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The Challenges of Magnetic Recording on Tape for Terabyte Capacities

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Capacity and Data Rates

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

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

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,**

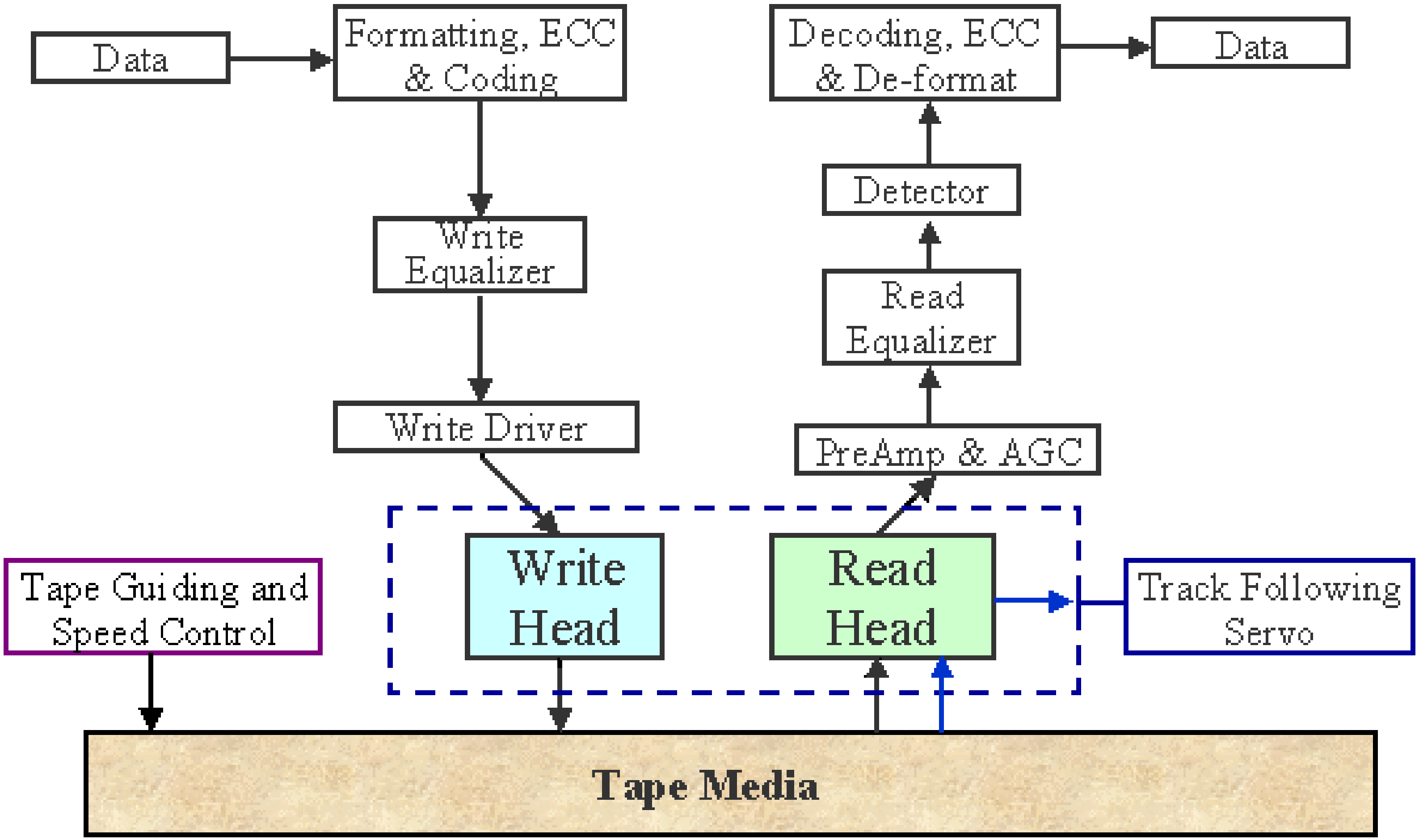
V **= tape speed**

TeraByte Operating Points

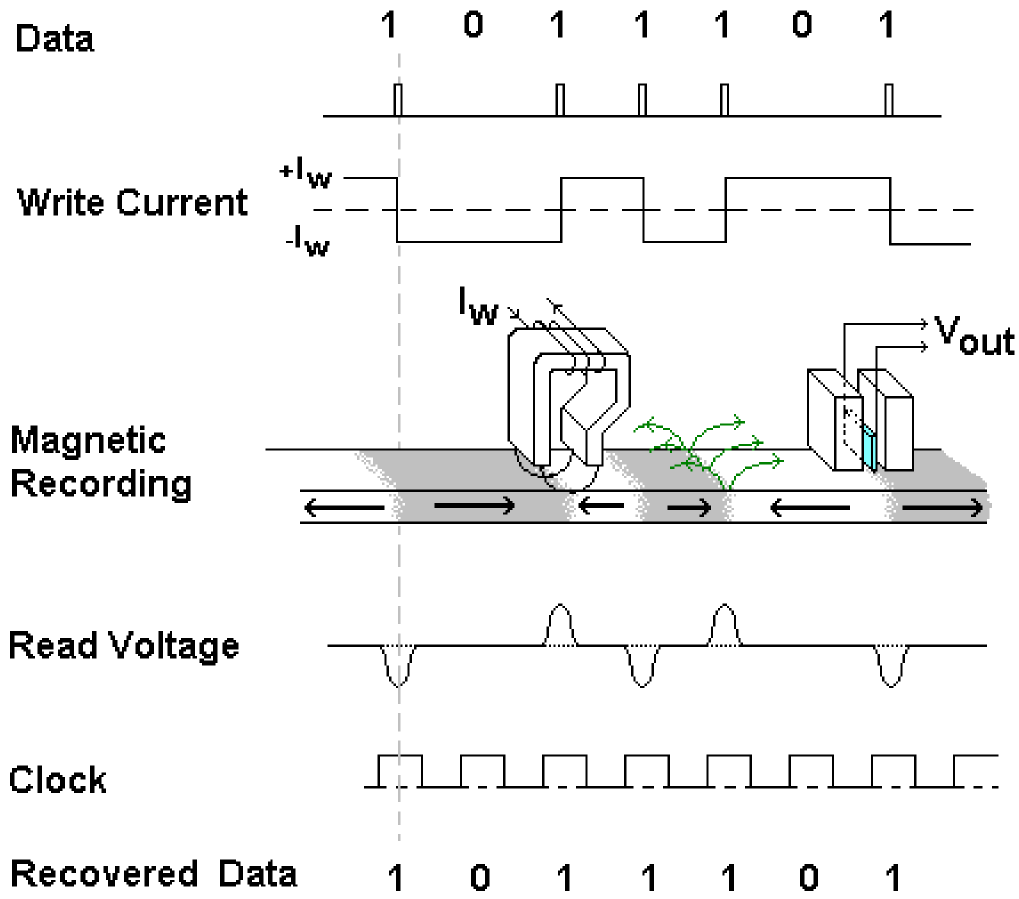
½"wide tape, 3480/9940 form factor

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 Pll 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

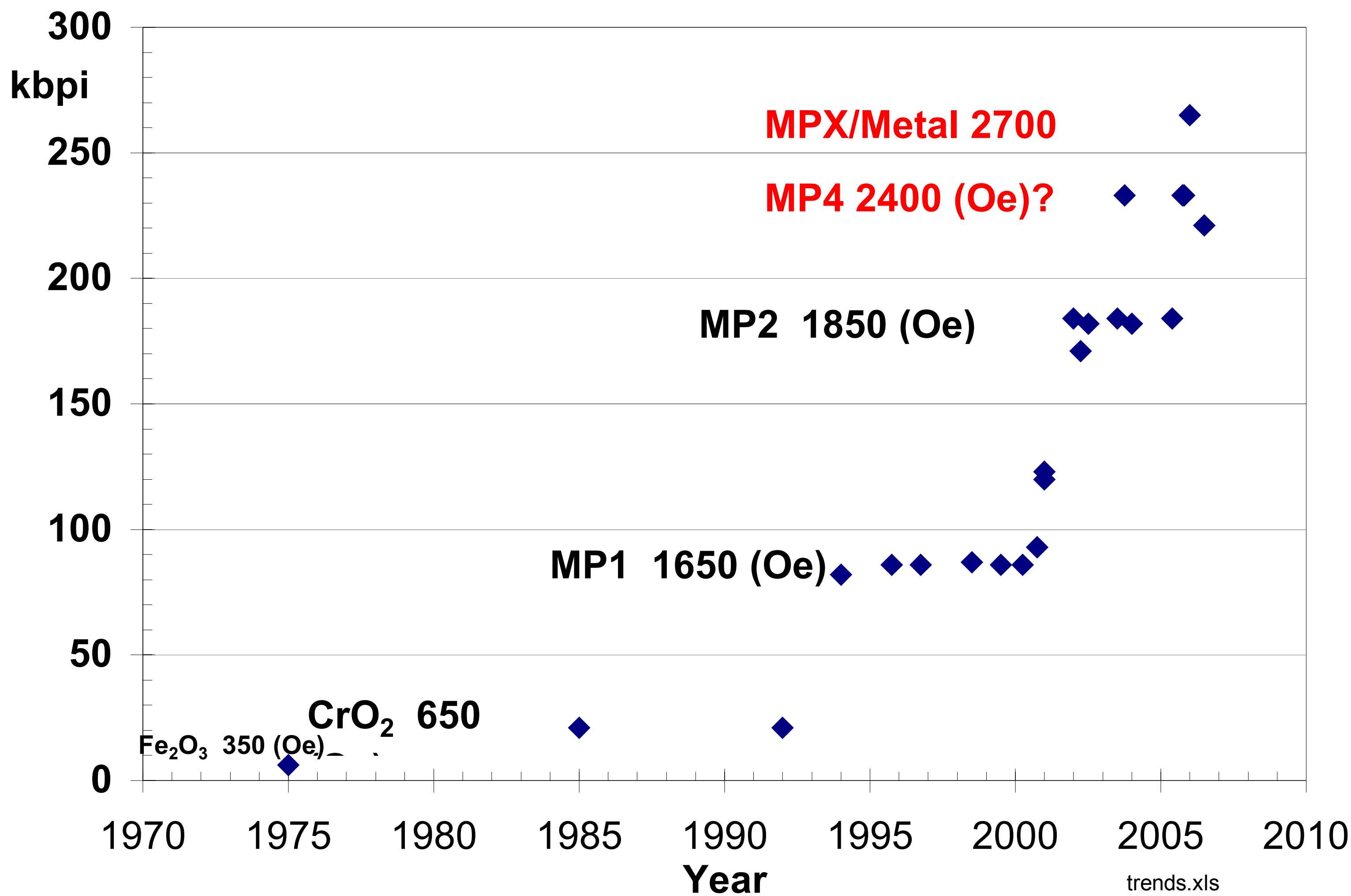
Block Diagram of a Magnetic Recording Channel



Digital Magnetic Recording



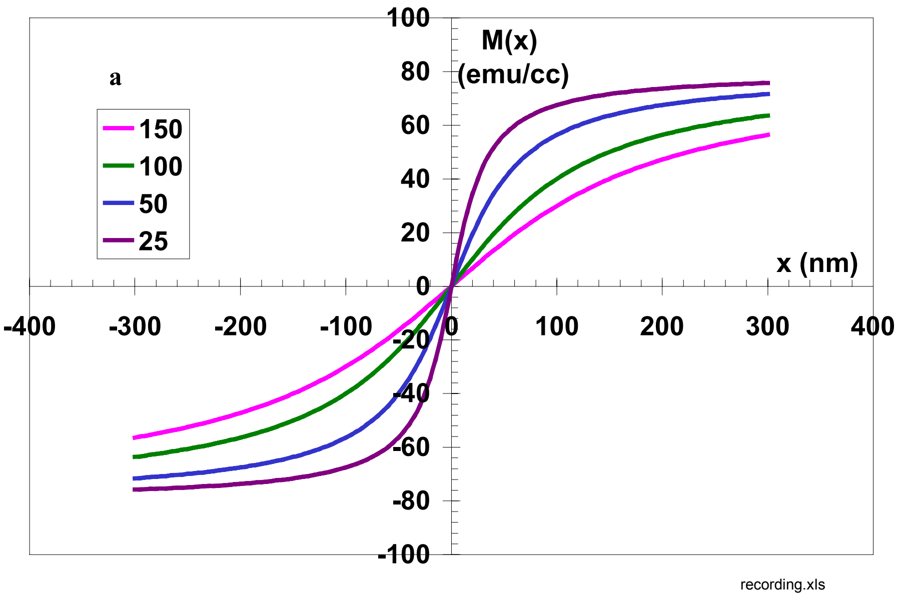
Linear Density Trend



Recording Theory

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

ArcTangent Transition

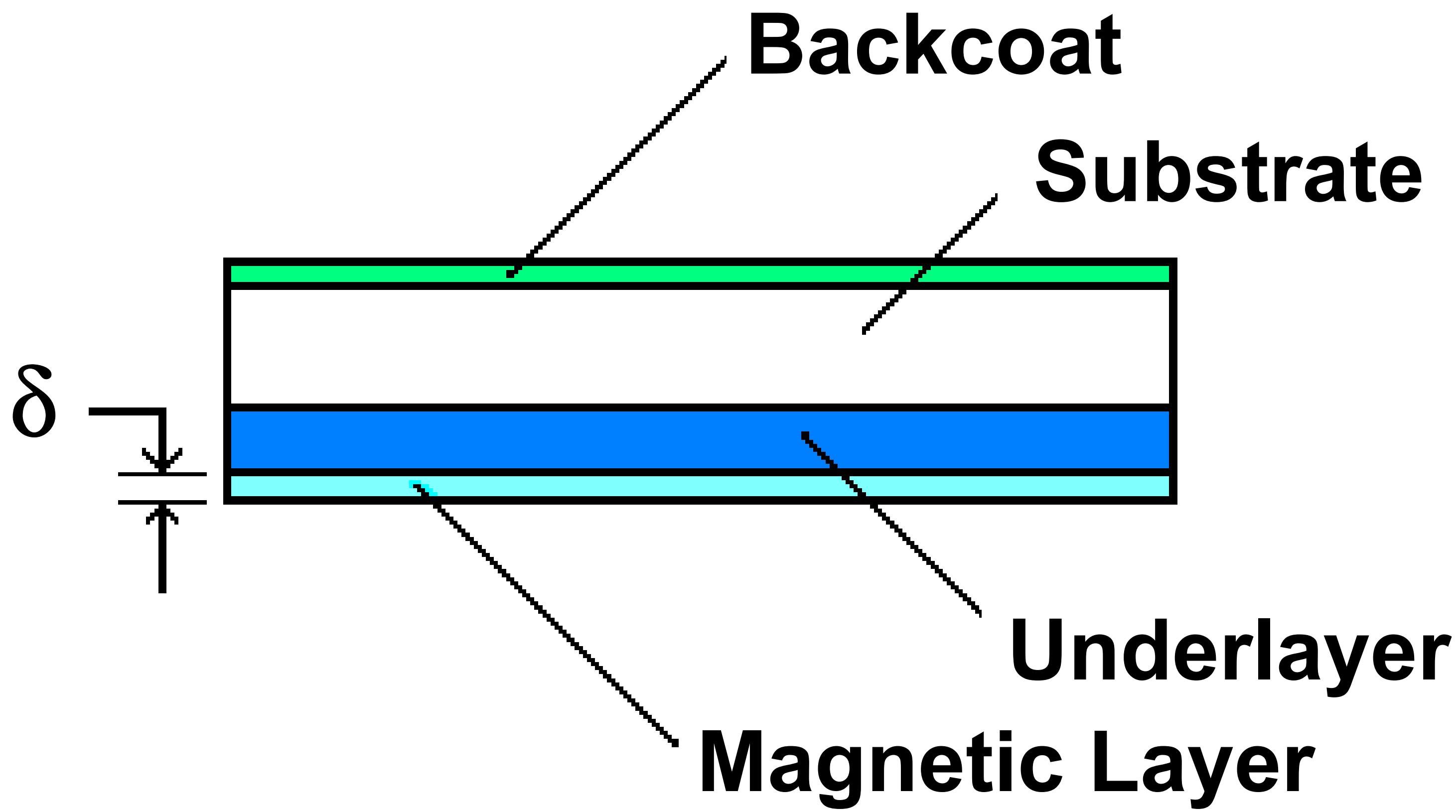


$$M(x) = \frac{2M_r}{\pi}\tan^{-1}\left(\frac{x}{a}\right)$$

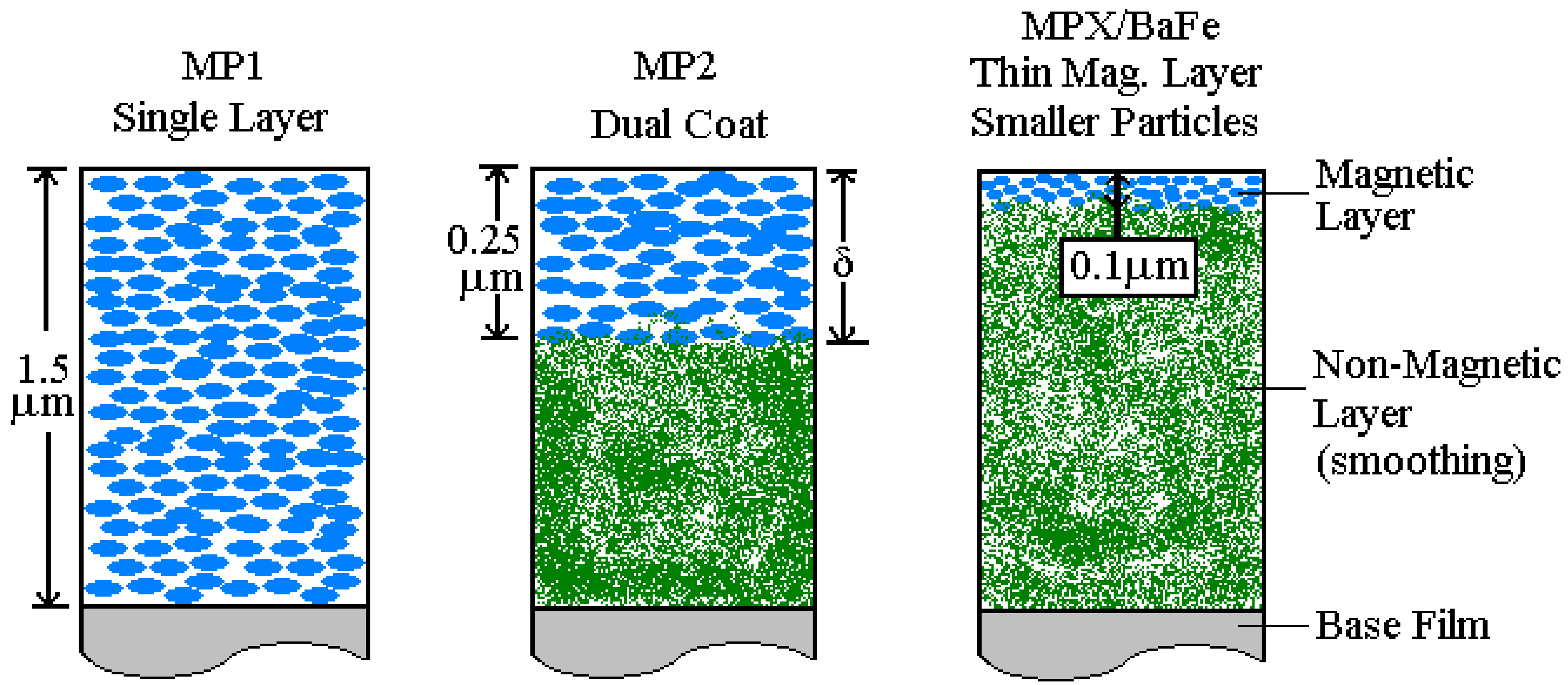
$$a = 2\left[\left(\frac{2}{\sqrt{3}}\right)\left(\frac{M_r\delta}{H_c}\right)\left(d+\frac{\delta}{2}\right)\right]^{1/2}$$

All these parameters are scaling down

Tape Media Section Diagram



Particulate Tape Media Progression



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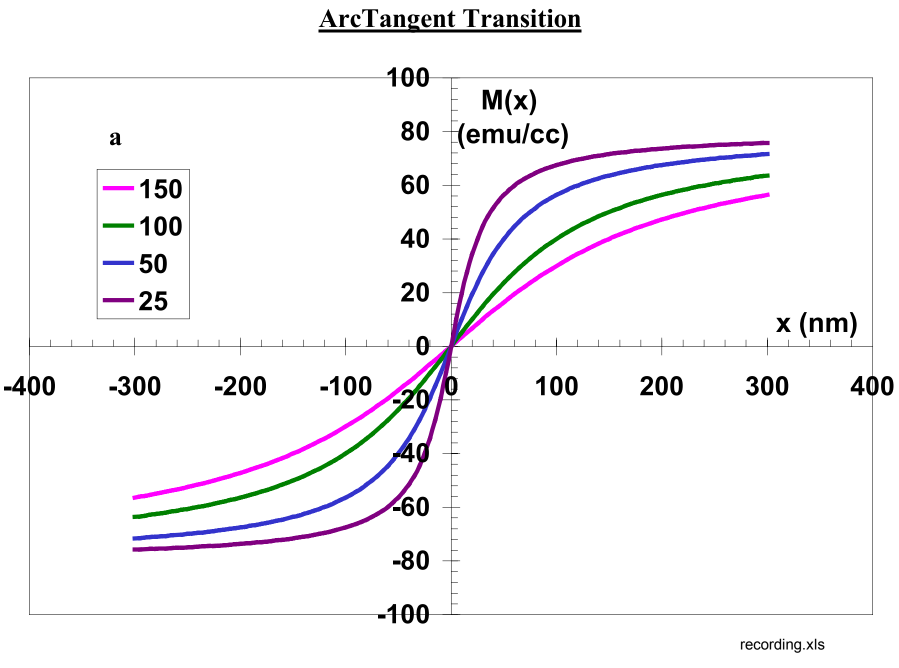

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Recording Theory (2)

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)

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

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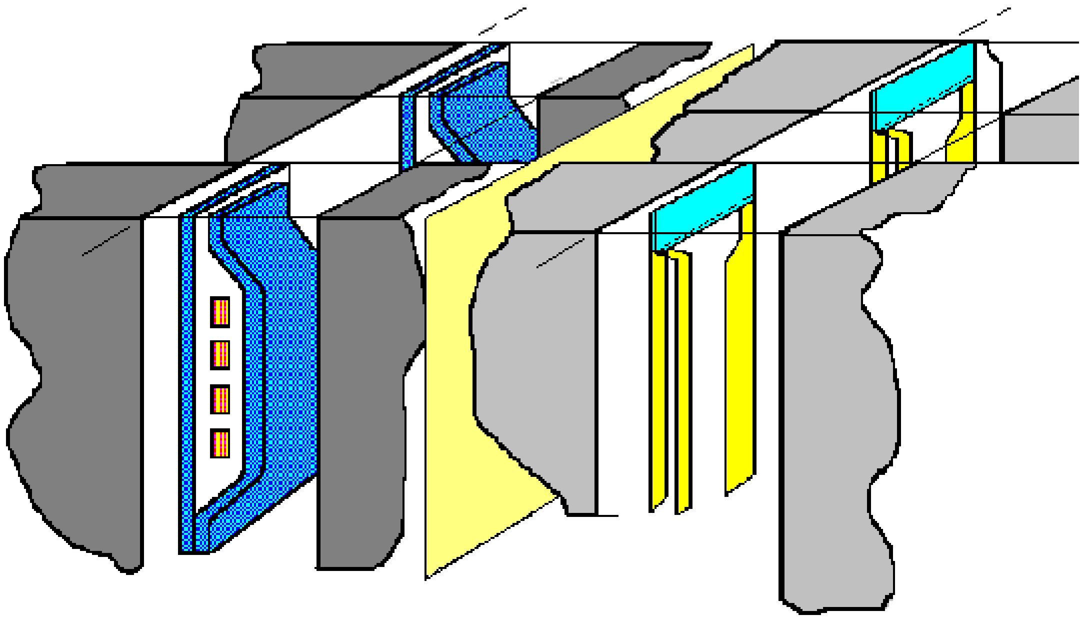
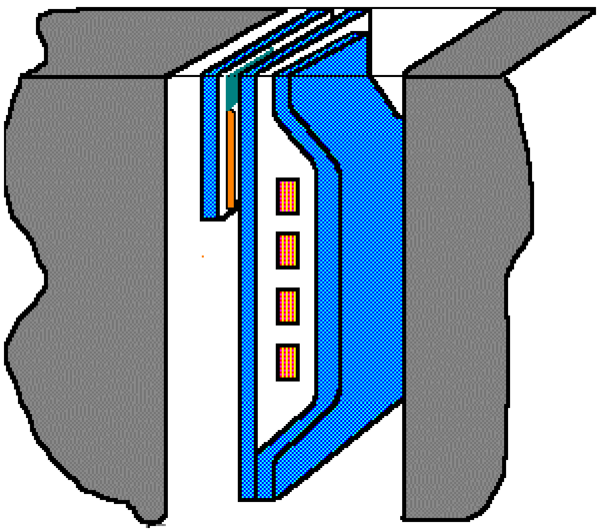
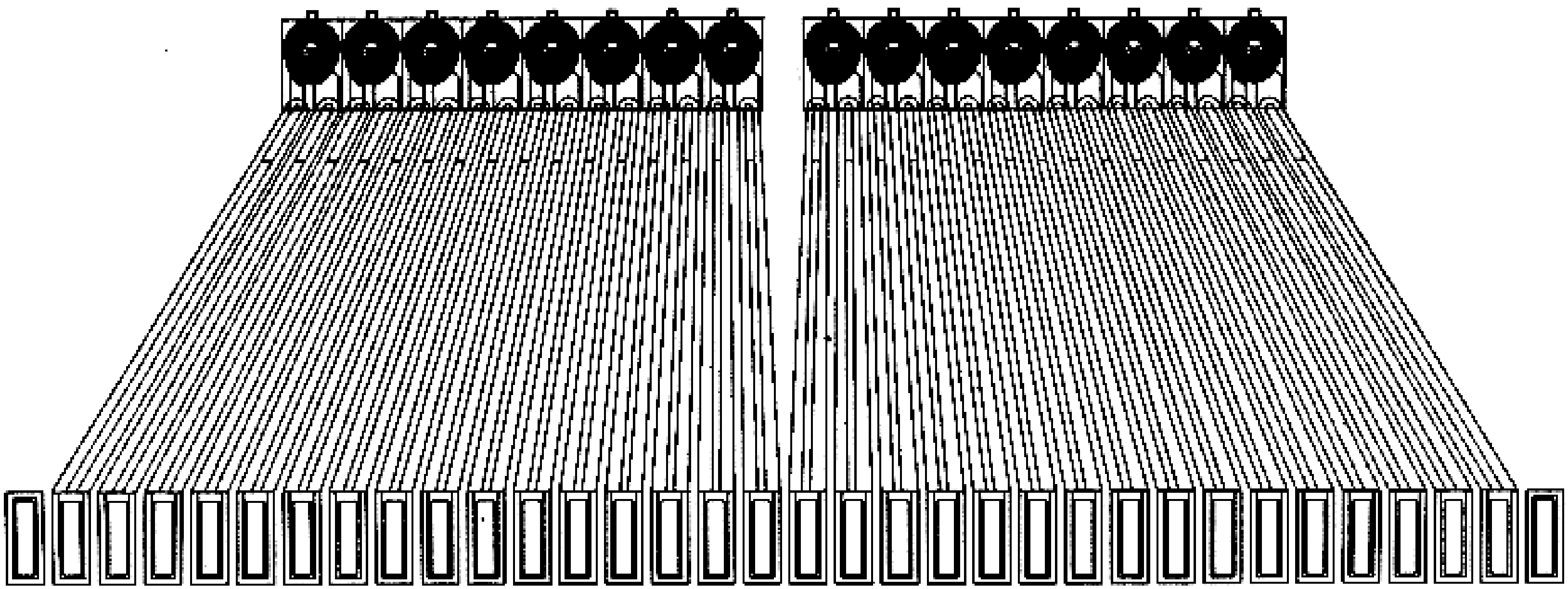
Head Technology





Thin Film Write Head Array



Media Stability Consequences

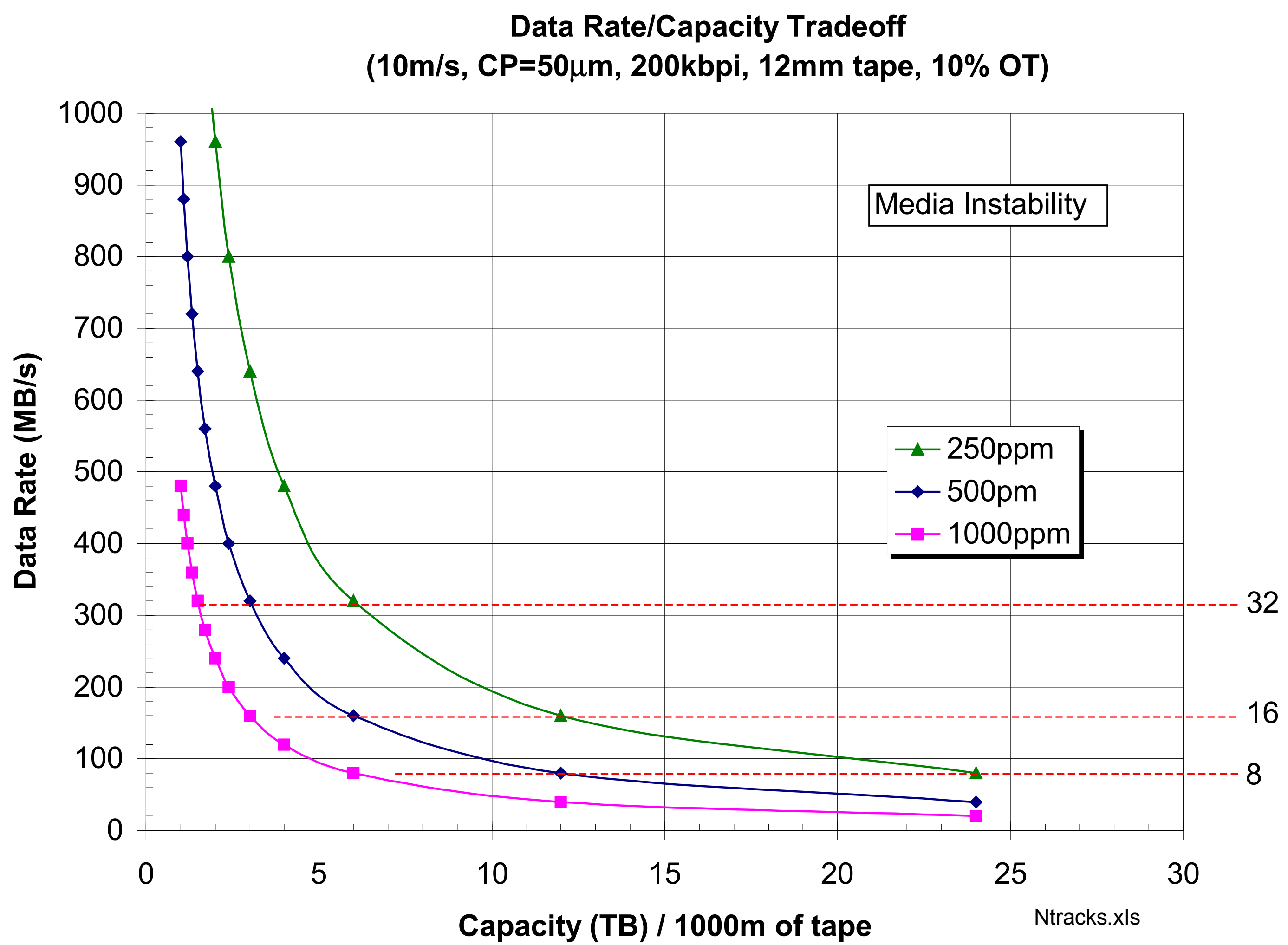
$$D = \frac{2(OT)LWVb^2\varepsilon^2}{64Cc_p m_c}$$

OT **Offtrack allowance**

c_p **channel pitch**

m_c **media stability coeff.**

Data Rate – Capacity Trade Off



NSIC 1998

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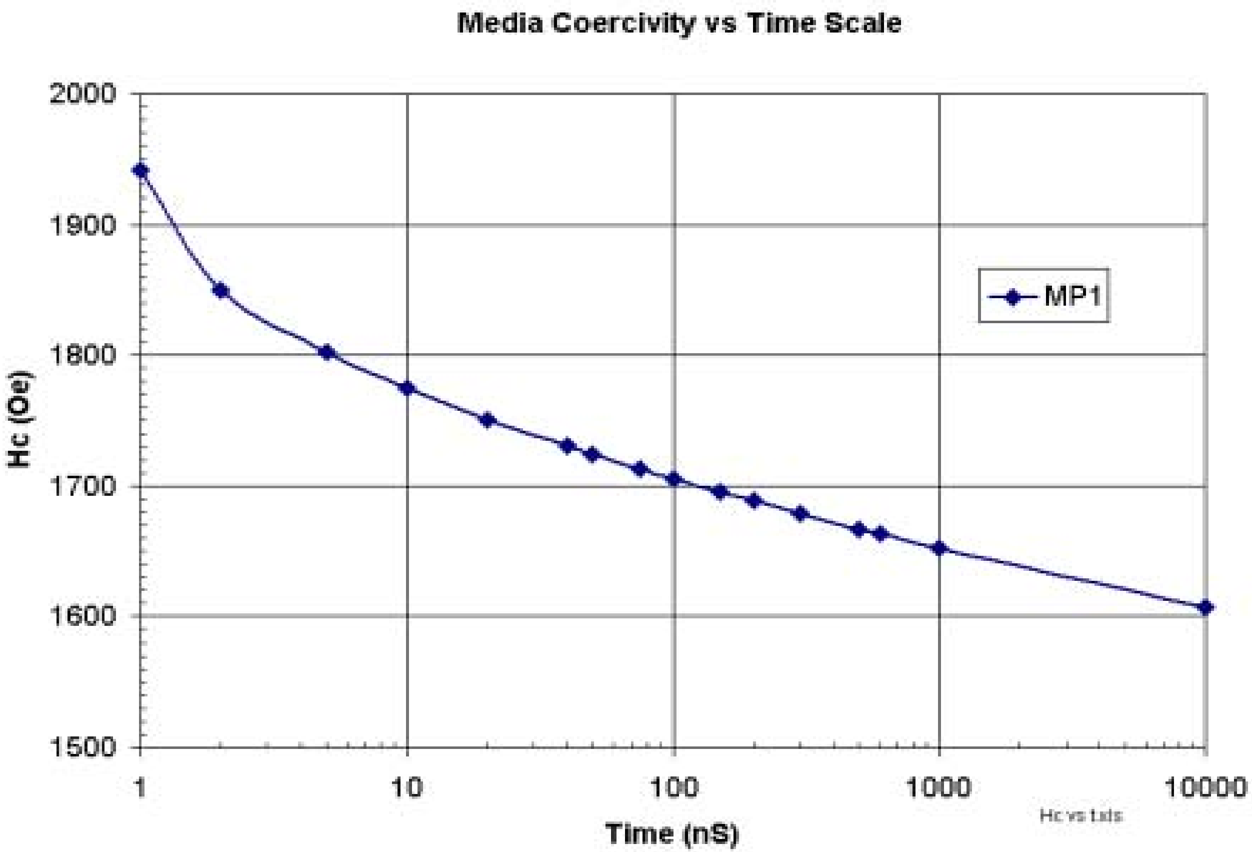
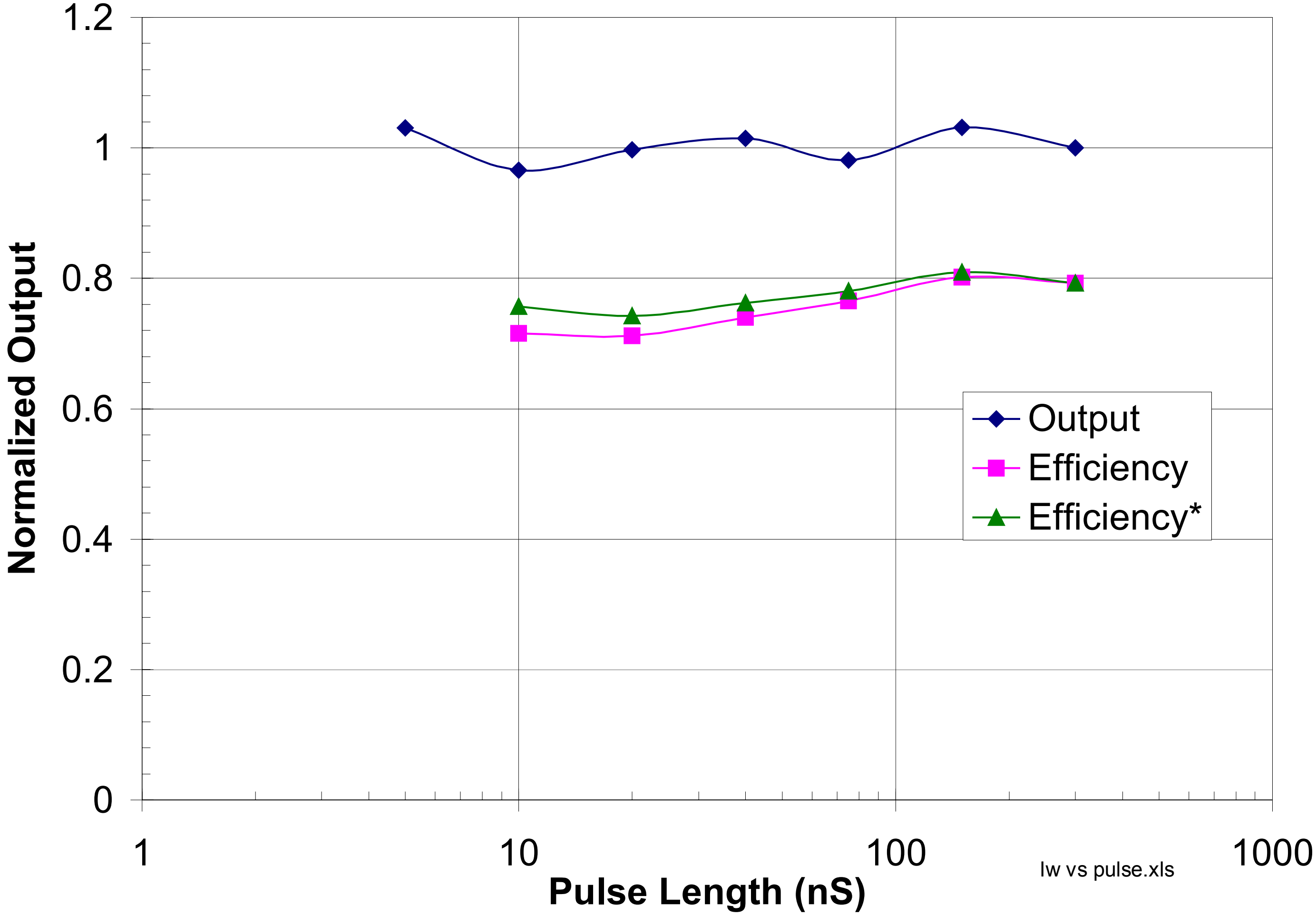
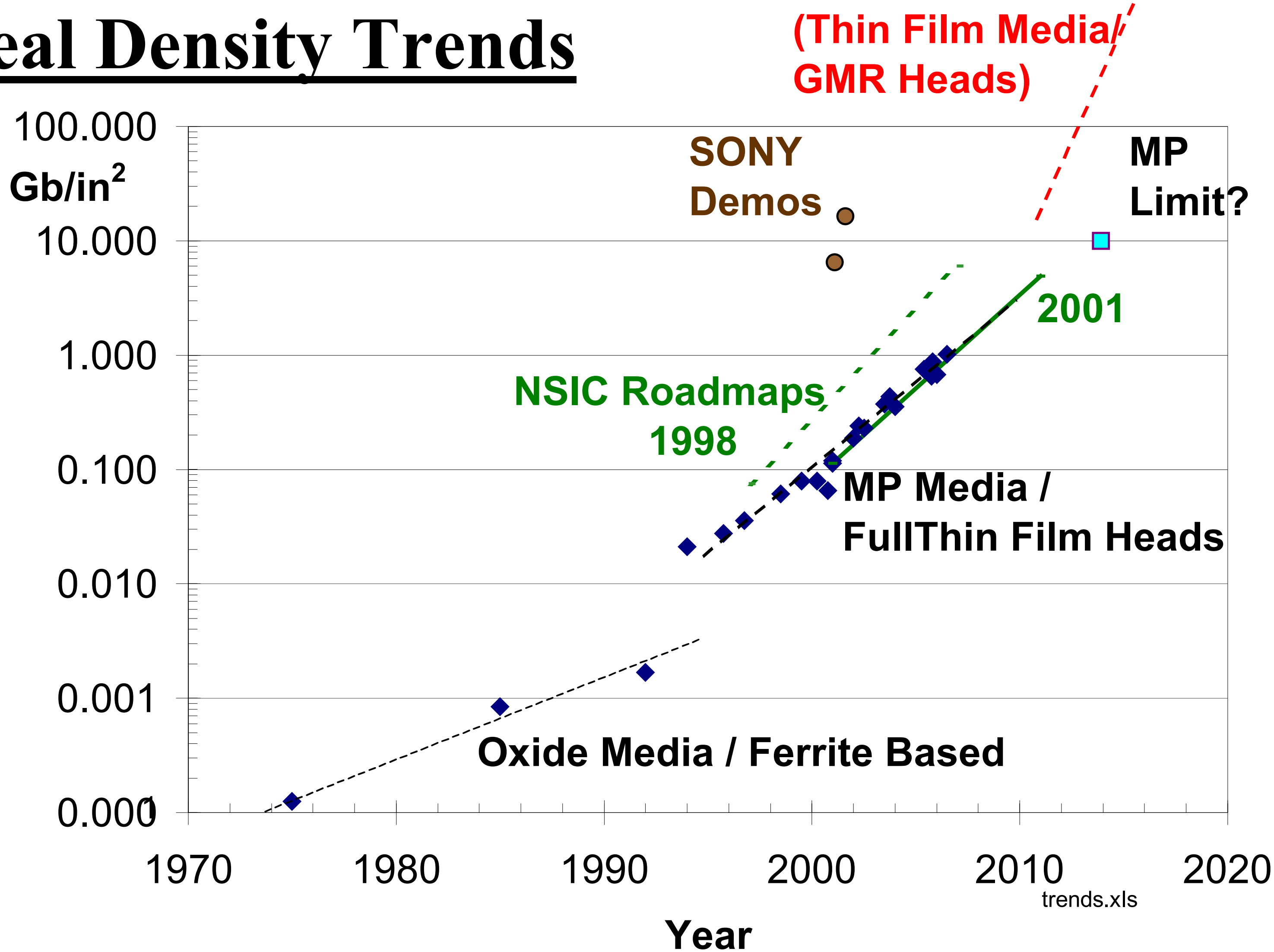
Media Coercivity Time Dependence



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 ~10Gb/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