROWTH RATE

nasa00301-2 density increase
Media

• Higher Coercivity (> 2500 Oe)
• Improved SNR/unit width
  – Reduced Defects
  – Smaller Particles
  – Smoother Surfaces
• Thinner Magnetic Layer ( <.05 um)
  – Multi-layers
• Metal Film
  – Perpendicular?
Substrate

- Reduced Dimensional Instability
  - 1000 PPM $\rightarrow$ 100-200 PPM
    - Humidity
    - Temperature
    - Tension
    - Creep/Compliance

- High $T_G$ (For Metal Film)
- Thinner (4 um $\rightarrow$ 2 um?)
- Smoother
- Stronger
Summary - Goals

6 Gb/in² ---- 3.8 TB/in³

- 3X Bit Density
- ~25X Track Density

>10 TB/Large Cart

>200 MB/sec Data Rate

< 1 cent/GB per Cart (<$100/Cart)

< $0.5/GB per Drive (< $5000/Drive)
Summary - Challenges

- Data Rate
- Substrate Dimensional Stability
- Head Complexity/Span
- Mechanical Tracking
- Tape Speed
  - Head Wear
  - Handling
  - Tape Durability
Summary

“Tape Will Never Die!
-Jim Hughes – StorageTek
NASA Mass Storage Conference – April 2000