The Challenges of Magnetic Recording on Tape for Terabyte Capacities

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Capacity and Data Rates

\[ \text{Capacity} = \frac{N b L \varepsilon}{8} \]

\[ \text{DataRate} = \frac{n b V \varepsilon}{8} \]

\( N = \) number of tracks, \( b = \) bit density, \( L = \) length of tape,

\( \varepsilon = \) efficiency, \( n = \) number of channels, \( V = \) tape speed
Capacity and Data Rates (alt.)

\[
\text{Capacity} = \frac{(tpi)(bpi)WL\varepsilon}{8}
\]

\[
\text{DataRate} = \frac{n(bpi)V\varepsilon}{8}
\]

\(tpi\) = track density, \(bpi\) = bit density, \(L\) = length of tape,
\(W\) = width of tape, \(\varepsilon\) = efficiency, \(n\) = number of channels,
\(V\) = tape speed
# TeraByte Operating Points

½" wide tape, 3480/9940 form factor

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Block Diagram of a Magnetic Recording Channel

Data → Formatting, ECC & Coding → Write Equalizer → Write Driver

Decoding, ECC & De-format → Detector → Read Equalizer → PreAmp & AGC

Write Head → Tape Media

Read Head → Track Following Servo

Tape Guiding and Speed Control
Digital Magnetic Recording

Data: 1 0 1 1 1 0 1

Write Current: $I_w$, $-I_w$

Magnetic Recording

Read Voltage

Clock

Recovered Data: 1 0 1 1 1 0 1

Linear Density Trend

- **MPX/Metal 2700**
- **MP4 2400 (Oe)?**
- **MP2 1850 (Oe)**
- **MP1 1650 (Oe)**
- **CrO₂ 650**
- **Fe₂O₃ 350 (Oe)**

Year:
- 1970
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010

Source: trends.xls

Recording Theory

Transition from \(+M_r\) to \(-M_r\) over a distance, \(a\)

\[
M(x) = \frac{2M_r}{\pi} \tan^{-1}\left(\frac{x}{a}\right)
\]

\[
a = 2 \left[\left(\frac{2}{\sqrt{3}}\right)\left(\frac{M_r \delta}{H_c}\right)\left(d + \frac{\delta}{2}\right)\right]^{1/2}
\]

All these parameters are scaling down

6/12/2002
Tape Media Section Diagram

Backcoat

Substrate

Underlayer

Magnetic Layer
Particulate Tape Media Progression

MP1
Single Layer

MP2
Dual Coat

MPX/BaFe
Thin Mag. Layer
Smaller Particles

Magnetic Layer
Non-Magnetic Layer (smoothing)
Base Film
Recording Theory

Transition from \( +M_r \) to \( -M_r \) over a distance, \( a \)

\[
M(x) = \frac{2M_r}{\pi} \tan^{-1} \left( \frac{x}{a} \right)
\]

\[
a = 2 \left[ \frac{2}{\sqrt{3}} \left( \frac{M_r \delta}{H_c} \right) \left( d + \frac{\delta}{2} \right) \right]^{1/2}
\]

All these parameters are scaling down
Recording Theory (2)

Spacing Loss due to Head-Medium spacing, $d$

$$\text{Loss} = -55 \left( \frac{d}{\lambda} \right)$$

Signal to Noise Ratio depends on the number of particles being read

$$\text{SNR} = \frac{nW\lambda^2}{6}$$
Areal Density Limit Calculation

\[ A_{\text{lim}} = t^{\frac{1}{2}} \left( \frac{2 p \text{SNR}}{3} \right)^{\frac{1}{2}} \]

\( t = \text{track density, } p = \text{particle density,} \)
\( \text{SNR} = \text{Signal-to-Noise Ratio} \)

Areal Density Limit Calculation (Gbit/sq.in) (2)

(8000 tpi)

<table>
<thead>
<tr>
<th>SNR(dB)</th>
<th>$10^{16}$</th>
<th>$10^{17}$</th>
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<tbody>
<tr>
<td>20</td>
<td>3.2</td>
<td>10.4</td>
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<td>16</td>
<td>5.2</td>
<td>16.5</td>
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<td>12</td>
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1/2" wide tape, 3480/9940 form factor

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Head Technology
Thin Film Write Head Array
Media Stability Consequences

\[ D = \frac{2(OT)LWVb^2 \varepsilon^2}{64Cc_p m_c} \]

*OT* Offtrack allowance

*\(c_p\)* channel pitch

*\(m_c\)* media stability coeff.
Data Rate – Capacity Trade Off

Data Rate/Capacity Tradeoff
(10m/s, CP=50µm, 200kbpi, 12mm tape, 10% OT)

Media Instability

NSIC 1998

www.StorageTek.com
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Media Coercivity Time Dependence

![Graph showing Media Coercivity vs Time Scale](image)
Magnetic Recording with Short Pulses (MP Tape)

- **Normalized Output**
- **Efficiency**
- **Efficiency***

![Graph showing normalized output and efficiency as a function of pulse length.](Iw vs pulse.xls)
Summary

- Medium has primary impact on areal density growth
- $M_r\delta$ has to be reduced (as it was in disk)
- Side-by-side head channel architecture sets up tradeoffs
- Head technology in good shape (StorageTek Tour)!
- Limit for MP tape $\sim10\text{Gb/in}^2$
  (Careful!! Disk prediction in 1997 36Gb/in$^2$)
- Tape wins on volumetric efficiency and $$/\text{GByte}$
- Tape not near any fundamental limits at this time