

The Challenges of Magnetic Recording on Tape for Terabyte Capacities

Richard H. Dee

Storage Technology Corporation

1 StorageTek Drive, Louisville, Colorado 80028-4274

Phone: +1-303-673-3976 FAX: +1-303-673-8406

E-mail: richard_dee@storagetek.com

**Presented at the THIC Meeting at the National Center
for Atmospheric Research**

Boulder CO 80305-5602

June 11-12, 2002



www.StorageTek.com



Inc.

The Premier Advanced Recording Technology Forum

Capacity and Data Rates

$$\textit{Capacity} = \frac{NbL\varepsilon}{8}$$

$$\textit{DataRate} = \frac{nbV\varepsilon}{8}$$

**N = number of tracks, b = bit density, L = length of tape,
 ε = efficiency, n = number of channels, V = tape speed**

Capacity and Data Rates (alt.)

$$Capacity = \frac{(tpi)(bpi)WL\varepsilon}{8}$$

$$DataRate = \frac{n(bpi)V\varepsilon}{8}$$

tpi = track density, ***bpi*** = bit density, ***L*** = length of tape,

W = width of tape, **ε** = efficiency, ***n*** = number of channels,

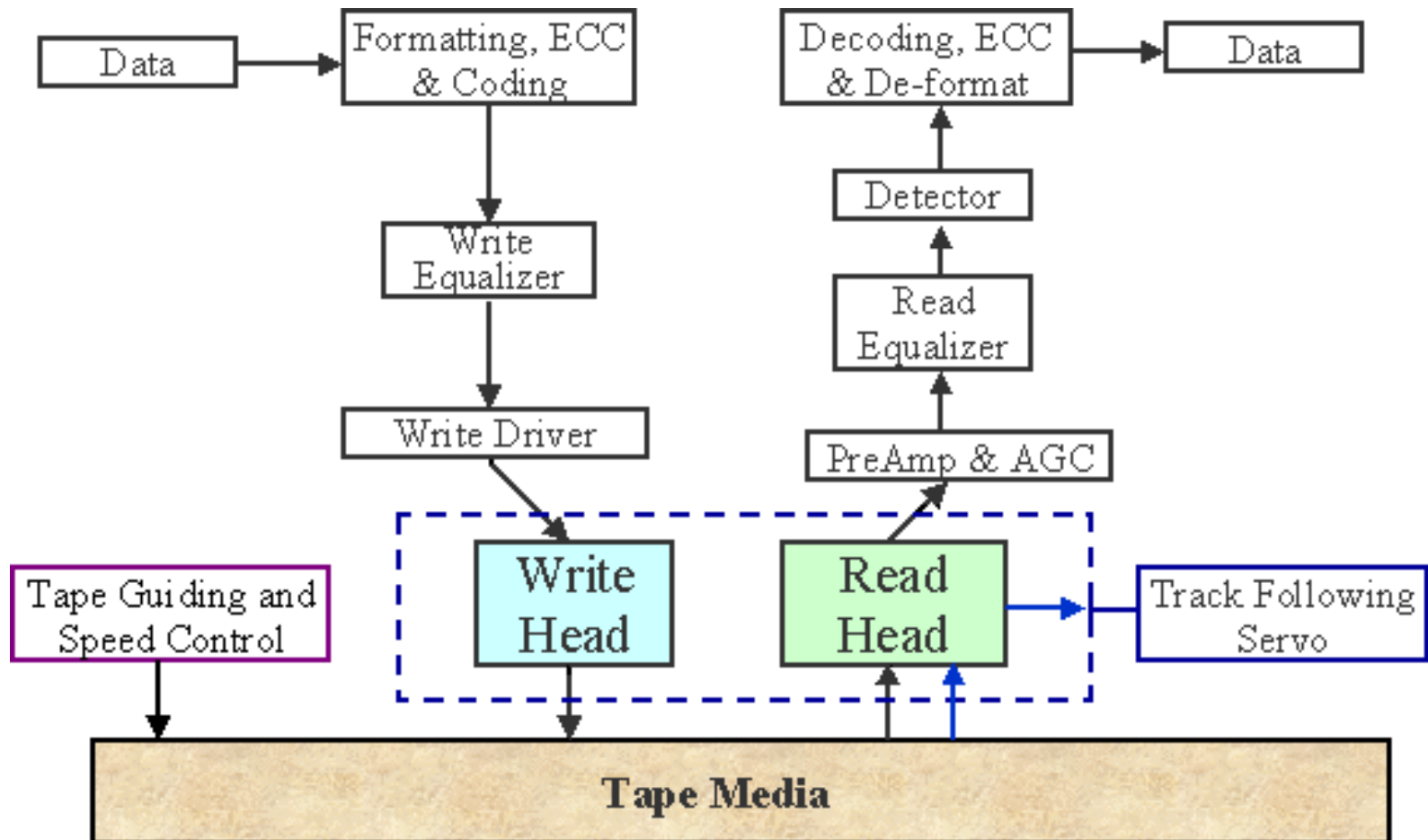
V = tape speed

TeraByte Operating Points

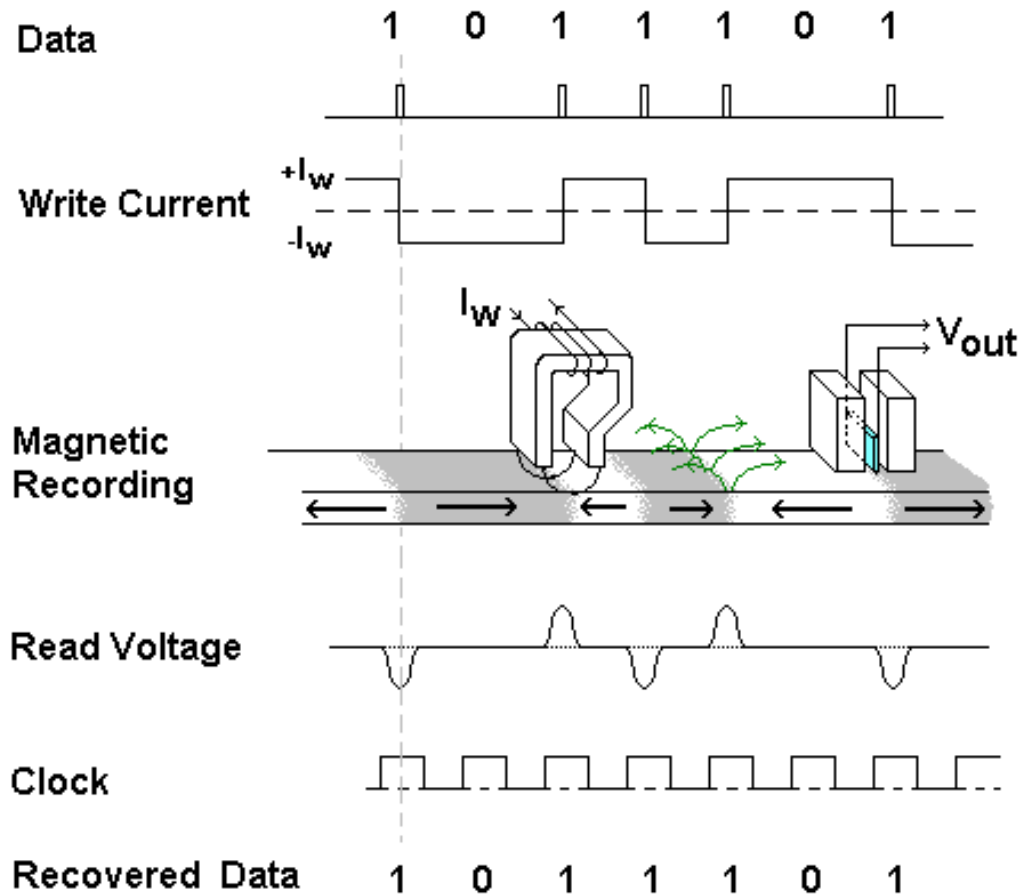
1/2" wide tape, 3480/9940 form factor

Capacity (TB)	0.5	0.5	1	1	5	5	10	10
Data Rate (MB/sec)	60	120	110	220	150	300	280	559
No. of PII Data Channels, <i>n</i>	16	32	16	32	16	32	16	32
No. of Data Tracks, <i>N</i>	768	768	1344	1344	4750	4750	4140	4140
Trk. Pitch (μm)	14.0	14.0	8.0	8.0	2.3	2.3	2.6	2.6
Channel Pitch, c_p (μm)	109	55	109	55	109	55	109	55
Rd. Track Width (μm)	7.0	7.0	4.0	4.0	1.1	1.1	1.3	1.3
Tape Speed, <i>V</i> (m/s)	4.8	4.8	8.0	8.0	9.0	9.0	10.0	10.0
Bit Density (kbpi)	224	224	248	248	298	298	500	500
Track Density (tpi)	1812	1812	3172	3172	11211	11211	9771	9771
Areal Density (Gb/in ²)	0.41	0.41	0.79	0.79	3.35	3.35	4.89	4.89
Bit Cell (nm)	114	114	103	103	85	85	51	51
Bit Cell (ns)	23.7	23.7	12.9	12.9	9.5	9.5	5.1	5.1
Write Eq. Pulse (nS)	9.5	9.5	5.2	5.2	3.8	3.8	2.0	2.0
Tape Length (m)	865	865	865	865	1000	1000	1400	1400
Write Time per Cart. (min)	144	72	152	76	550	275	604	302

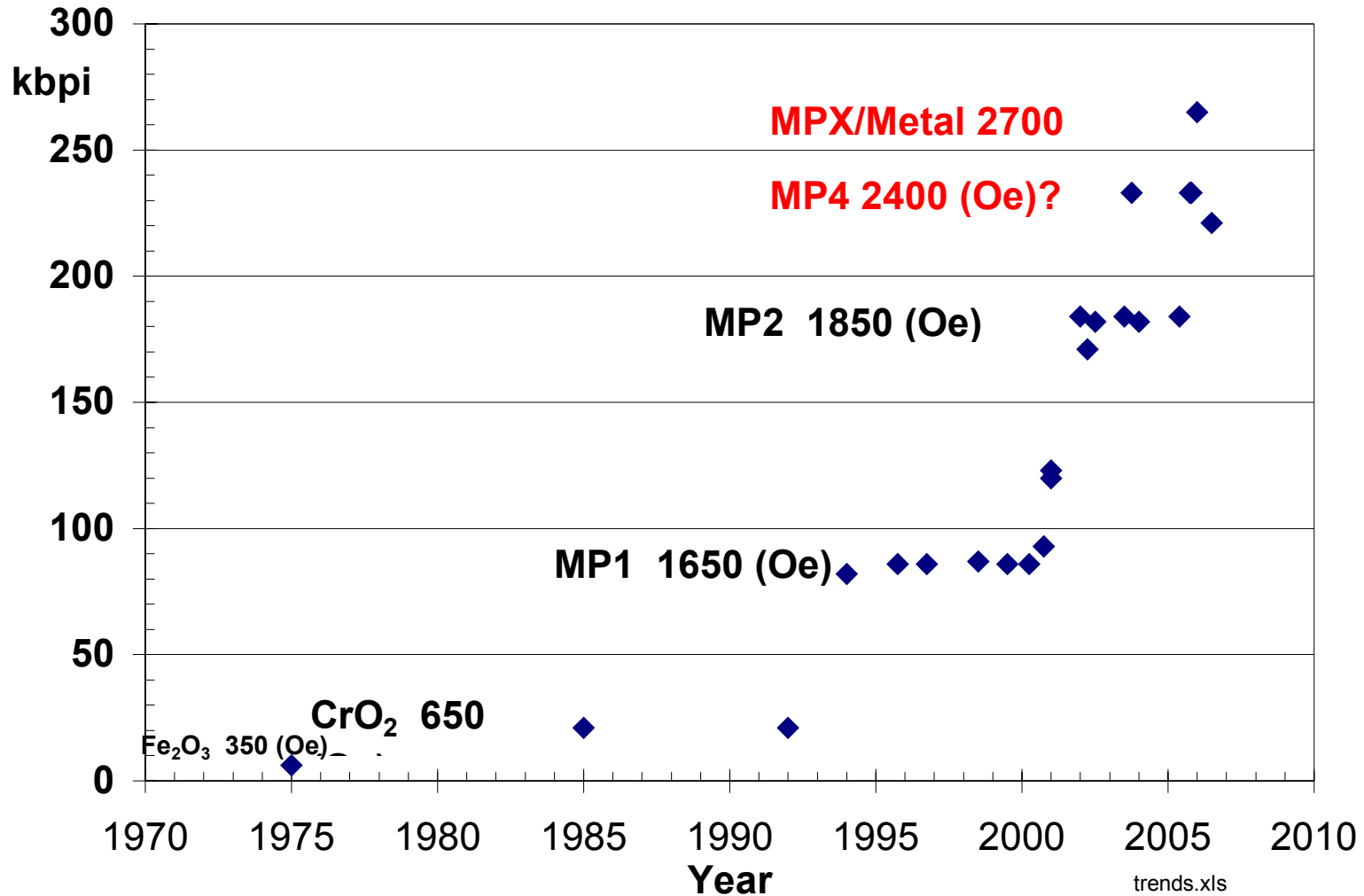
Block Diagram of a Magnetic Recording Channel



Digital Magnetic Recording



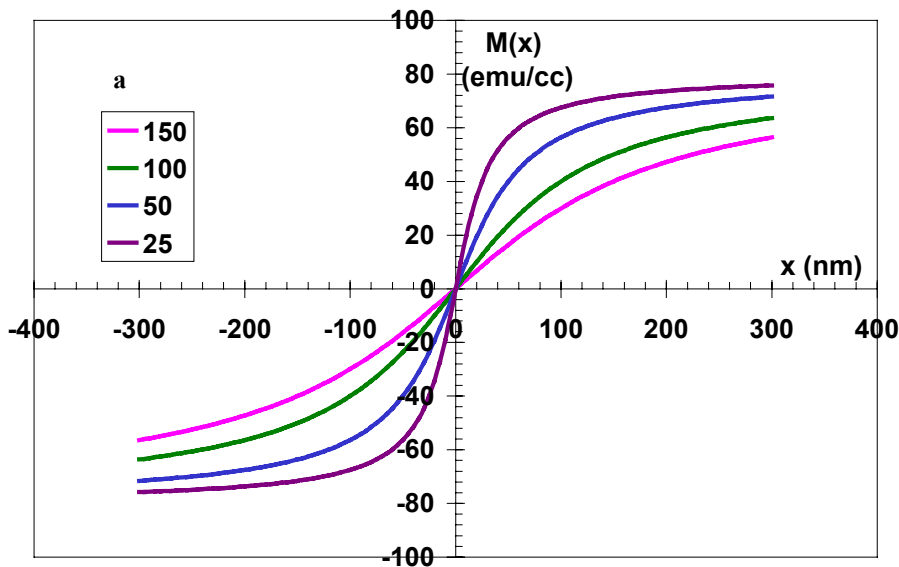
Linear Density Trend



Recording Theory

Transition from $+M_r$ to $-M_r$ over a distance, a

ArcTangent Transition

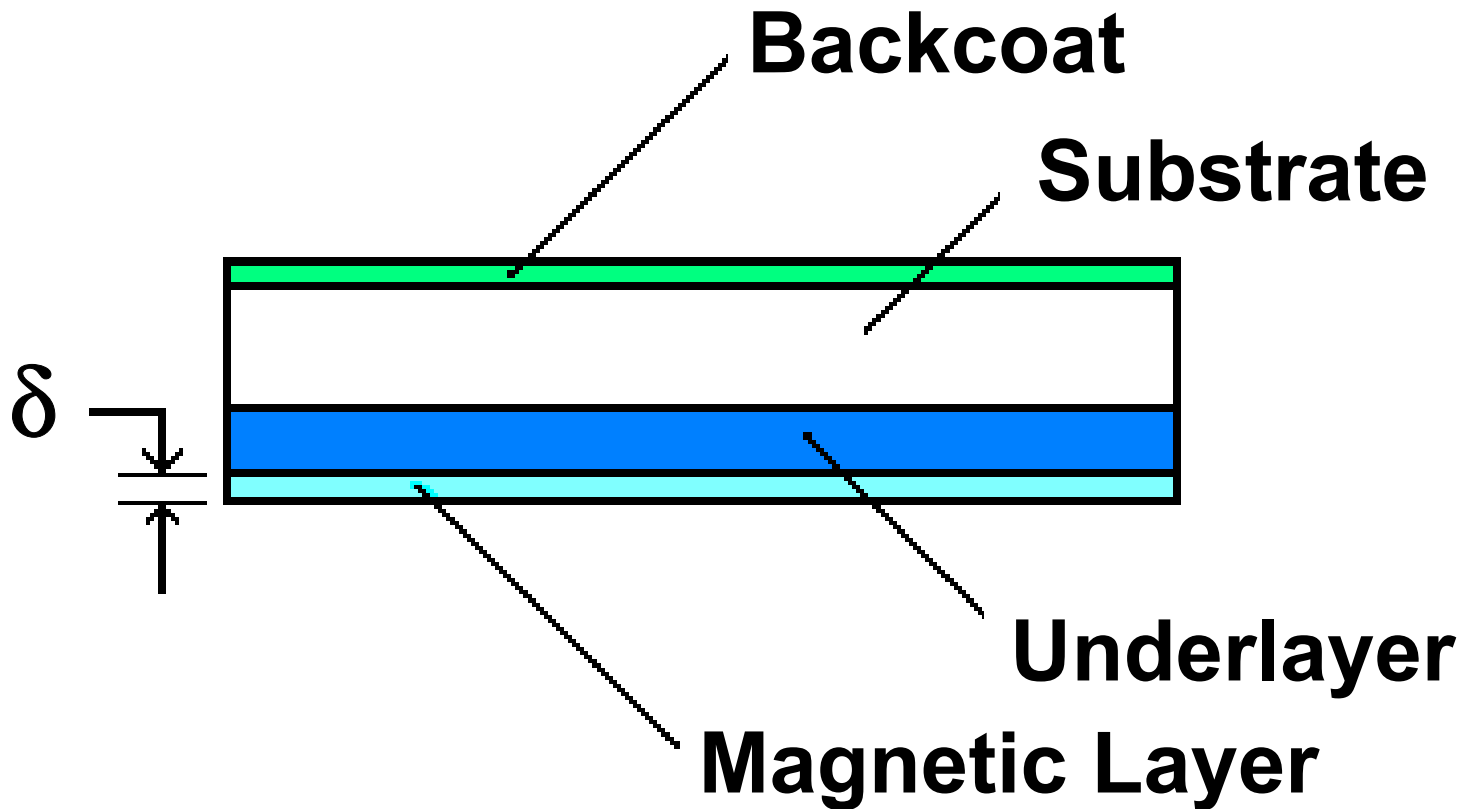


$$M(x) = \frac{2M_r}{\pi} \tan^{-1}\left(\frac{x}{a}\right)$$

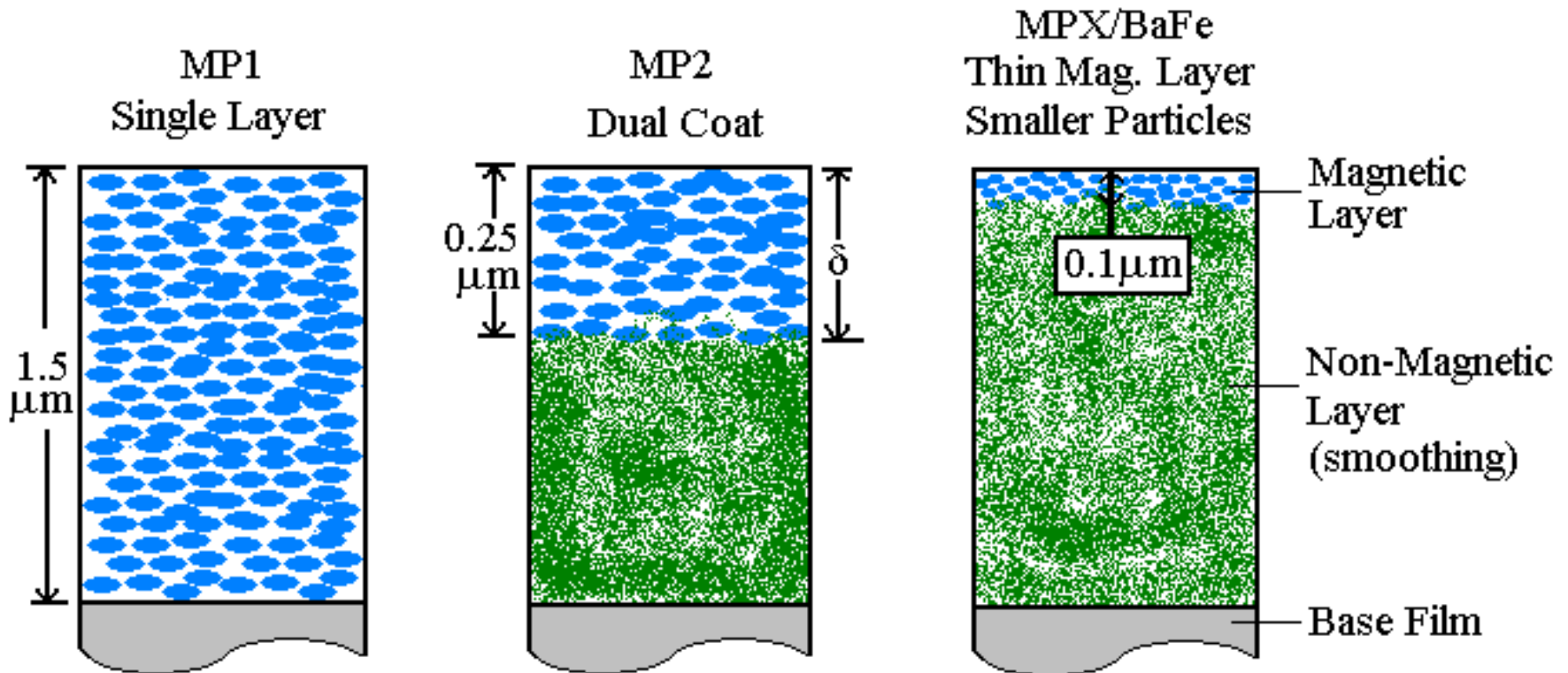
$$a = 2 \left[\left(\frac{2}{\sqrt{3}} \right) \left(\frac{M_r \delta}{H_c} \right) \left(d + \frac{\delta}{2} \right) \right]^{1/2}$$

All these parameters are scaling down

Tape Media Section Diagram



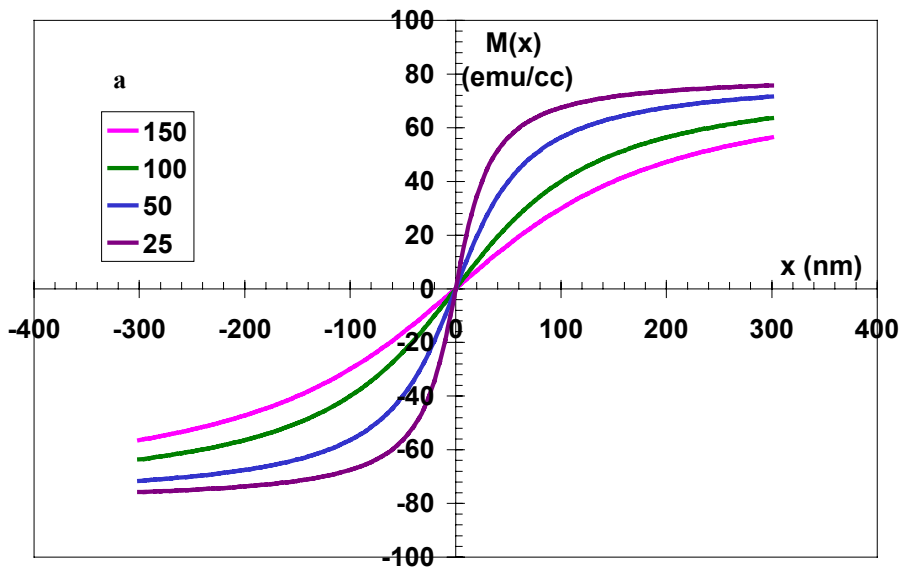
Particulate Tape Media Progression



Recording Theory

Transition from $+M_r$ to $-M_r$ over a distance, a

ArcTangent Transition



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

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

All these parameters are scaling down

Recording Theory (2)

Spacing Loss due to Head-Medium spacing, d

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

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

$$SNR = \frac{nW\lambda^2}{6}$$

Areal Density Limit Calculation

$$A_{\text{lim}} = t^{1/2} \left(\frac{2pSNR}{3} \right)^{1/2}$$

t = track density, p = particle density,

SNR = Signal-to-Noise Ratio

“The Foundations of Magnetic Recording”, J. C. Mallinson,
(Second Ed.), Academic Press (1993).

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

(8000 tpi)

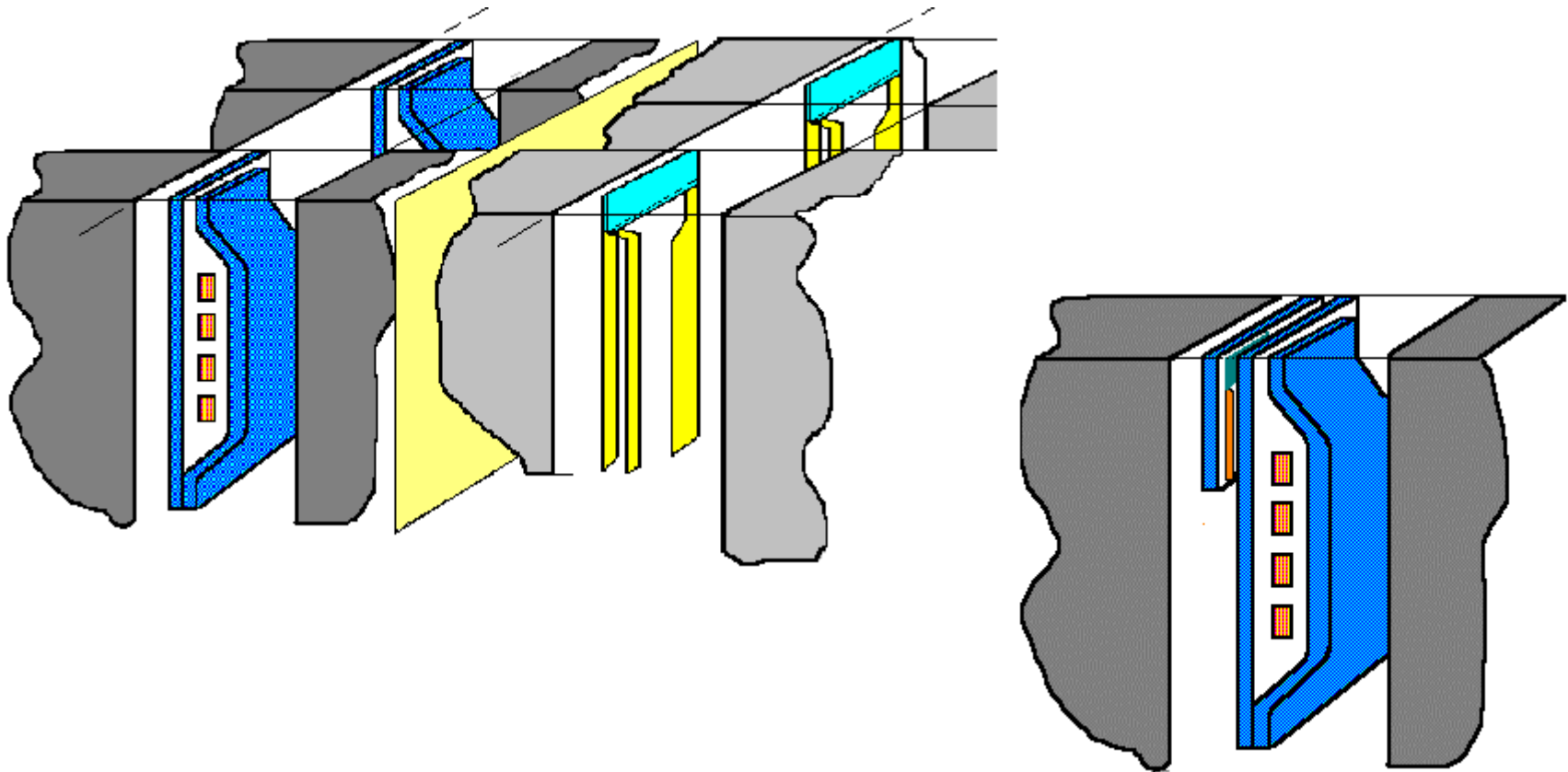
SNR(dB)	Particle Density, p (cm ⁻³)		
	10 ¹⁶	10 ¹⁷	10 ¹⁸
20	3.2	10.4	32
16	5.2	16.5	52
12	8.2	26.2	82

TeraByte Operating Points

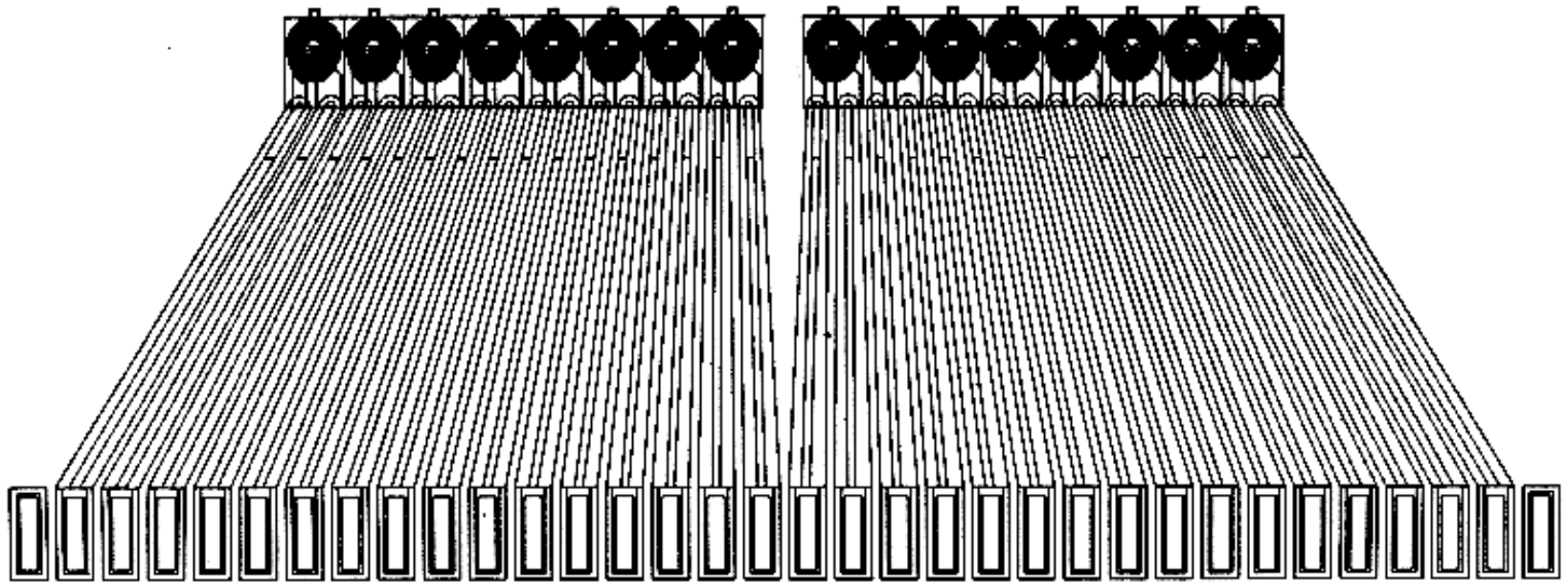
1/2" wide tape, 3480/9940 form factor

Capacity (TB)	0.5	0.5	1	1	5	5	10	10
Data Rate (MB/sec)	60	120	110	220	150	300	280	559
No. of PII Data Channels, n	16	32	16	32	16	32	16	32
No. of Data Tracks, N	768	768	1344	1344	4750	4750	4140	4140
Trk. Pitch (μm)	14.0	14.0	8.0	8.0	2.3	2.3	2.6	2.6
Channel Pitch, c_p (μm)	109	55	109	55	109	55	109	55
Rd. Track Width (μm)	7.0	7.0	4.0	4.0	1.1	1.1	1.3	1.3
Tape Speed, V (m/s)	4.8	4.8	8.0	8.0	9.0	9.0	10.0	10.0
Bit Density (kbpi)	224	224	248	248	298	298	500	500
Track Density (tpi)	1812	1812	3172	3172	11211	11211	9771	9771
Areal Density (Gb/in ²)	0.41	0.41	0.79	0.79	3.35	3.35	4.89	4.89
Bit Cell (nm)	114	114	103	103	85	85	51	51
Bit Cell (ns)	23.7	23.7	12.9	12.9	9.5	9.5	5.1	5.1
Write Eq. Pulse (nS)	9.5	9.5	5.2	5.2	3.8	3.8	2.0	2.0
Tape Length (m)	865	865	865	865	1000	1000	1400	1400
Write Time per Cart. (min)	144	72	152	76	550	275	604	302

Head Technology



Thin Film Write Head Array



Media Stability Consequences

$$D = \frac{2(OT)LWVb^2 \epsilon^2}{64C c_p m_c}$$

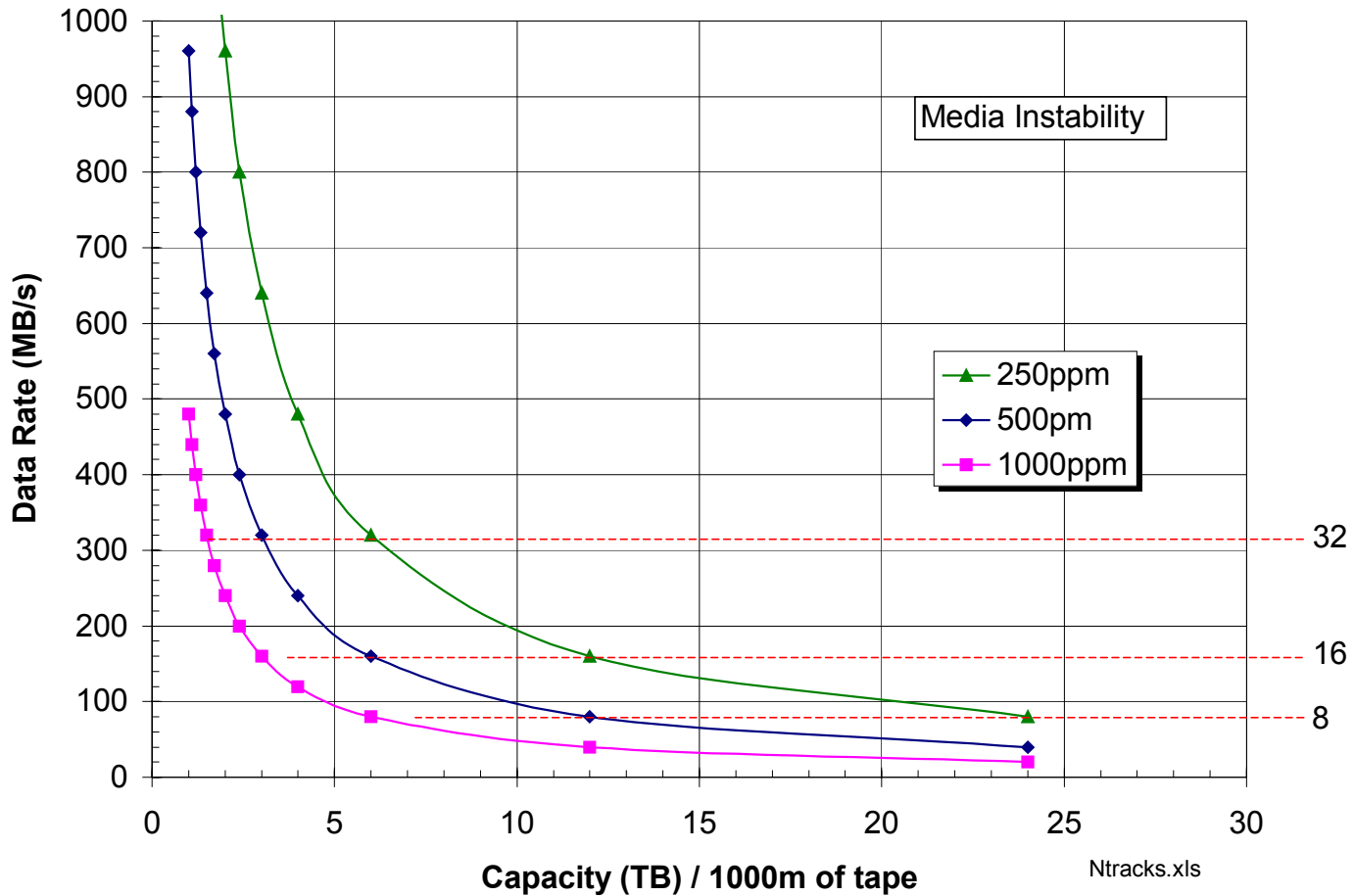
OT Offtrack allowance

c_p channel pitch

m_c media stability coeff.

Data Rate – Capacity Trade Off

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



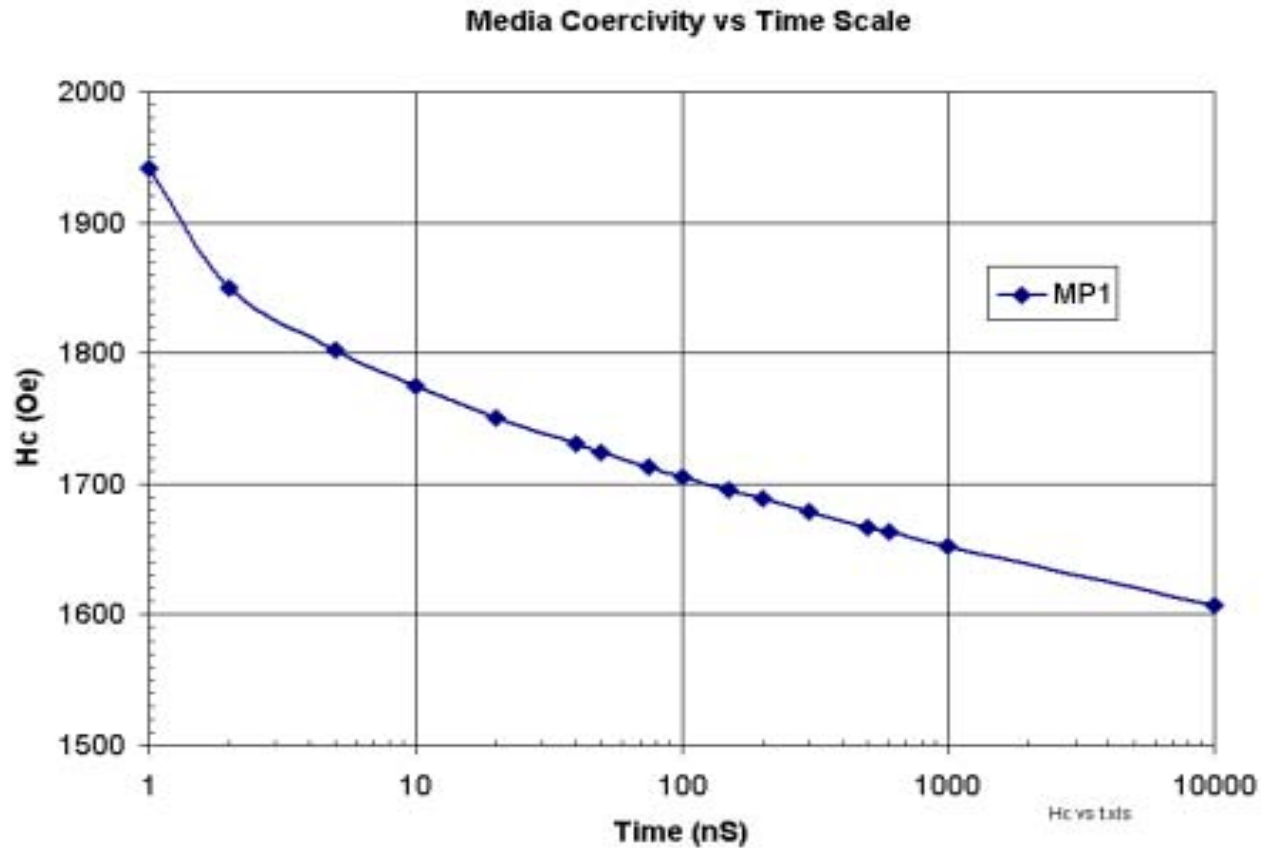
**NSIC
1998**

TeraByte Operating Points

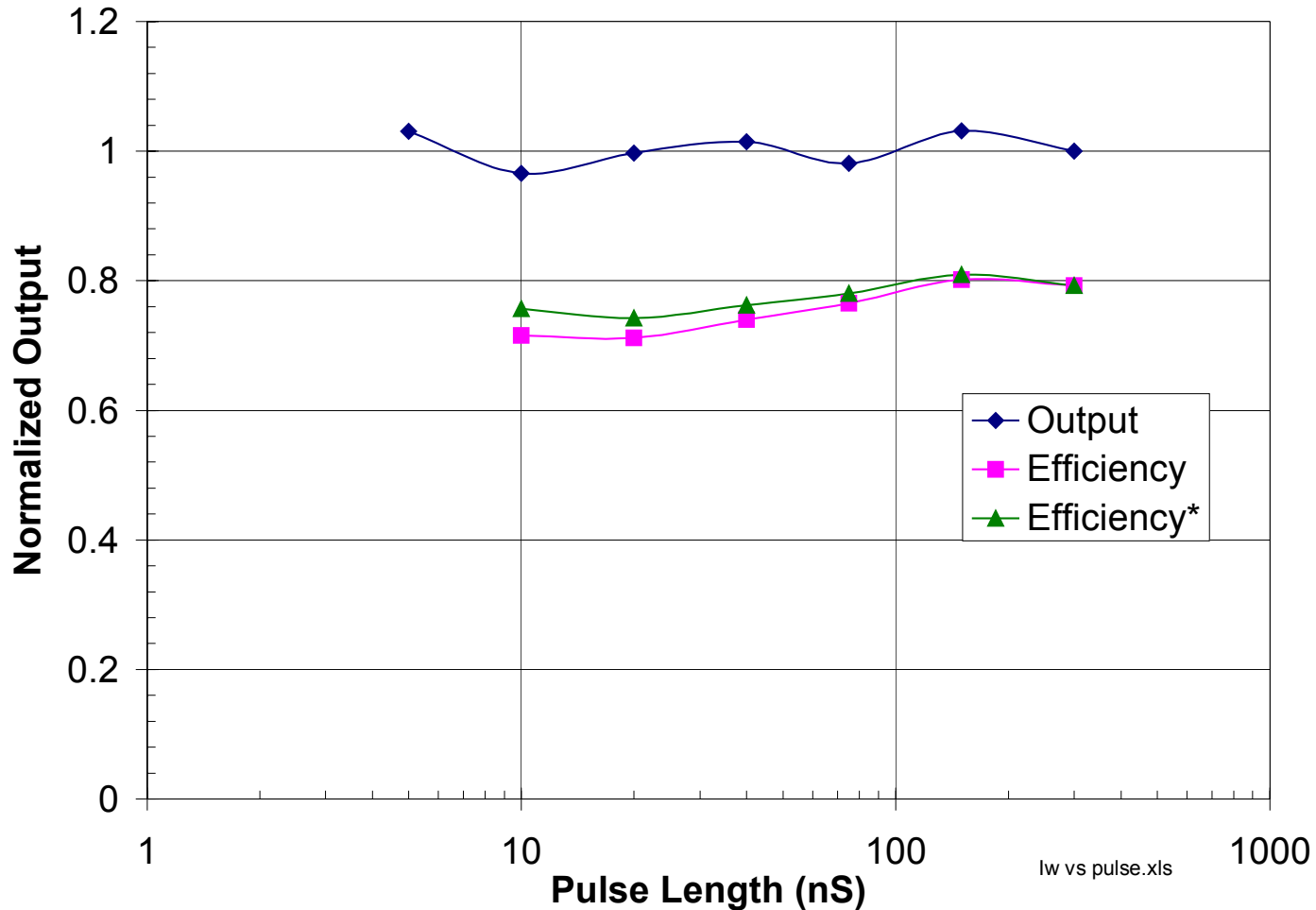
1/2" wide tape, 3480/9940 form factor

Capacity (TB)	0.5	0.5	1	1	5	5	10	10
Data Rate (MB/sec)	60	120	110	220	150	300	280	559
No. of PII Data Channels, <i>n</i>	16	32	16	32	16	32	16	32
No. of Data Tracks, <i>N</i>	768	768	1344	1344	4750	4750	4140	4140
Trk. Pitch (μm)	14.0	14.0	8.0	8.0	2.3	2.3	2.6	2.6
Channel Pitch, c_p (μm)	109	55	109	55	109	55	109	55
Rd. Track Width (μm)	7.0	7.0	4.0	4.0	1.1	1.1	1.3	1.3
Tape Speed, <i>V</i> (m/s)	4.8	4.8	8.0	8.0	9.0	9.0	10.0	10.0
Bit Density (kbpi)	224	224	248	248	298	298	500	500
Track Density (tpi)	1812	1812	3172	3172	11211	11211	9771	9771
Areal Density (Gb/in ²)	0.41	0.41	0.79	0.79	3.35	3.35	4.89	4.89
Bit Cell (nm)	114	114	103	103	85	85	51	51
Bit Cell (ns)	23.7	23.7	12.9	12.9	9.5	9.5	5.1	5.1
Write Eq. Pulse (nS)	9.5	9.5	5.2	5.2	3.8	3.8	2.0	2.0
Tape Length (m)	865	865	865	865	1000	1000	1400	1400
Write Time per Cart. (min)	144	72	152	76	550	275	604	302

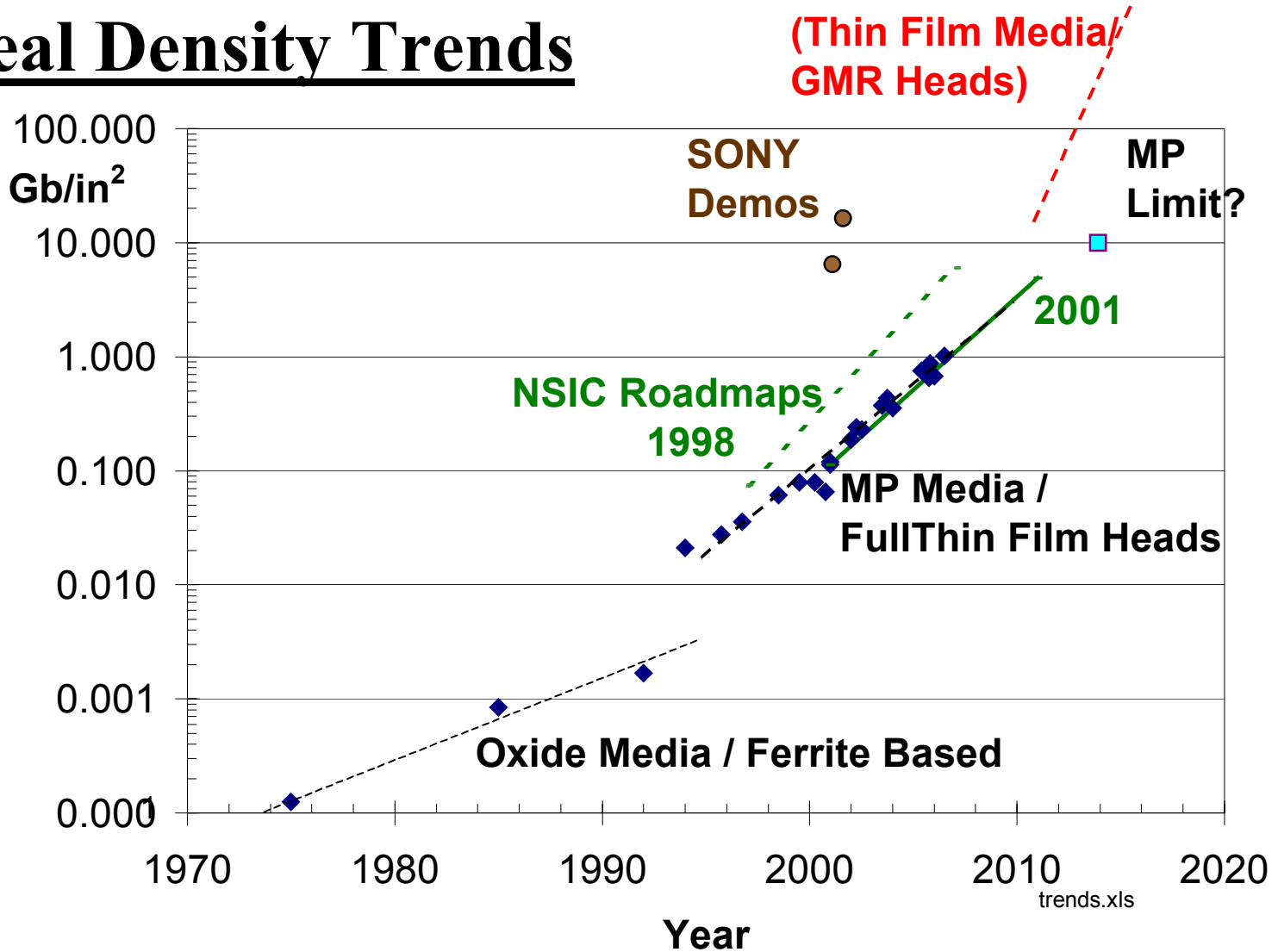
Media Coercivity Time Dependence



Magnetic Recording with Short Pulses (MP Tape)



Areal Density Trends



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 $\sim 10\text{Gb/in}^2$
(Careful!! Disk prediction in 1997 36Gb/in^2)
- Tape wins on volumetric efficiency and \$/GByte
- Tape not near any fundamental limits at this time