A Prototype Tape System Using Multi Channel Stack Heads and Metal Evaporated Tape

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Contents

- Introduction
- Writing 1.5um track with multi-channel head
- New Reading technology for 1.5um track
- Prototype drive
- Corrosion resistance of spin-valve head and ultra-thin metal evaporated tape
- Conclusion

Contents

Previous Works

An SNR of 26dB was obtained using
a spin-valve head with a width of 0.8μm,
and a metal evaporated tape
with a contact tape/head interface.

--- reported in TMRC-2001

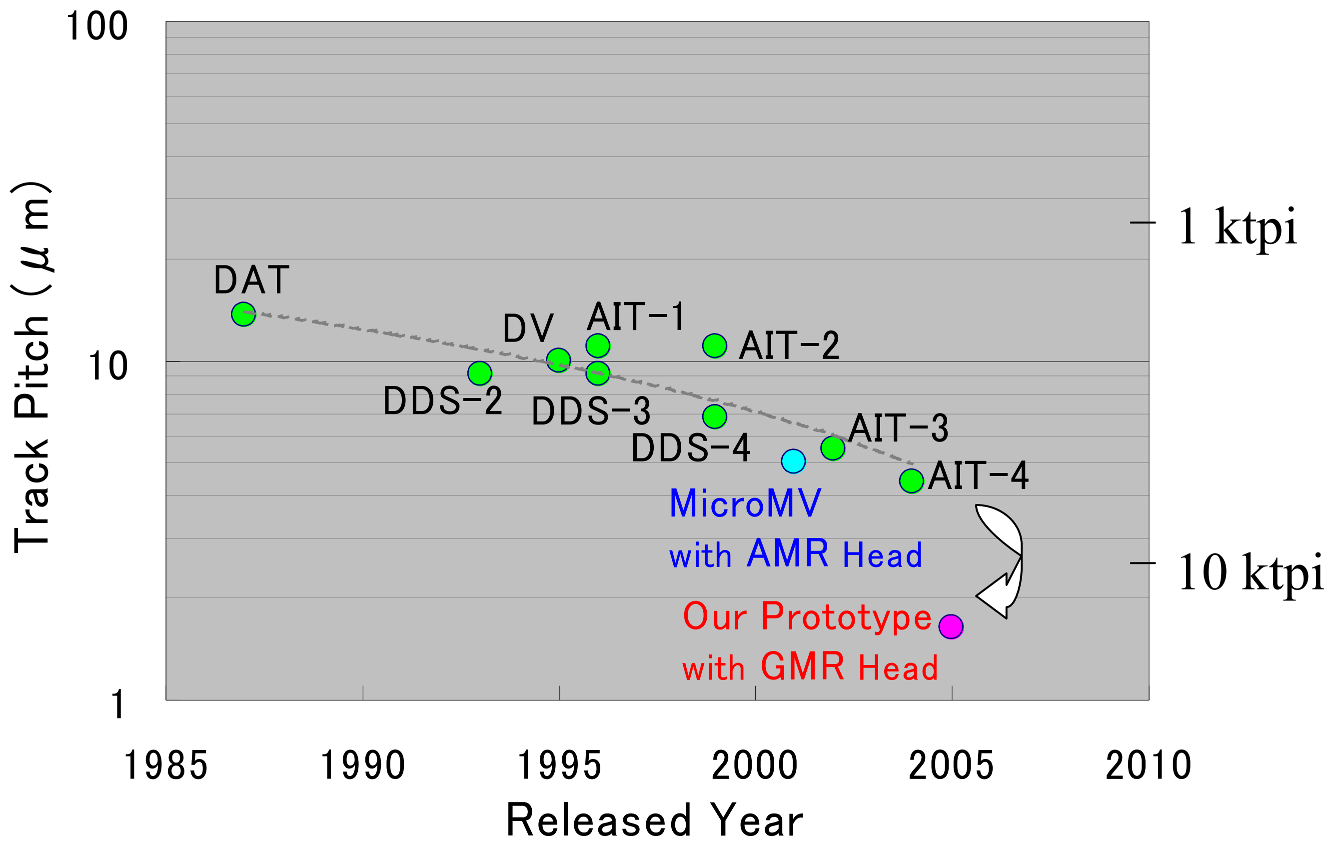
Possibility of a high track-density tape-drive

However, these were laboratory works using
a spin-stand tape tester, not a drive.

Target

To create a helical-scan tape drive with a track pitch of 1.5µm using a spin-valve head.

Progress of Track Density in Helical Scan



Track pitch should be reduced drastically from around 5um to 1.5um.

Contents

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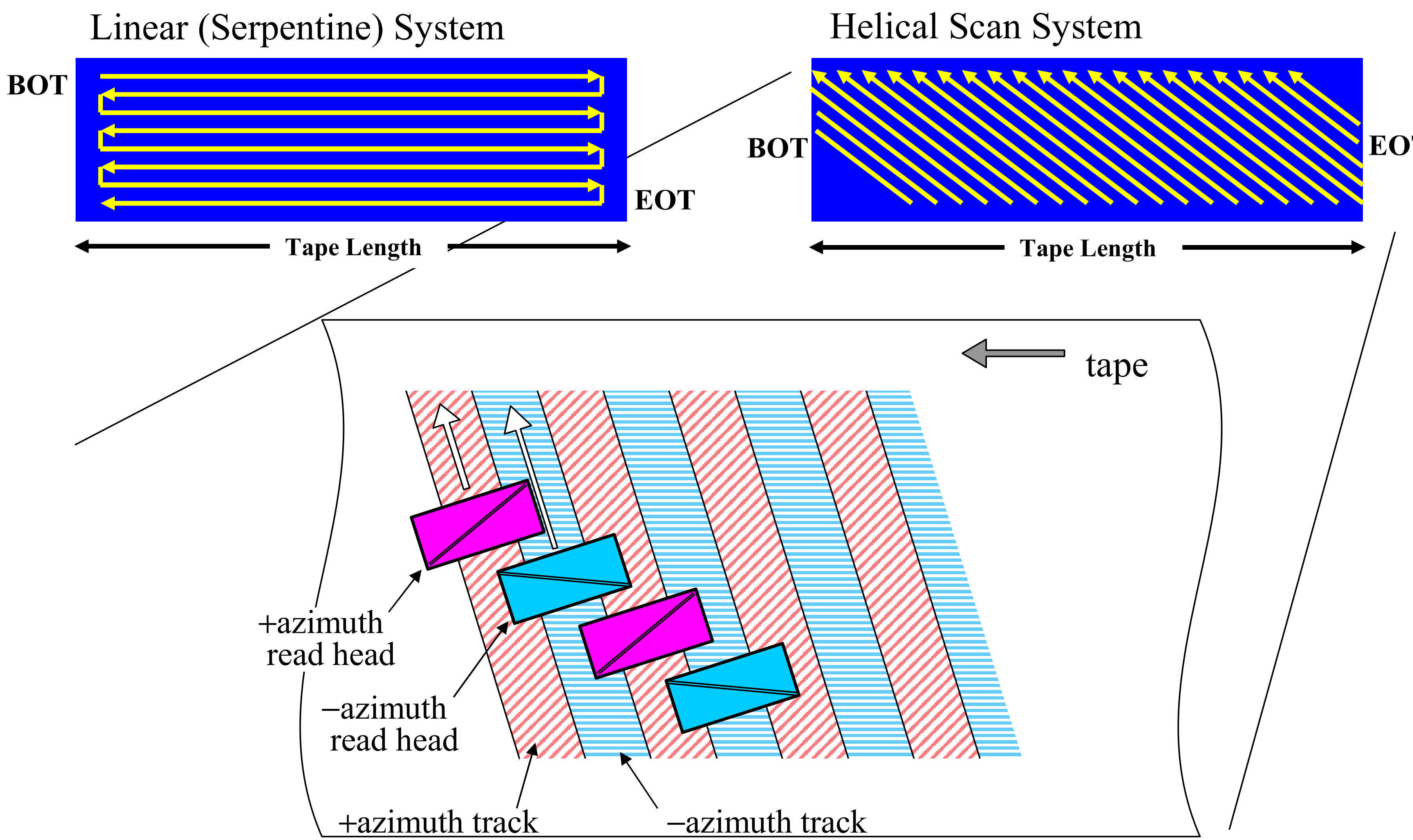
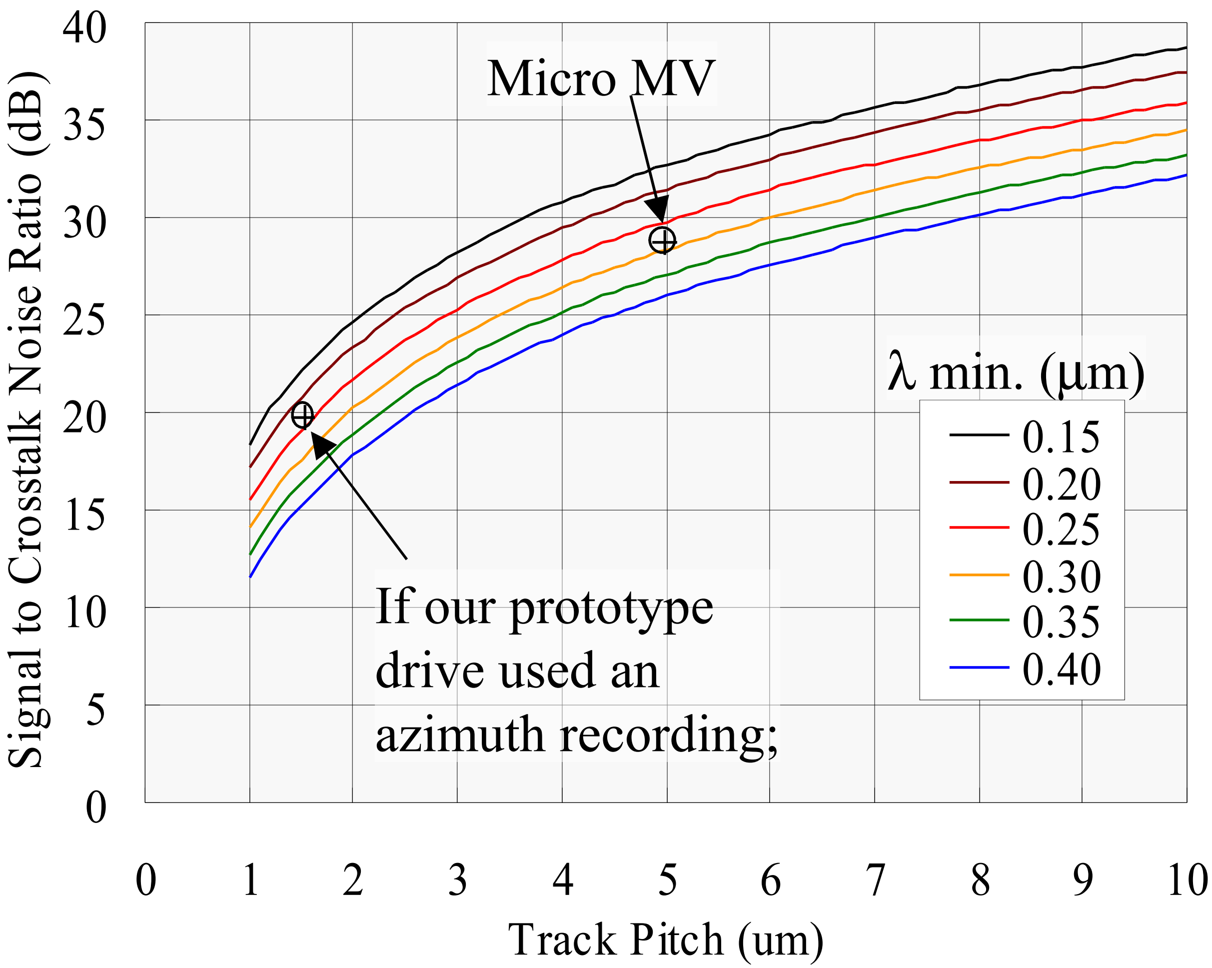
Azimuth Recording

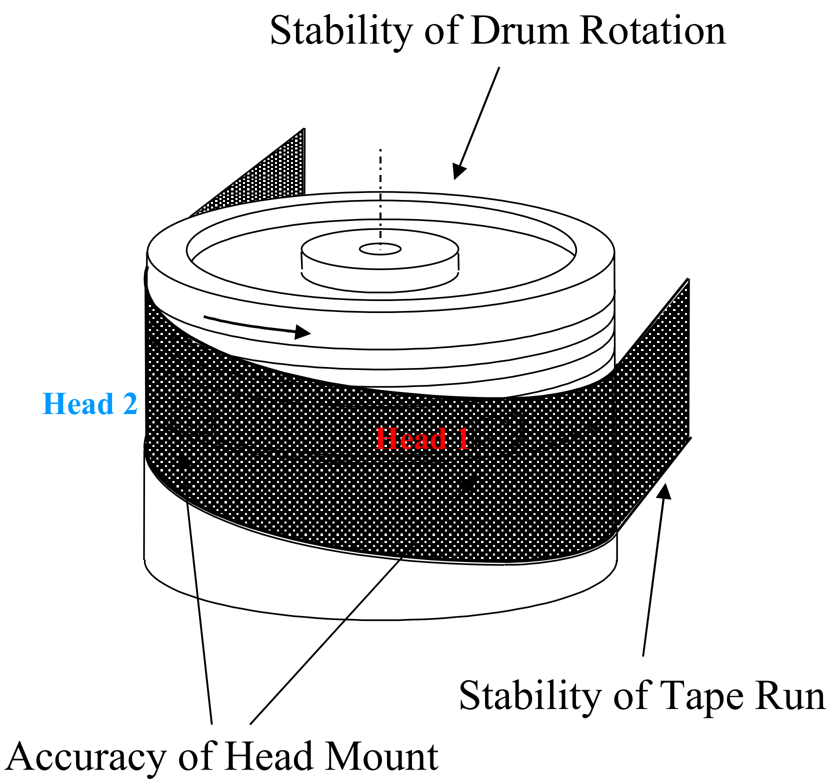


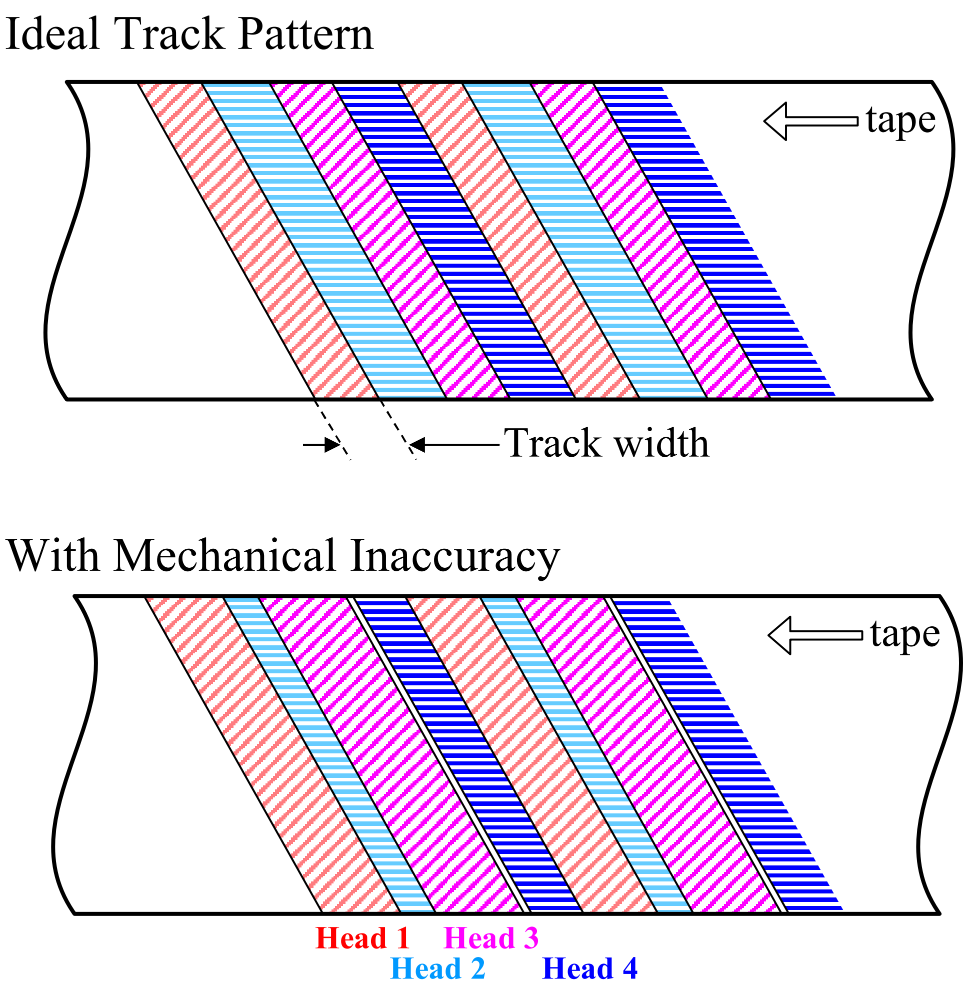
Signal to Crosstalk Noise Ratio



EQ: PR4
Code: 24/27
Azimuth:
+/−25 degrees
Tw=1.5 Tp

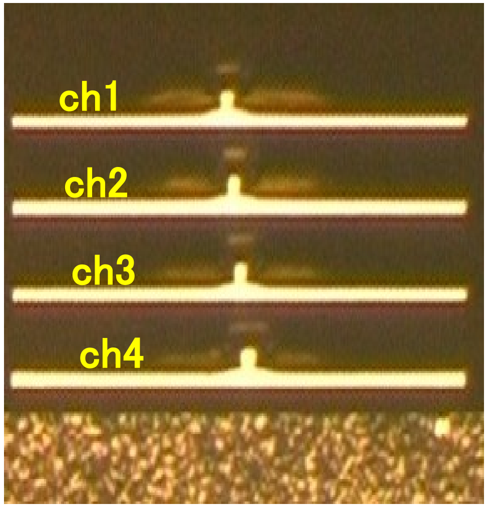
Influence of Mechanical Accuracy



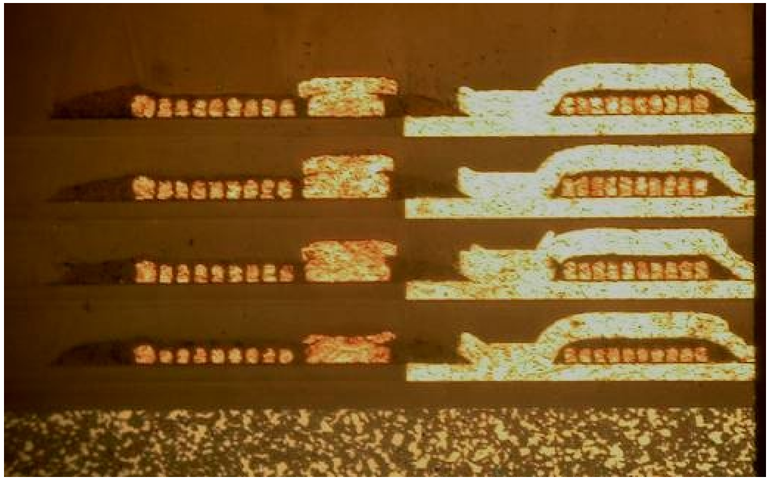


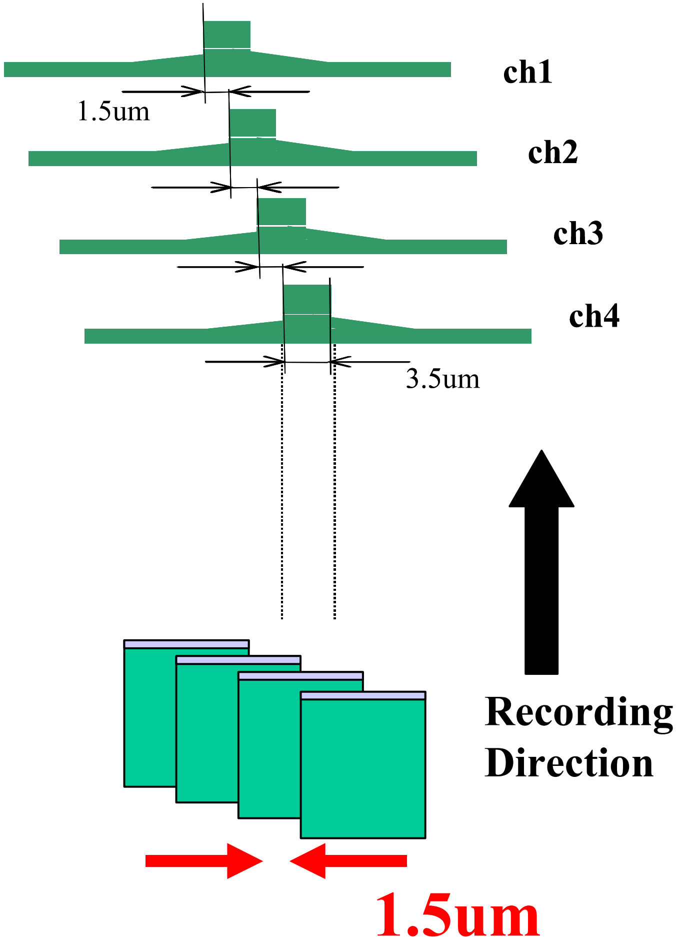
Multi-channel stack write head

Write Gaps



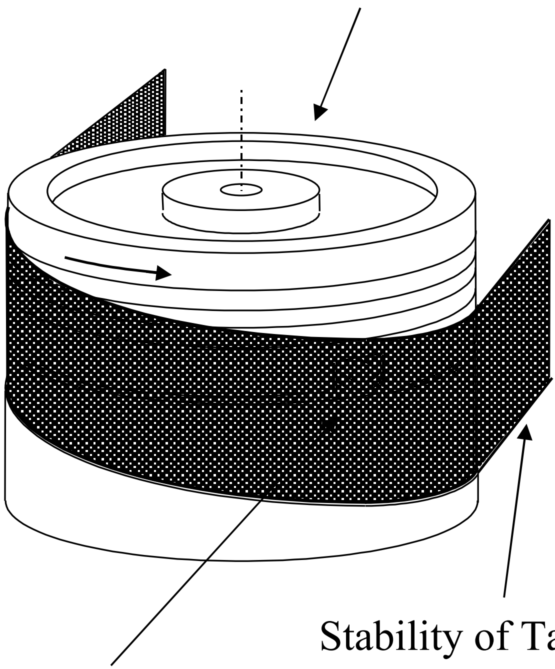
Cross Section





Track Pattern of Multi-channel Stack Head

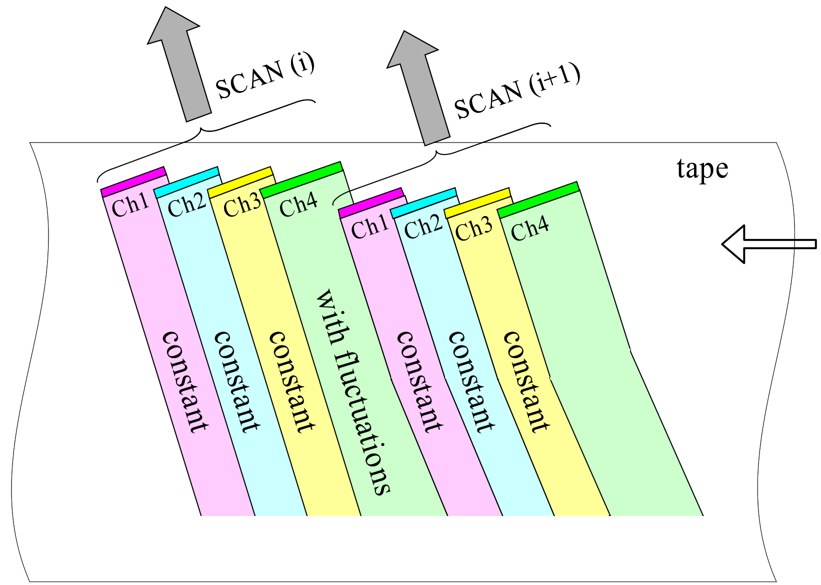
Stability of Drum Rotation



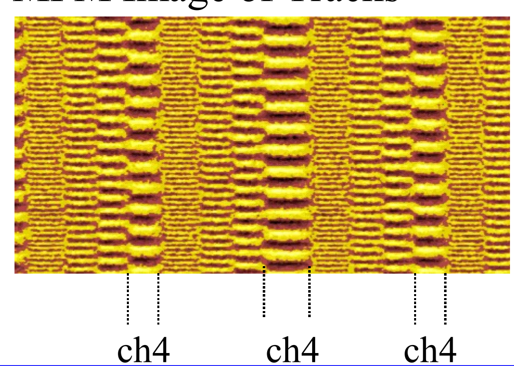
Stability of Tape Run

4ch Stack head

~~Accuracy of Head Mount~~

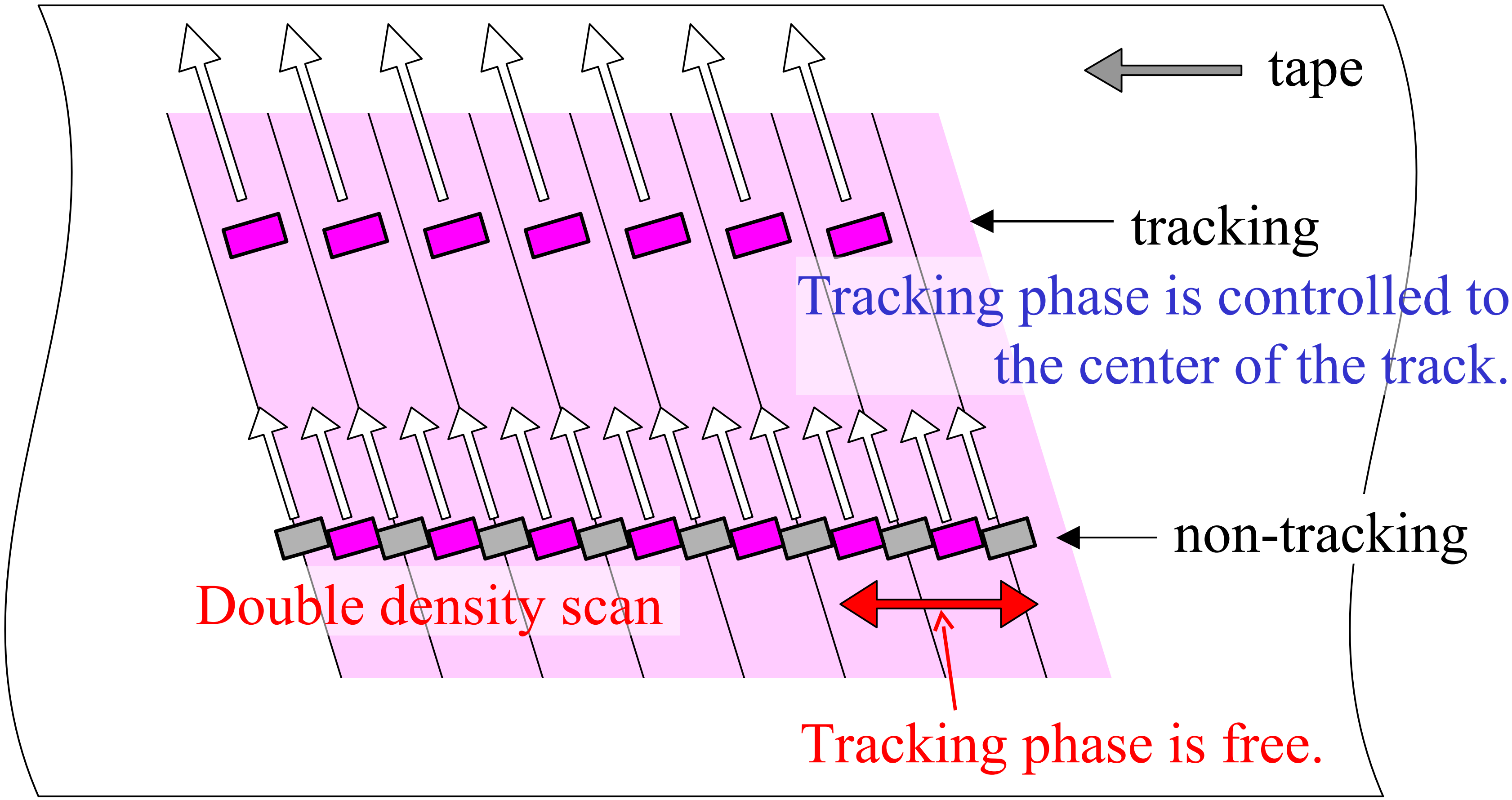


MFM Image of Tracks

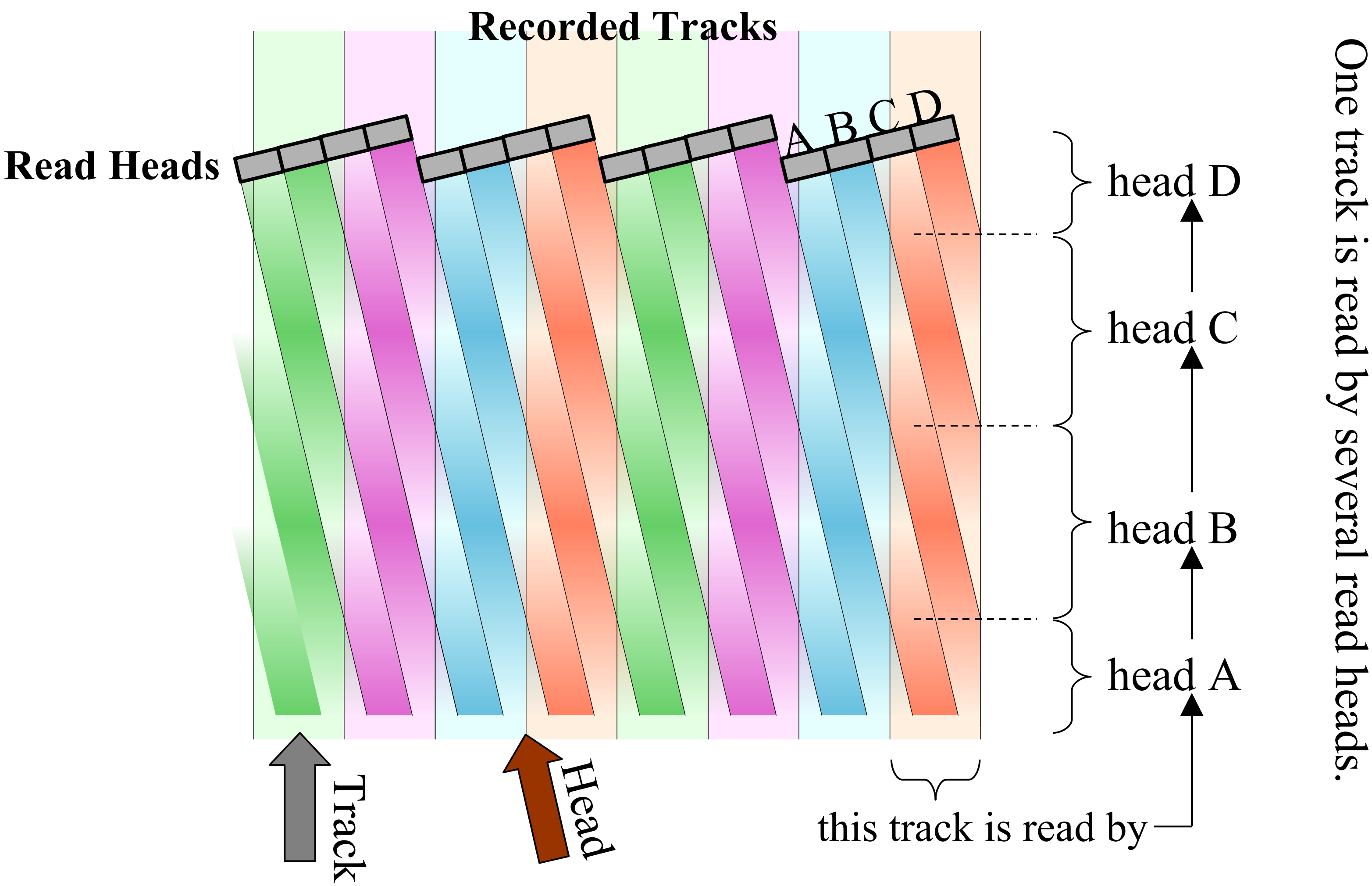


Contents

NANT
(Non-azimuth, Non-tracking)



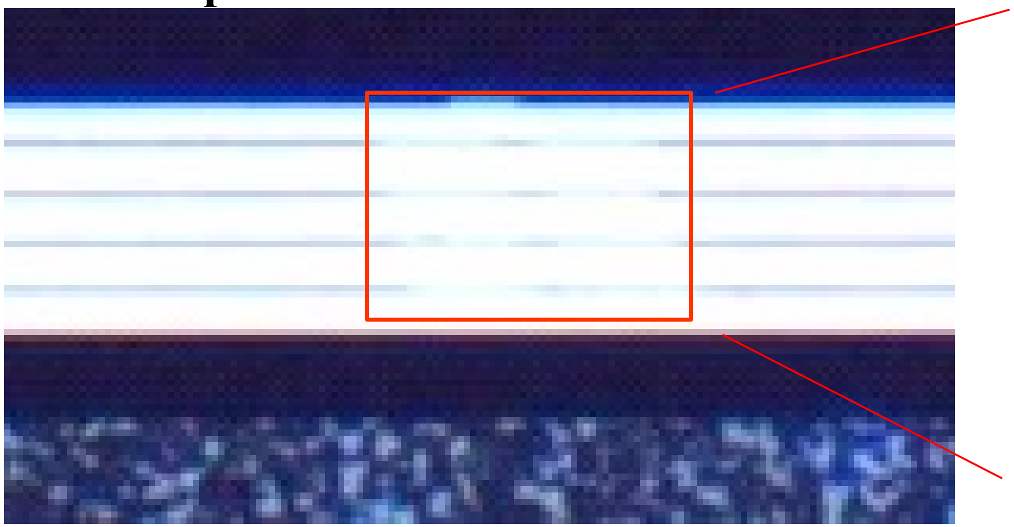
Multi-channel Read Head and NANT Reading



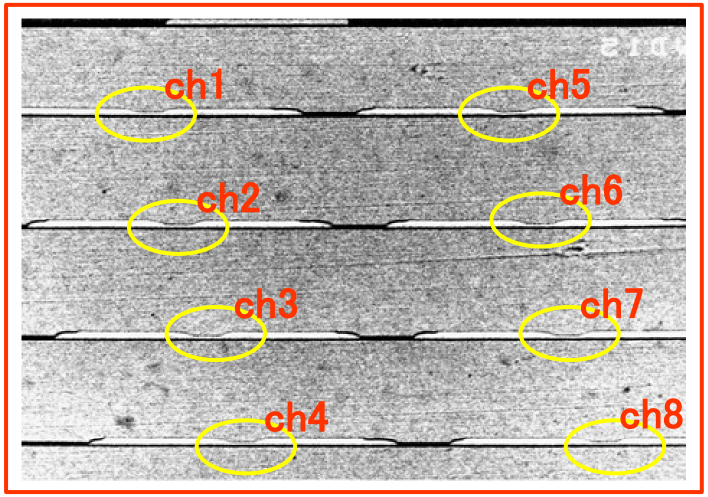
Example of 4 channel multi head

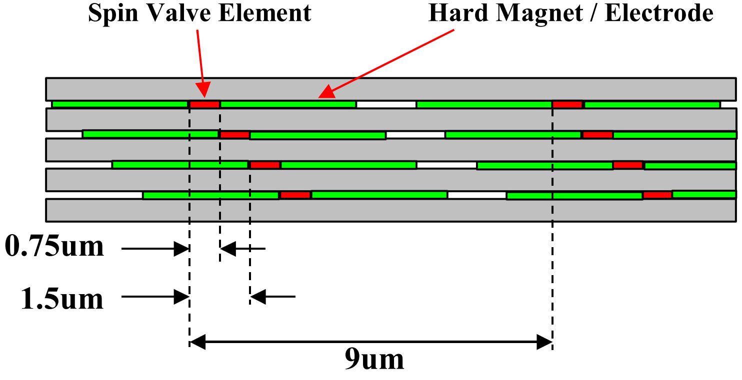
Multi-channel stack read head

Read Gaps

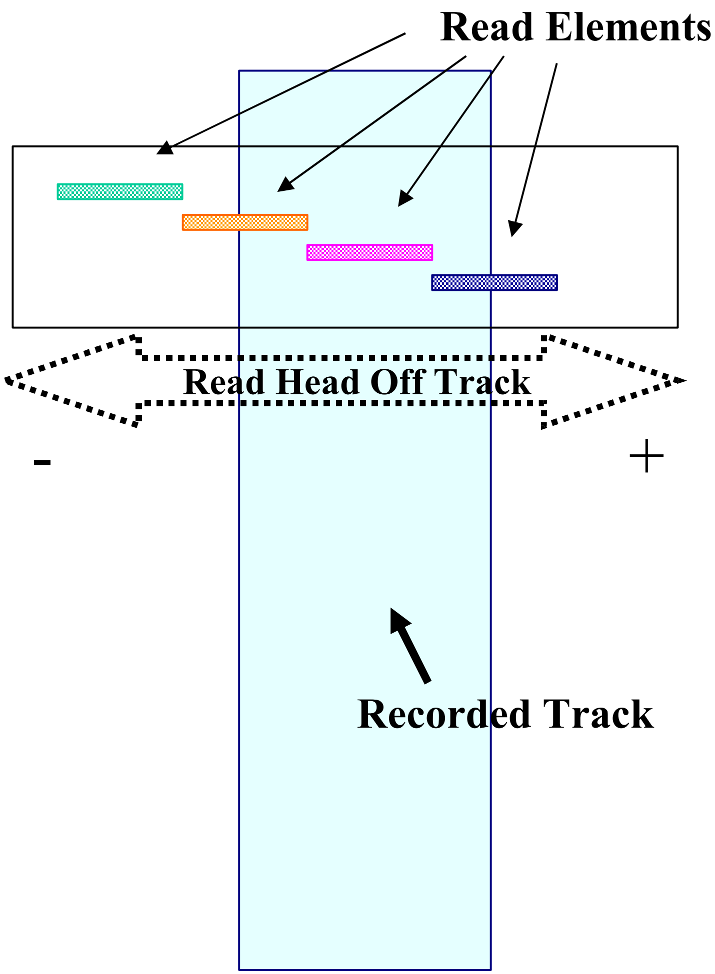


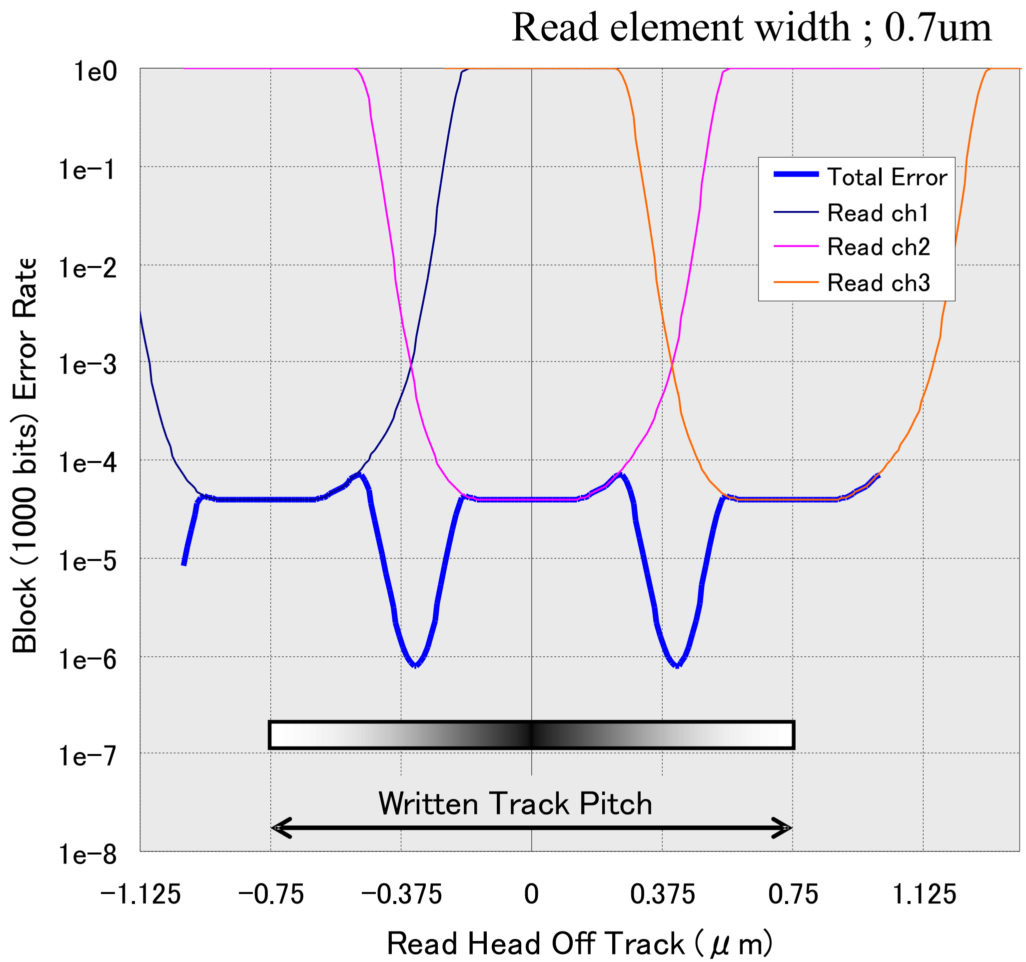
8ch Read Elements





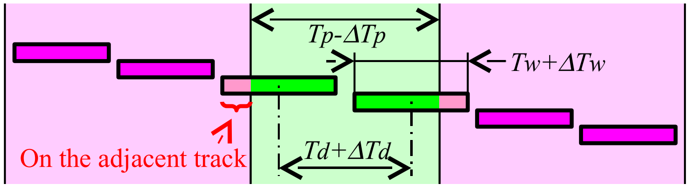
NANT Error Rate Off-track Characteristics





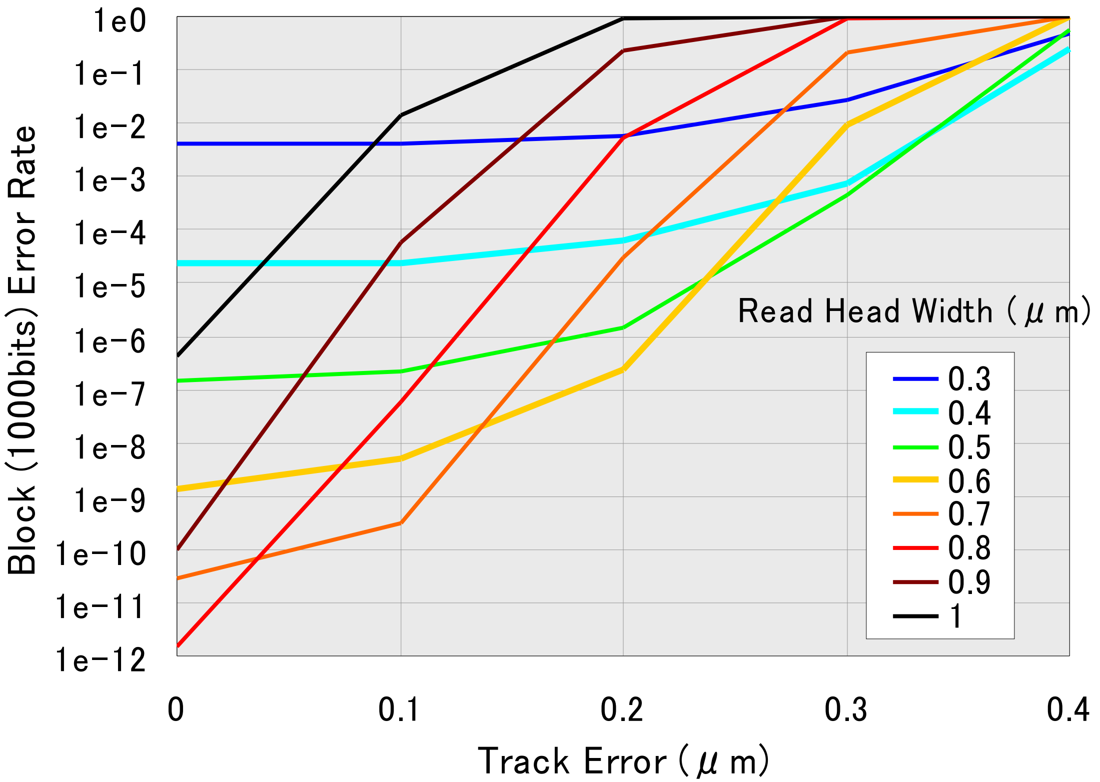
Worst-Phase Error Rate at SNR* of 20dB

Critical case (with mechanical errors)



Errors

narrow the *Tp*
widen the *Tw*
separate the *Td*



Track Error = *ΔTp+ΔTw+ΔTd* (definition)

* SNR at center tracking using 0.7μm head
EQ: PR4
Coding: 24/27
Tp: 1.5μm

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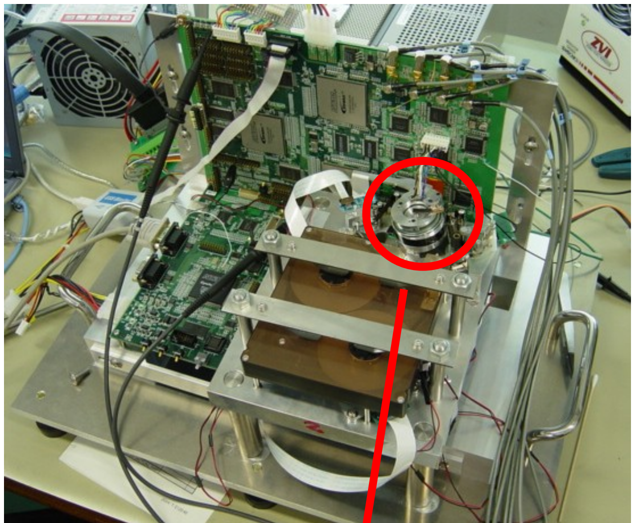
Prototype Drive

Prototype Drive



Specifications

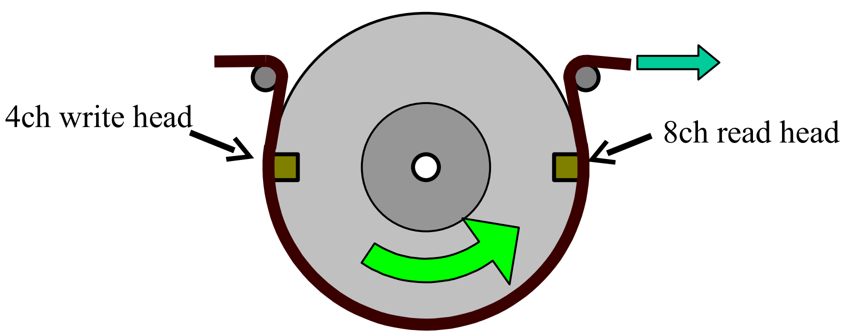
Drum Diameter	40mm
Track Width of Ch1 to Ch3	1.5um
Track Width of Ch4	2um
Tape Width	8mm
Write Channel	4ch
Read Channel	8ch
Coding Rate	8/9
Channel	PR4ML
Write Data Transfer Rate	20MBps
Channel Clock	148MHz
Minimum Wavelength	0.24um
Linear Density	188kbpi
Track Density	15.6ktpi
Areal Density	2.94Gbpi^2

1.625µm Average (Track Width of Ch1 to Ch3 and Ch4)

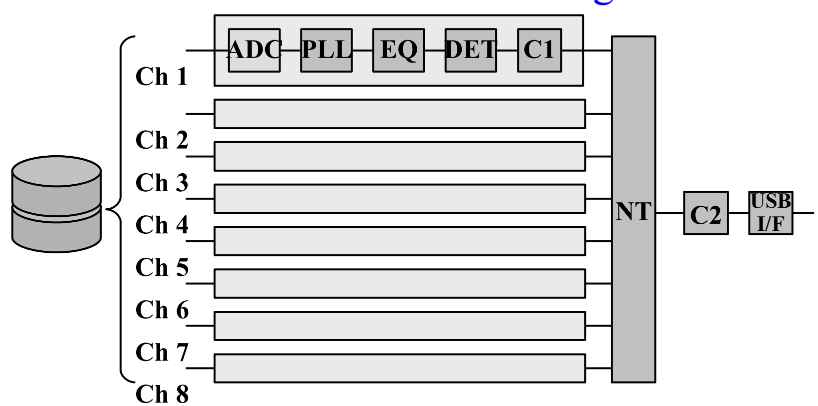
One head with 4 channels (Write Channel)

One head with 8 channels (Read Channel)

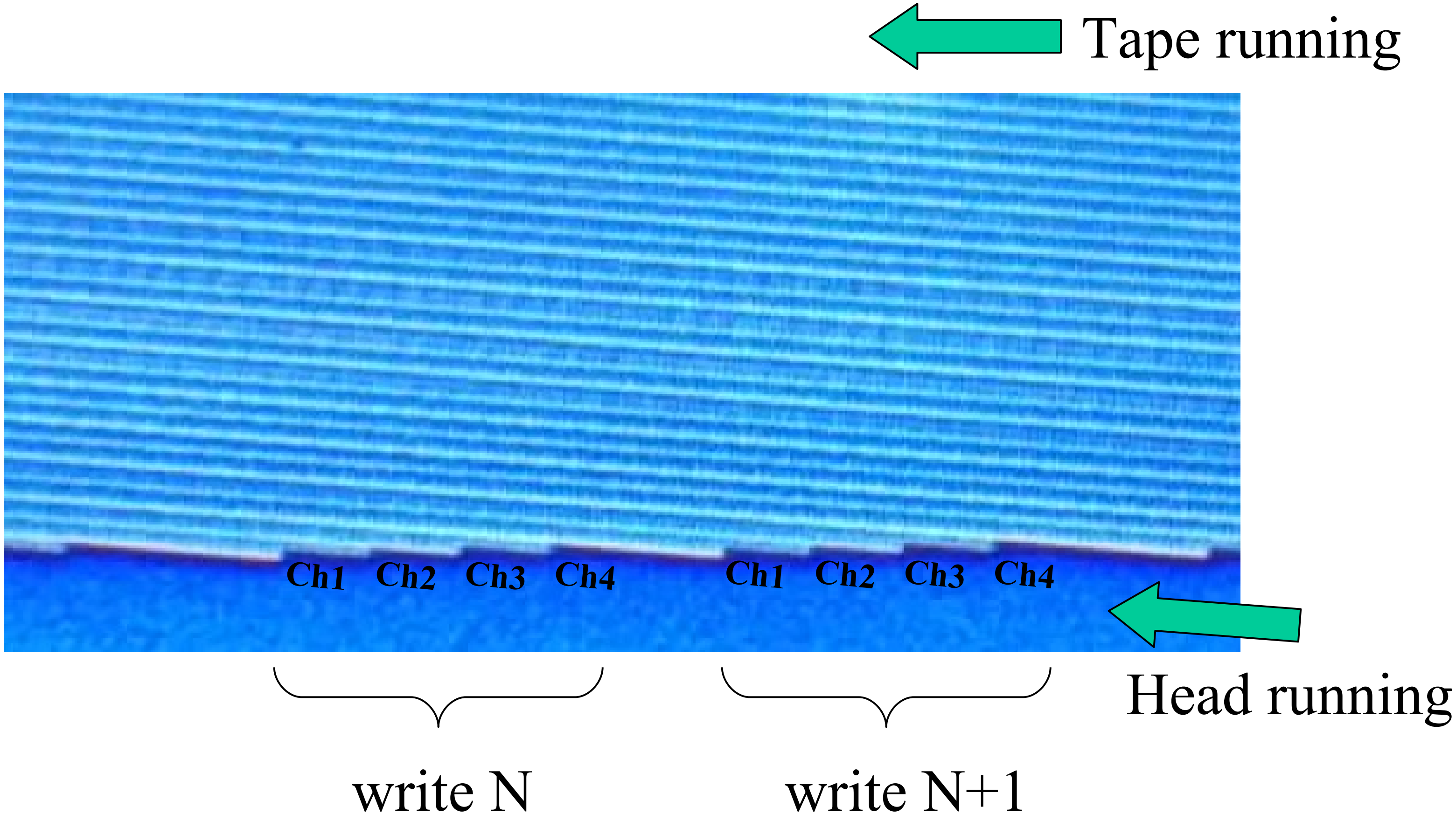
Head Placement



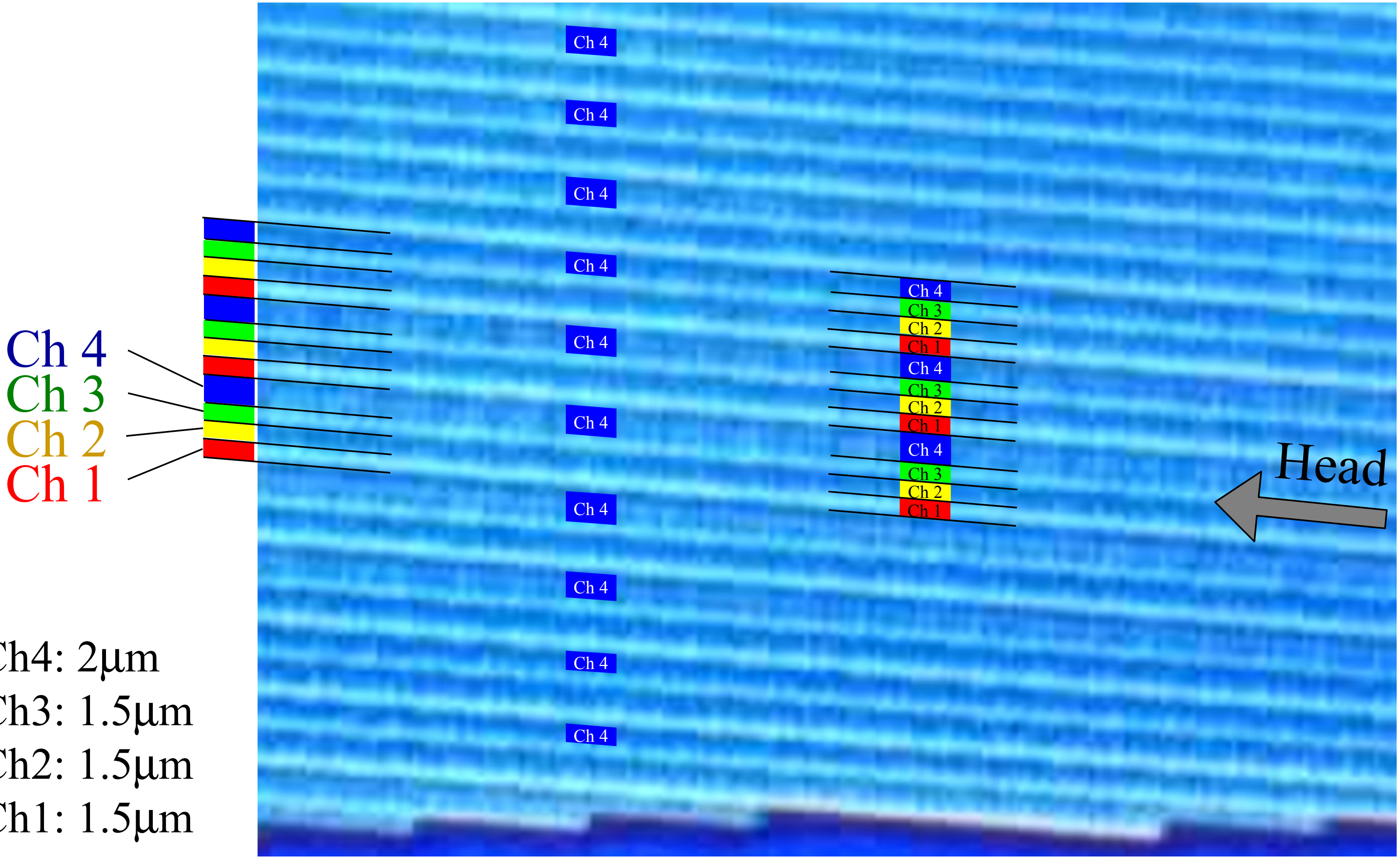
Read Channel Block Diagram



Recorded Pattern

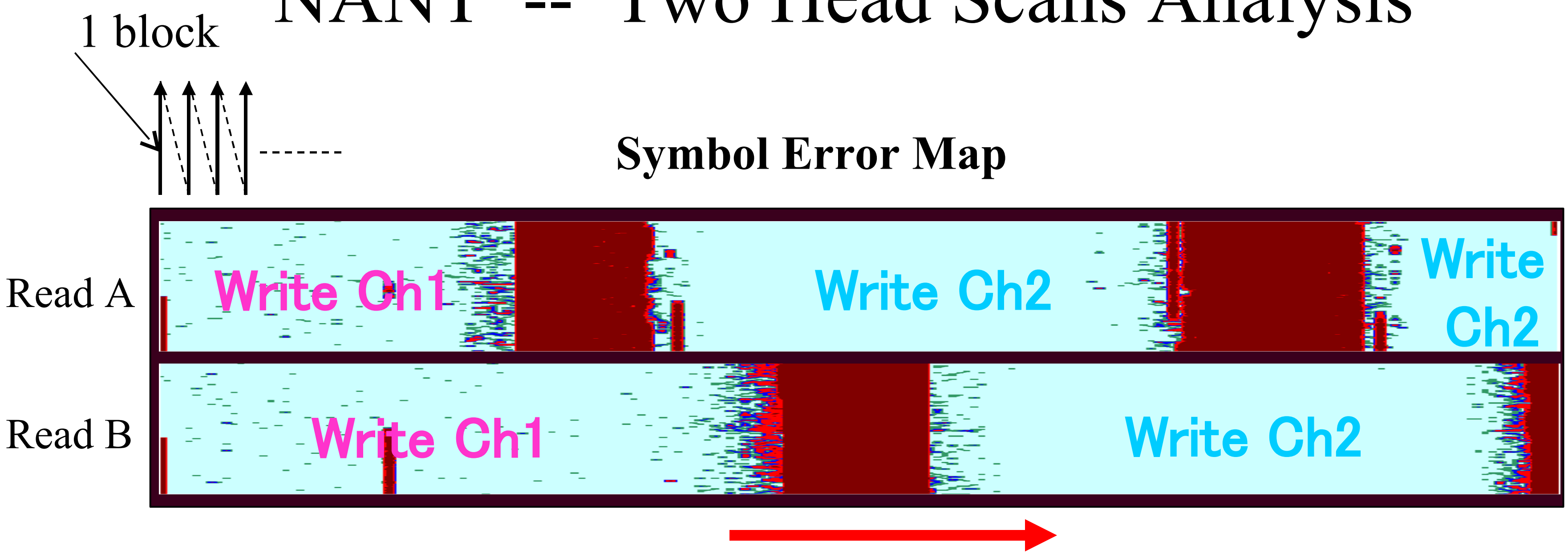


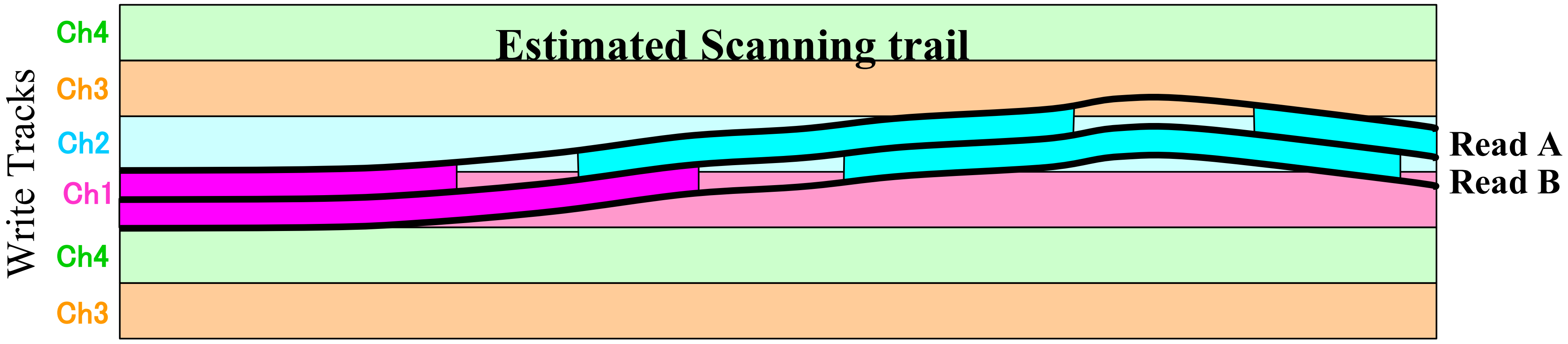
Recorded Pattern (enlargement)



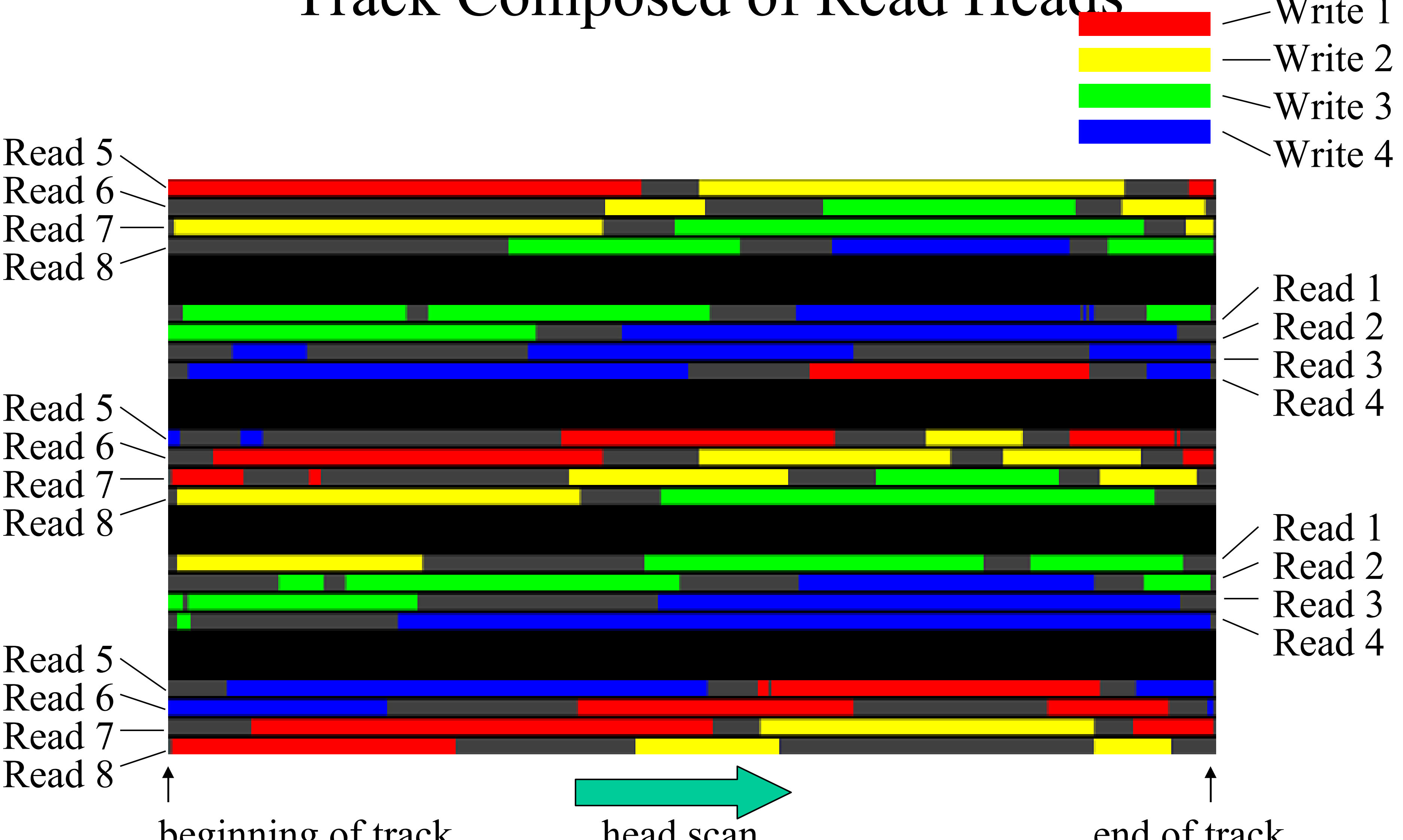
Ch4: 2µm
Ch3: 1.5µm
Ch2: 1.5µm
Ch1: 1.5µm

NANT -- Two Head Scans Analysis





Track Composed of Read Heads



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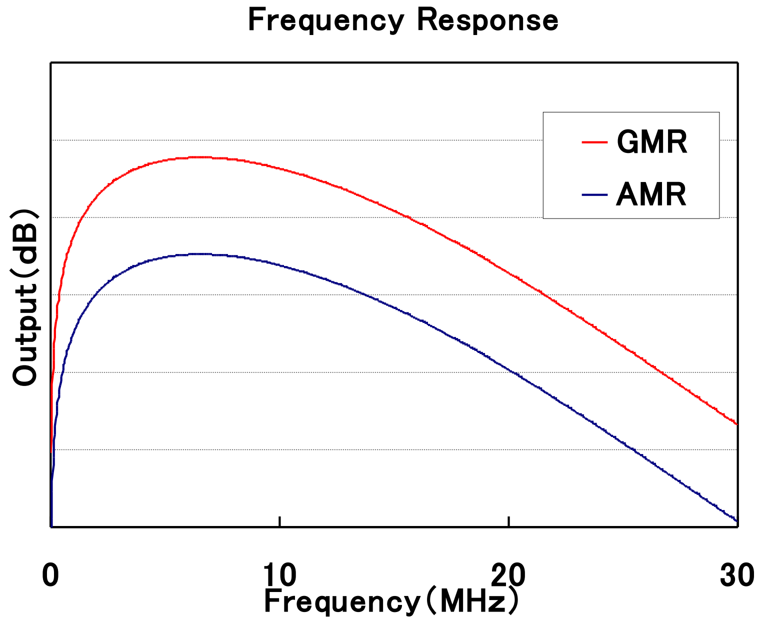
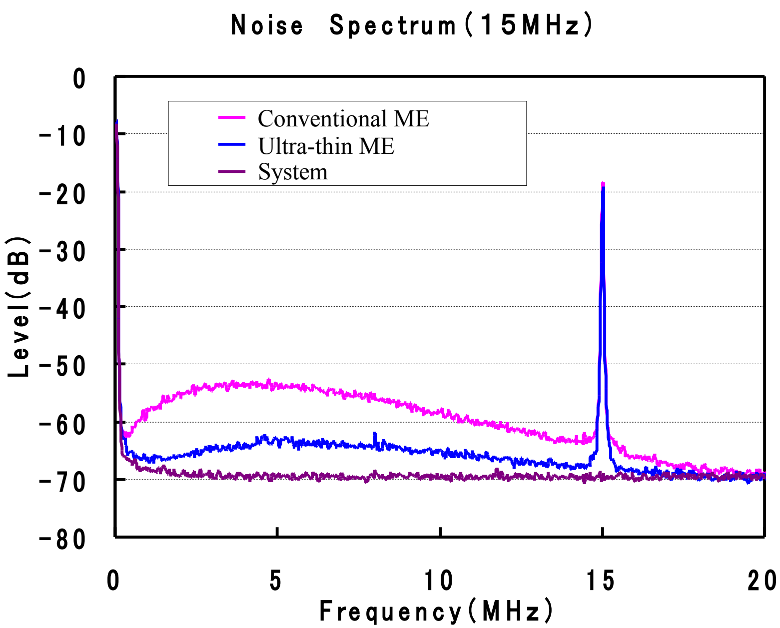
Key Devices for High Recording Density

High Sensitivity Head



Can not cover with protective layer.
(Head wear)

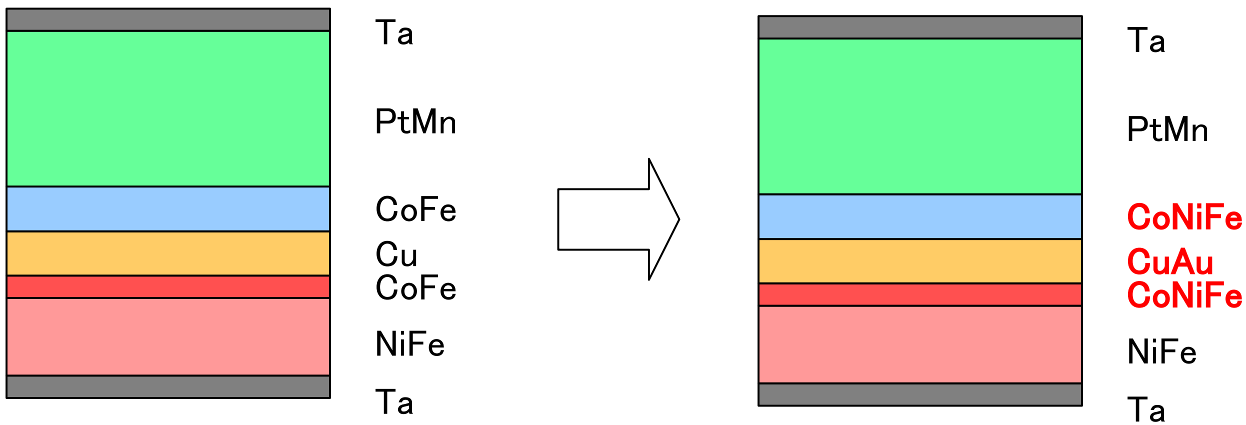
Low Noise Media



Magnetic layer must be thinner.

Need to improve corrosion resistance.

Corrosion resistant spin-valve head

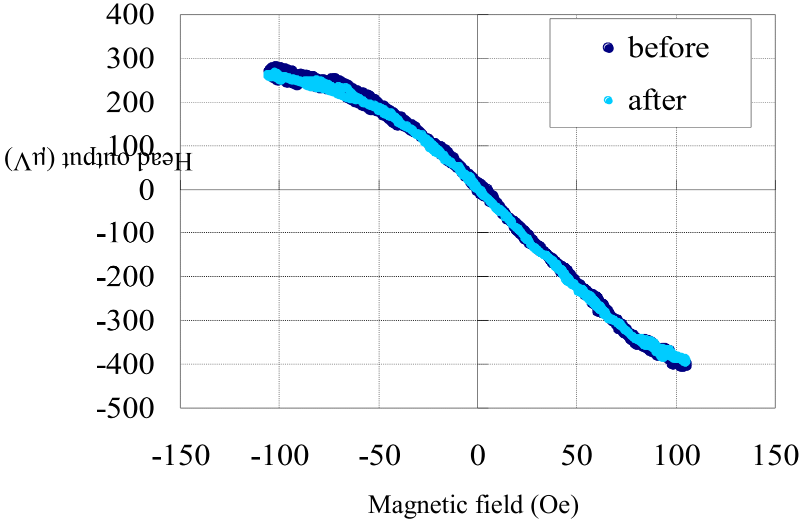


Battelle Class 2 test

Temperature	30 (degree C)
Humidity	70 (%)
H_2S gas	0.01 (ppm)
Cl_2 gas	0.01 (ppm)
NO_2 gas	0.2 (ppm)
Test time	20 days

= 10 years in office

Transfer Curves of the spin-valve head

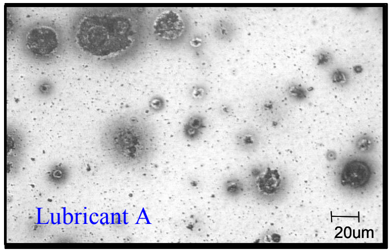


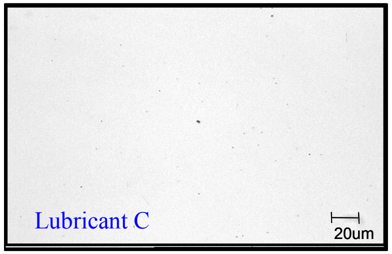
Ultra-thin ME tape with new lubricant

Test sample

Magnetic layer	33 (nm)
DLC Protective layer	10 (nm)
Lubricant A	No carboxyl group
Lubricant C	With 2 carboxyl group

Surface image of Tested samples



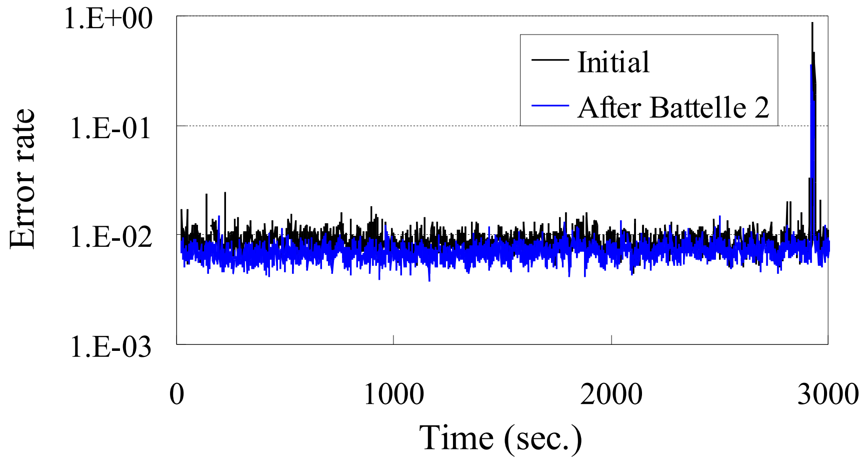


Battelle Class 2 test

Temperature	30 (degree C)
Humidity	70 (%)
H_2S gas	0.01 (ppm)
Cl_2 gas	0.01 (ppm)
NO_2 gas	0.2 (ppm)
Test time	100 days

= 50 years in office

Error rate of the sample C



Conclusion

✓Multi-channel stack heads and NANT were developed for narrow track helical scan tape system.

✓Corrosion resistant spin-valve element were developed.

✓New lubricant were developed for ultra-thin metal evaporated tape.

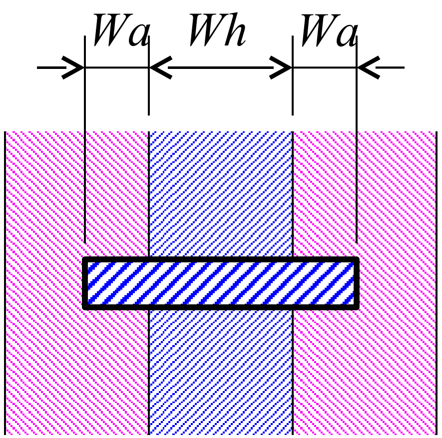
✓Prototype drive was created with minimum Tp=1.5μm.

Backup

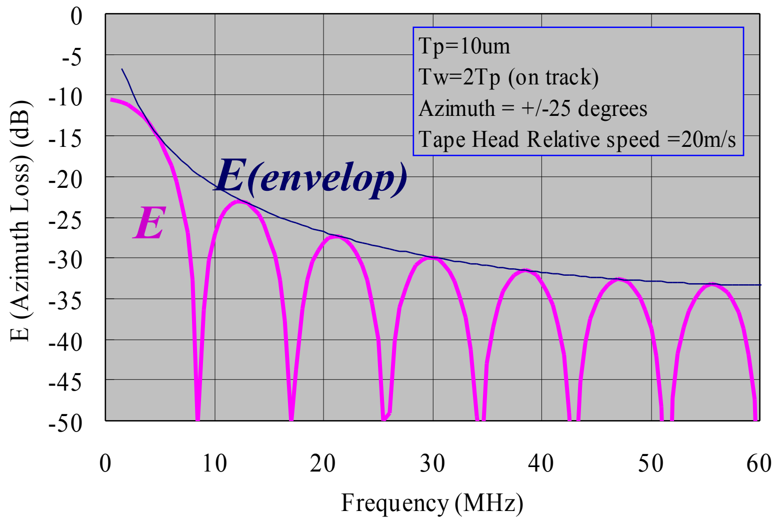
-

Azimuth Loss Effect

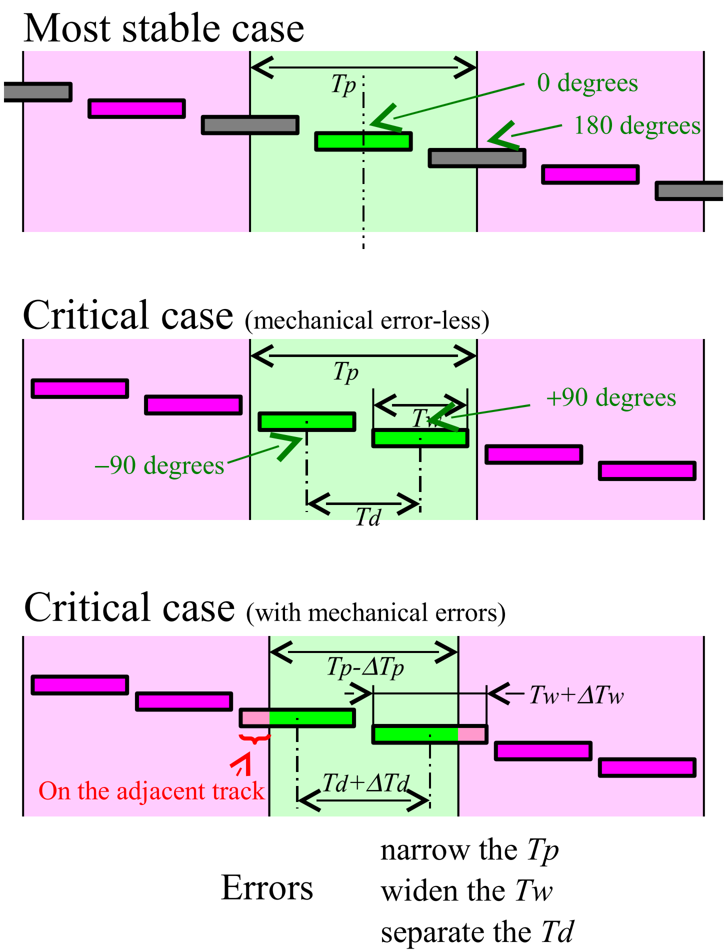
$$E = \frac{Wa}{Wh} \cdot \frac{\sin \dfrac{\pi G \cos 2\theta}{\lambda \cos \theta}}{\sin \dfrac{\pi G}{\lambda \cos \theta}} \cdot \frac{\sin \dfrac{2\pi Wa \tan \theta}{\lambda}}{\dfrac{2\pi Wa \tan \theta}{\lambda}}$$

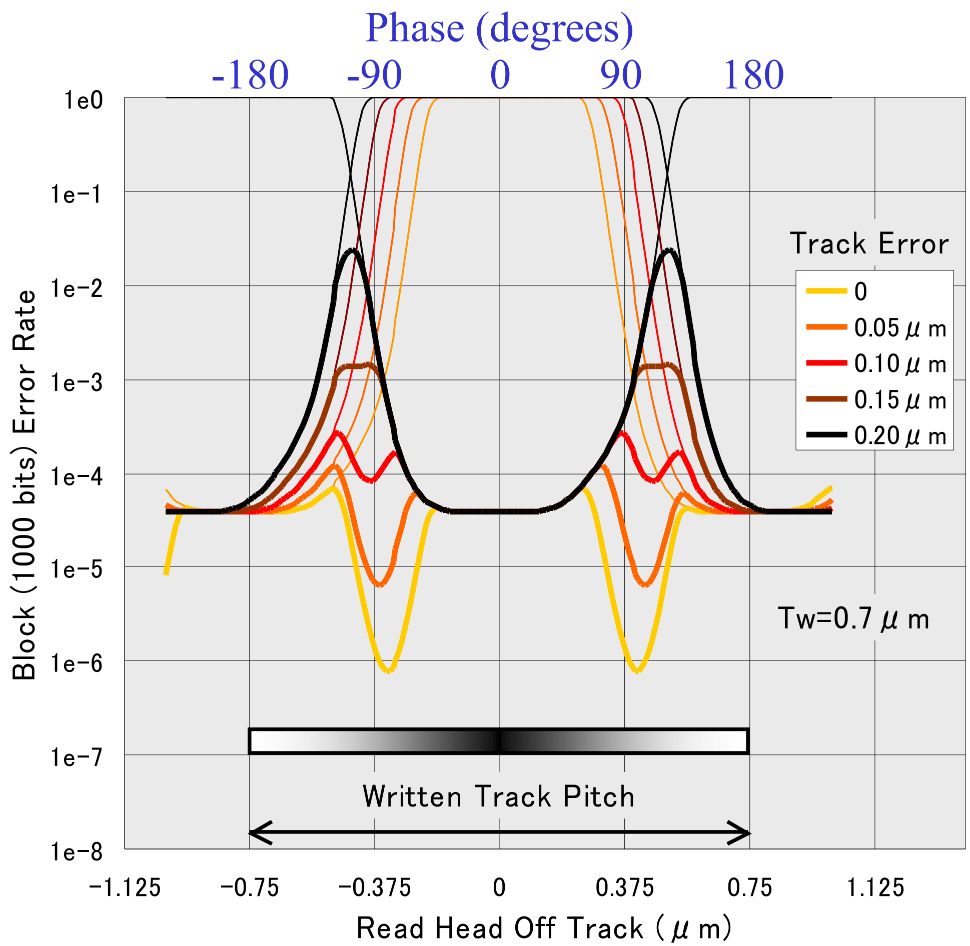


E: Signal from an adjacent track to home track ratio,
Wh: Home track width,
Wa: Head width on the adjacent track,
G: Head gap length,
λ: Write/read waveform period,
θ: Azimuth angle



NANT Error-rate vs Off-track Characteristics





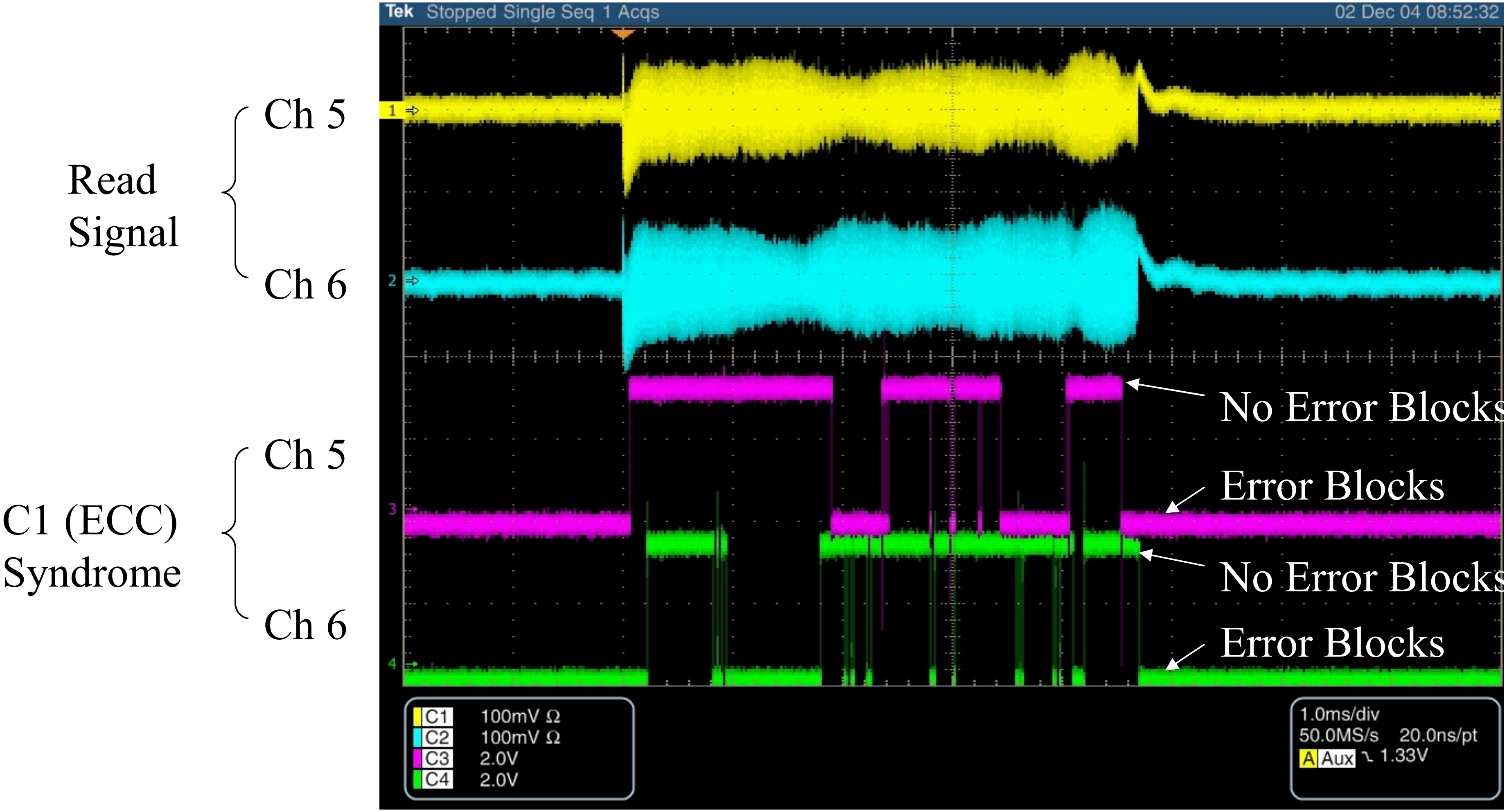
Track Error = $\Delta Tp + \Delta Tw + \Delta Td$ (definition)

Abandoning the Azimuth Recording

- We cannot count on the azimuth effect at the target track pitch of 1.5um.
- It is difficult to make a thin-film multi-channel write head with azimuth angle.
- Multi-channel stack write head has merit to reduce the influence of mechanical accuracy.

Good by and thank you azimuth recording we have employed for many years.

Read Signals and C1 Syndromes



Data Transfer Experiment

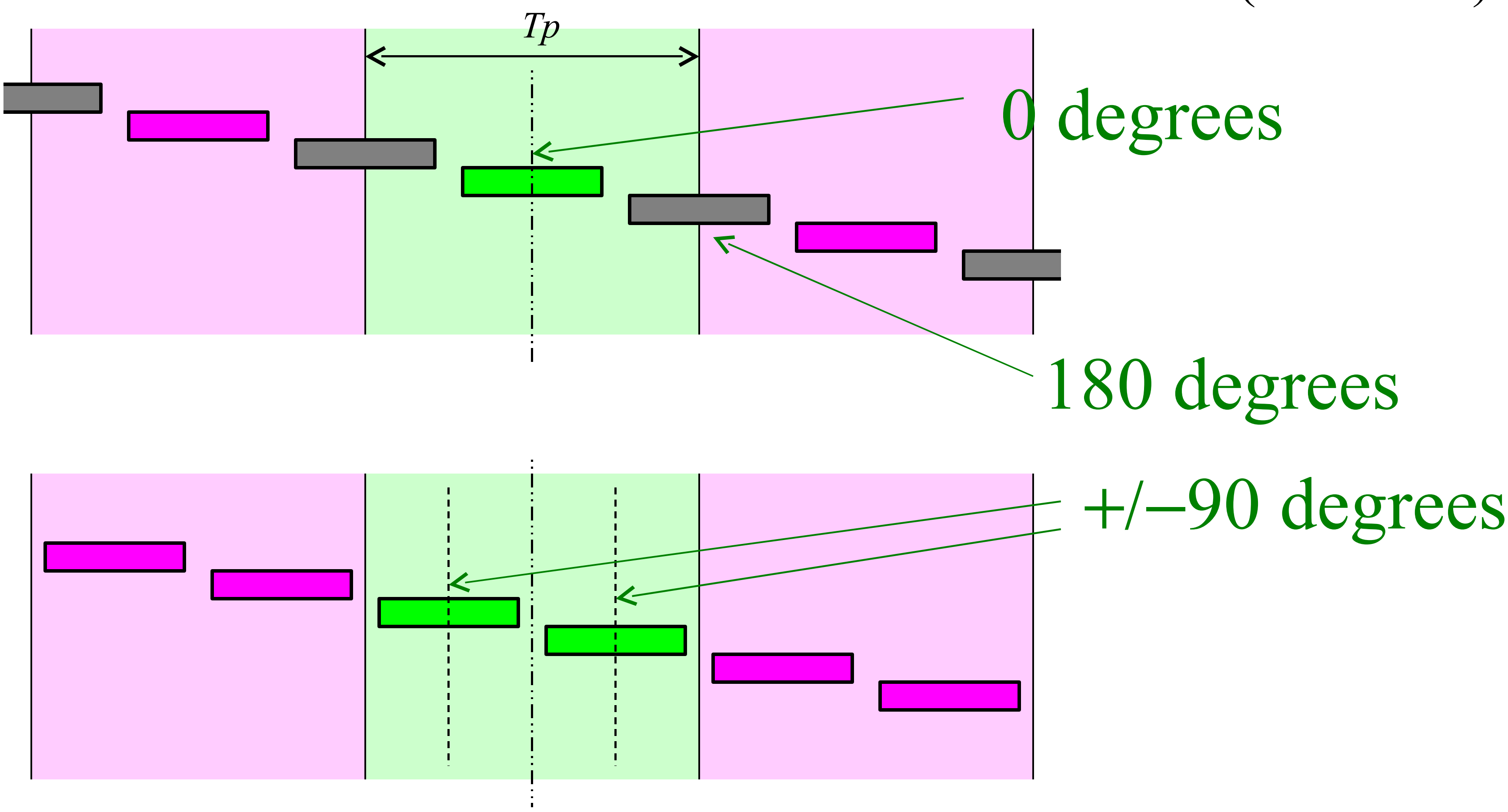
1. Recorded a file from PC to tape,
2. Reconstructed the recorded file from tape to PC,
3. Compared the reconstructed file to the original file. → same file!

* Recording transfer rate was 20MBps (160Mbps).

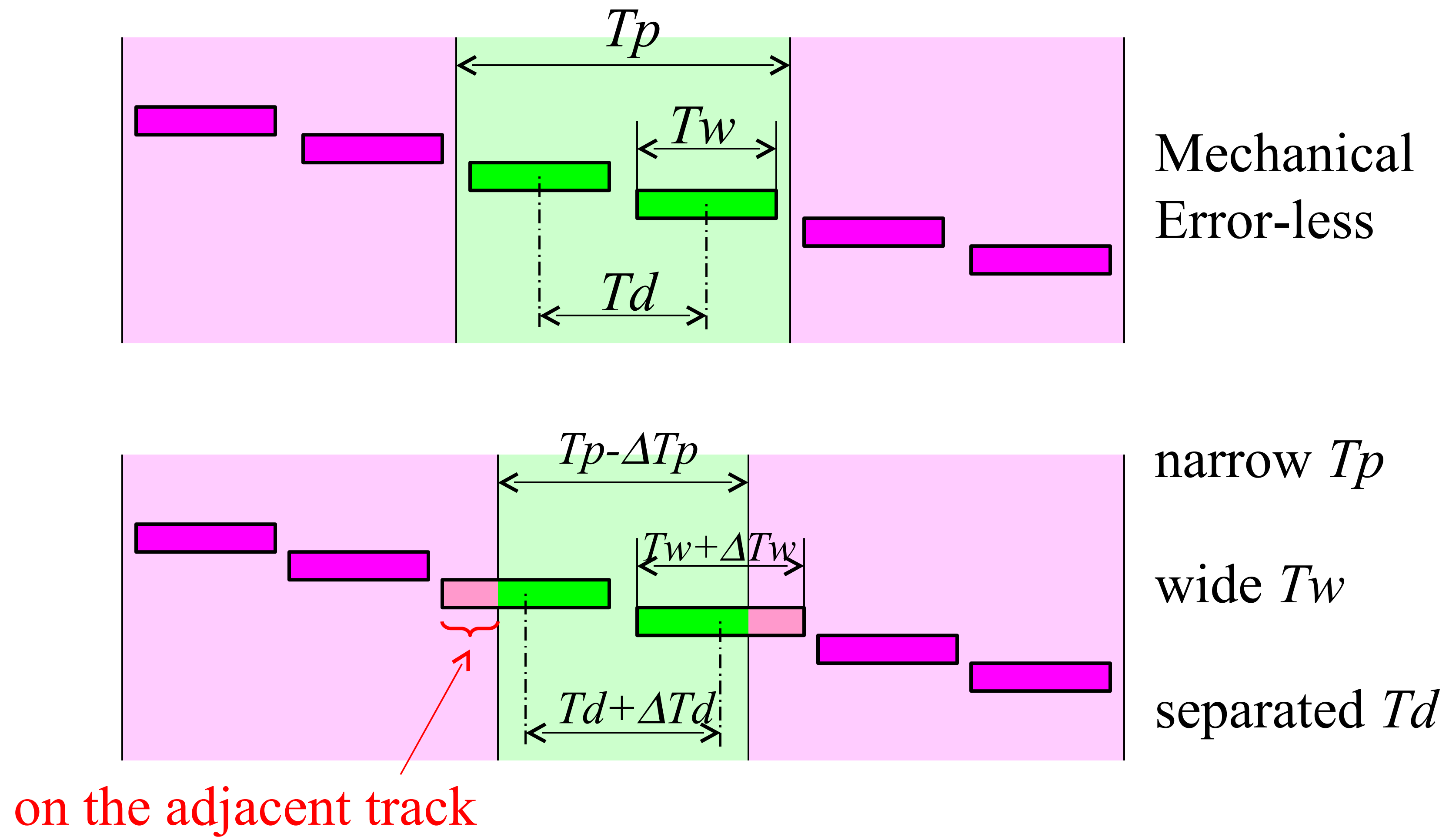
Contents

NANT Read Tracking Phase

(definition)

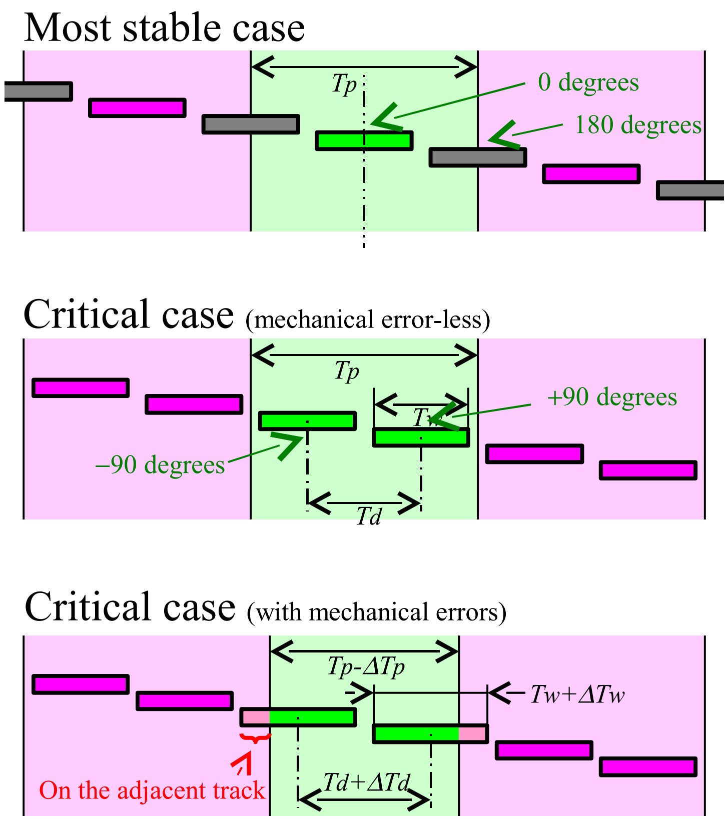


Critical Tracking Phase = +/−90 degrees



Track Error = $\Delta Tp + \Delta Tw + \Delta Td$ (definition)

Definition of track error



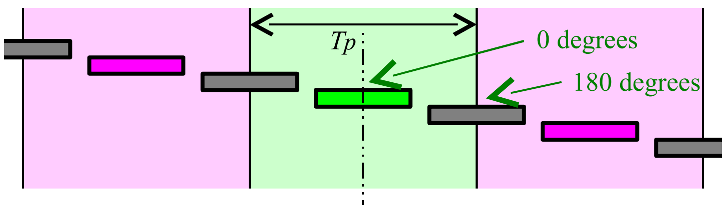
Errors
- narrow the *Tp*
- widen the *Tw*
- separate the *Td*

$$\text{Track Error} = \Delta Tp + \Delta Tw + \Delta Td$$

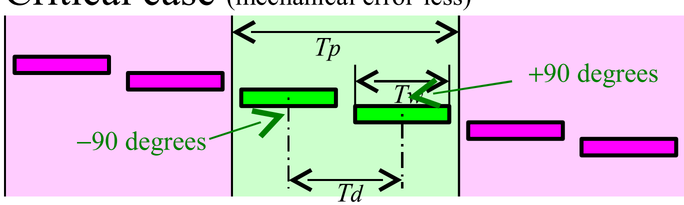
(definition)

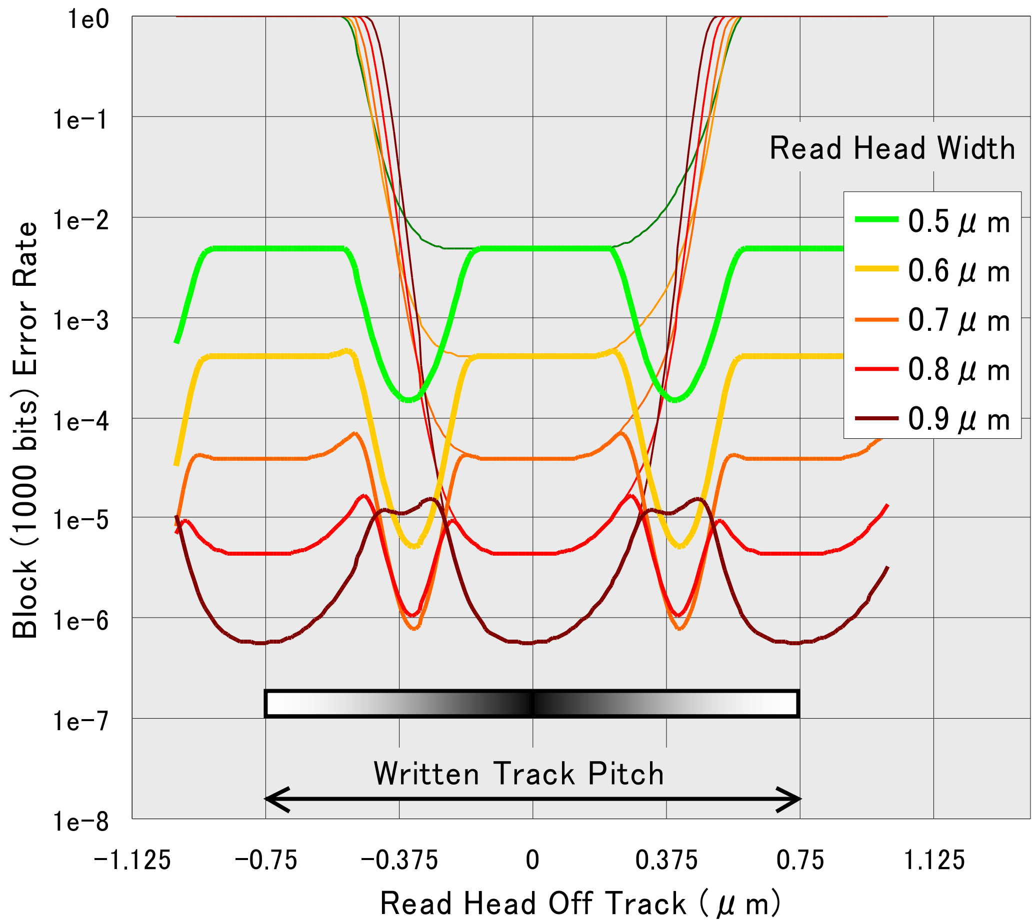
NANT Error-rate Off-track Characteristics

Most stable case



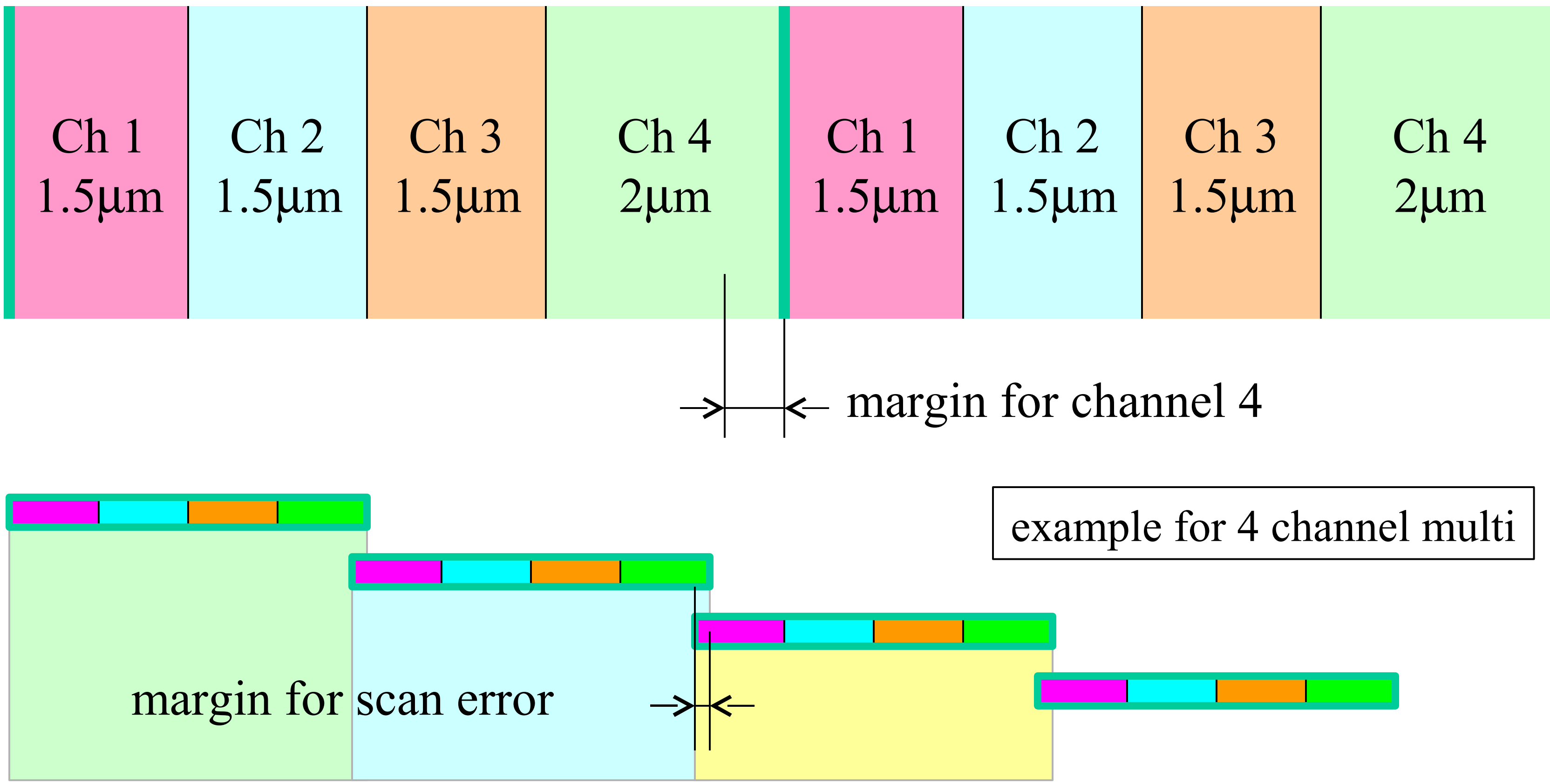
Critical case (mechanical error-less)





Compensation for Error between Scans

Recording Track Pattern

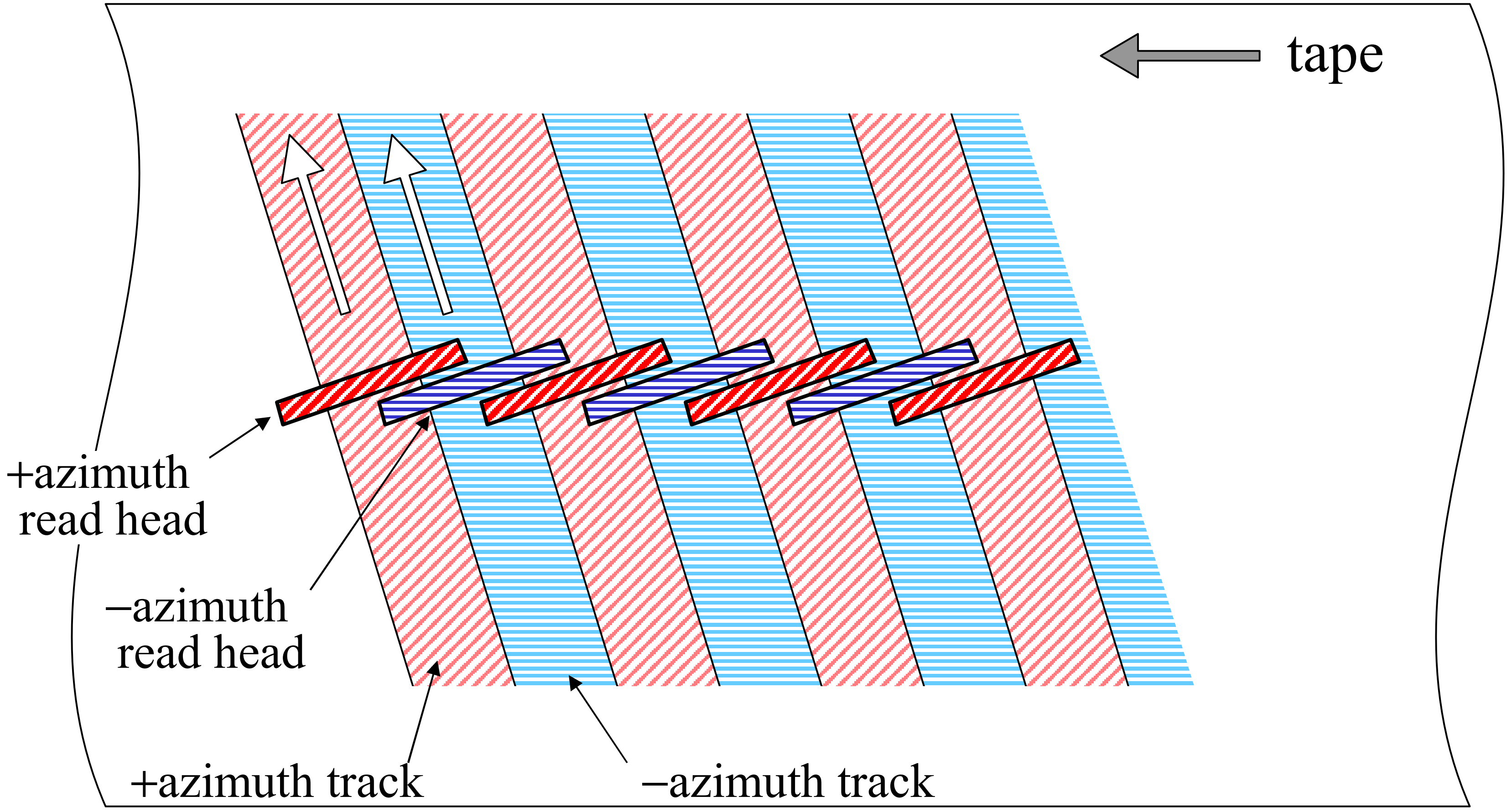


Read-head Scan-area Overlap

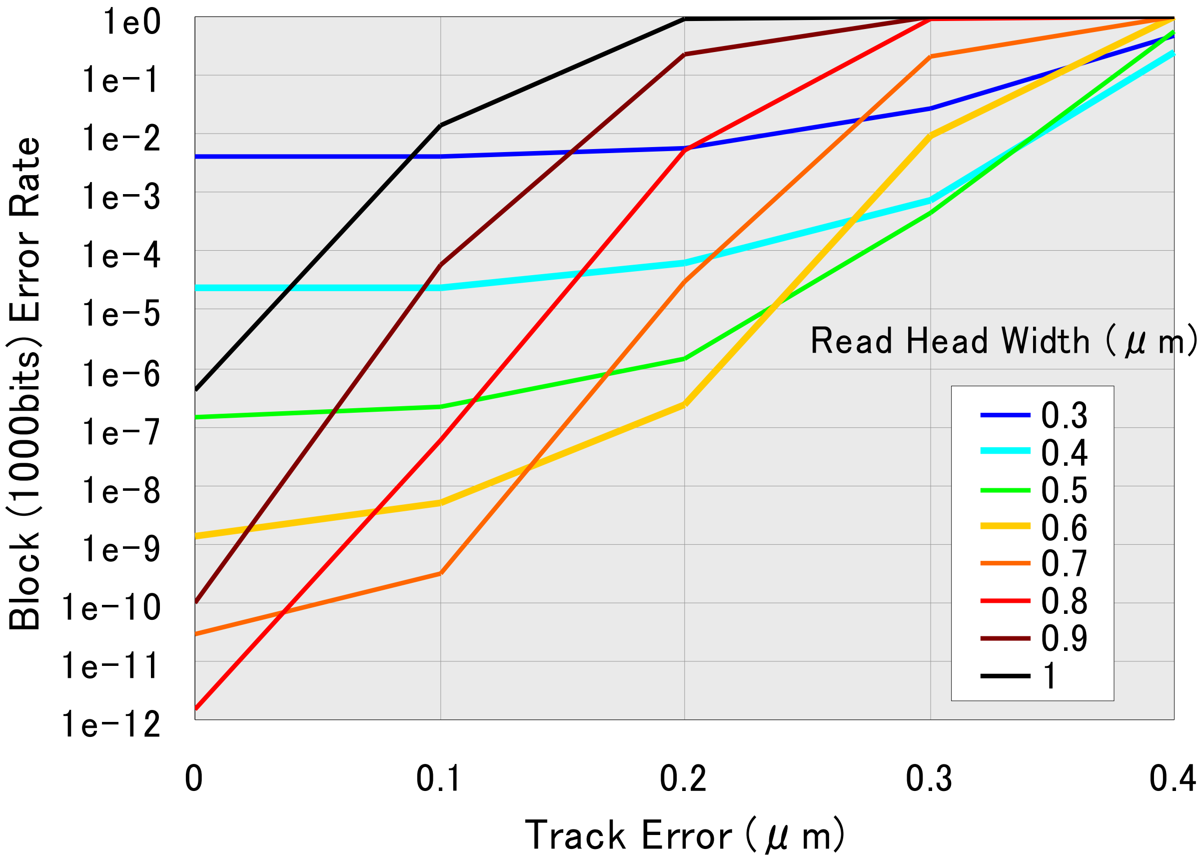
Recording Methods

	Tracking reading	Non-tracking reading
Azimuth recording	General helical scan systems	NT (audio), DAT walkman, Micro MV (video)
Non-azimuth recording	General magnetic recording systems (except helical scan)	Next generation for helical scan systems? (presents in this report)

Azimuth, Tracking



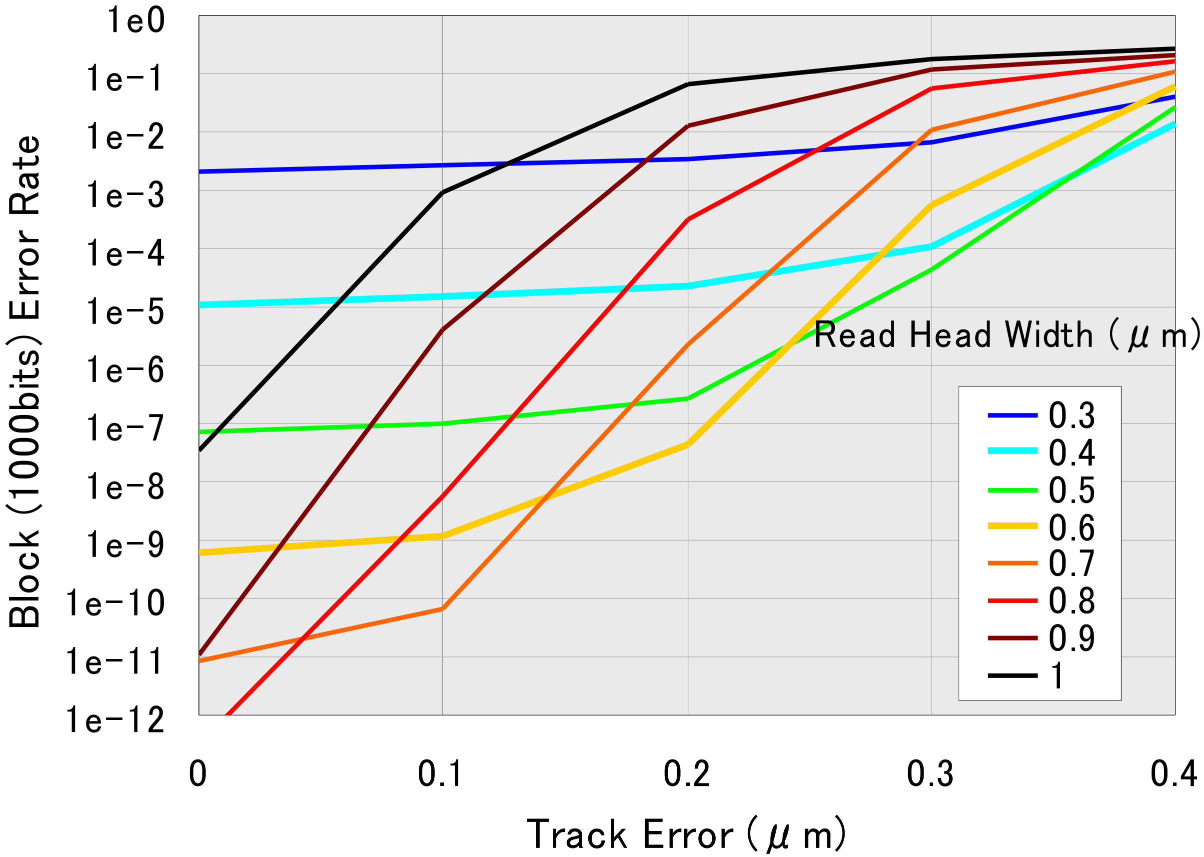
Worst-Phase Error Rate at SNR* of 20dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

Average Error Rate at SNR* of 20dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

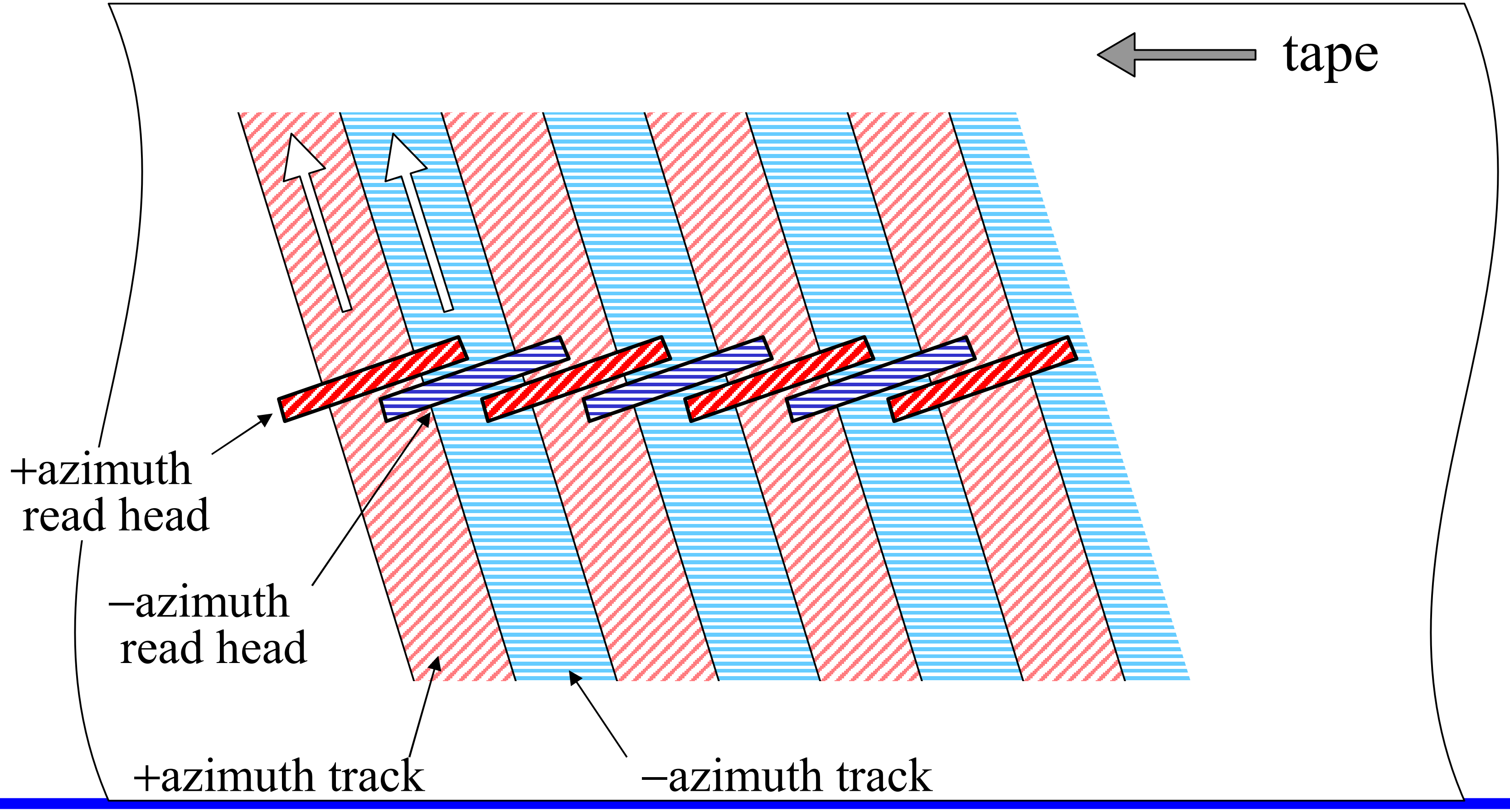
Progress of Track Density in Helical Scan

Format	DAT DDS	DDS2	DV	DDS3	AIT-1	AIT-2	DDS4	MMV	AIT-3	Prototype	unit
λ min	0.666	0.666	0.500	0.333	0.350	0.243	0.333	0.286	0.291	0.240	μ m
Track Pitch (Tp)	13.6	9.1	10.0	9.1	11.0	11.0	6.8	5.0	5.5	1.6	μ m
Tp/ λ min Ratio	20	14	20	27	31	45	20	17	19	6.7	
Equalize	Int	Int	PR4	PR1	PR1	PR1	PR1	PR4	EPR4	PR4	
Coding	8/10	8/10	24/25	8/10	8/10	16/20	8/10	24/27	16/18	24/27	
Azimuth Angle	±20	±20	±20	±20	±25	±25	±20	±25	±25	0	degrees

around 10μm (DAT DDS – AIT-2)   around 5μm (DDS4 – AIT-3)

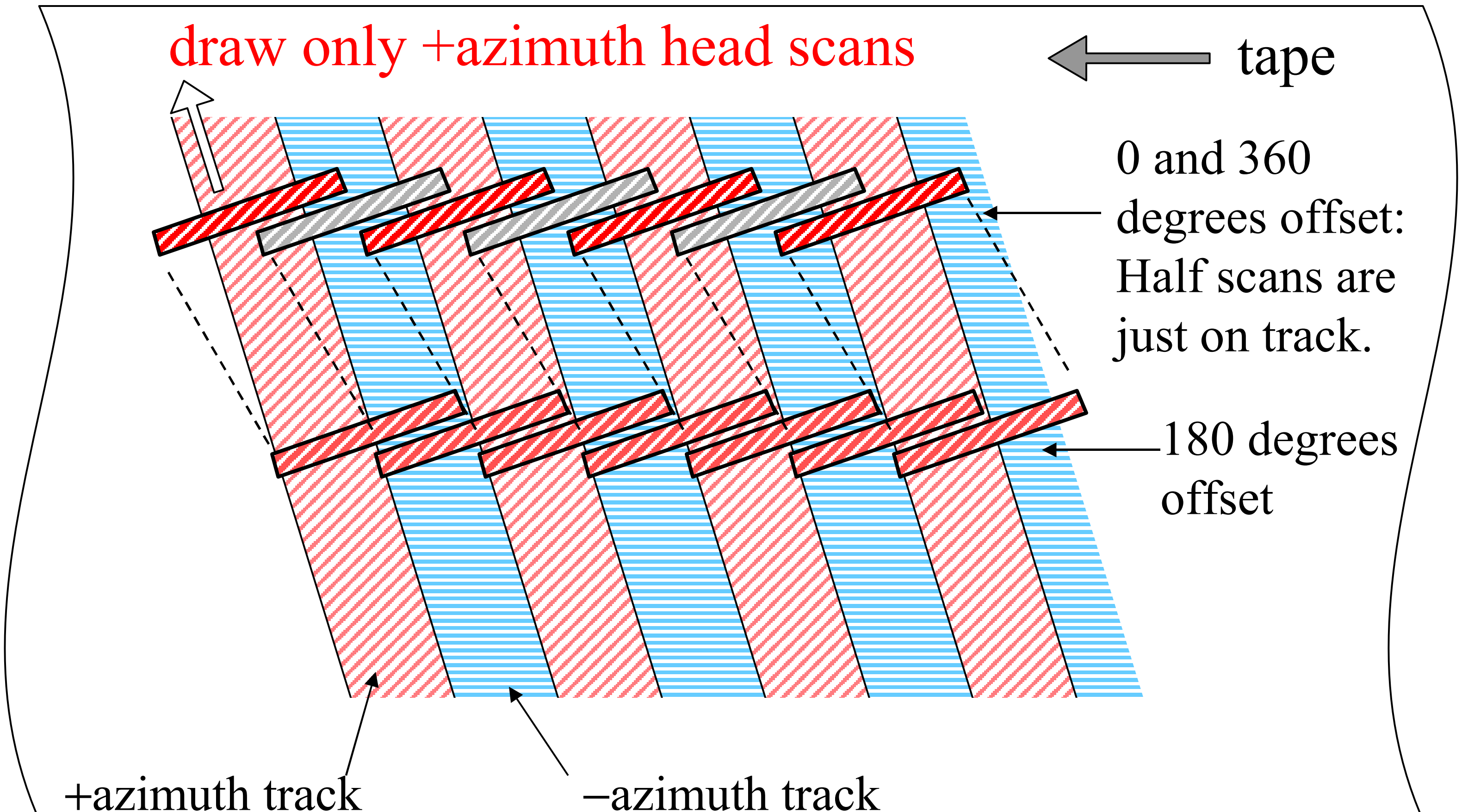
Azimuth, Tracking

1 scan per track, Tp << Tw < 2Tp
Maximum Tracking Margin = Tp/2



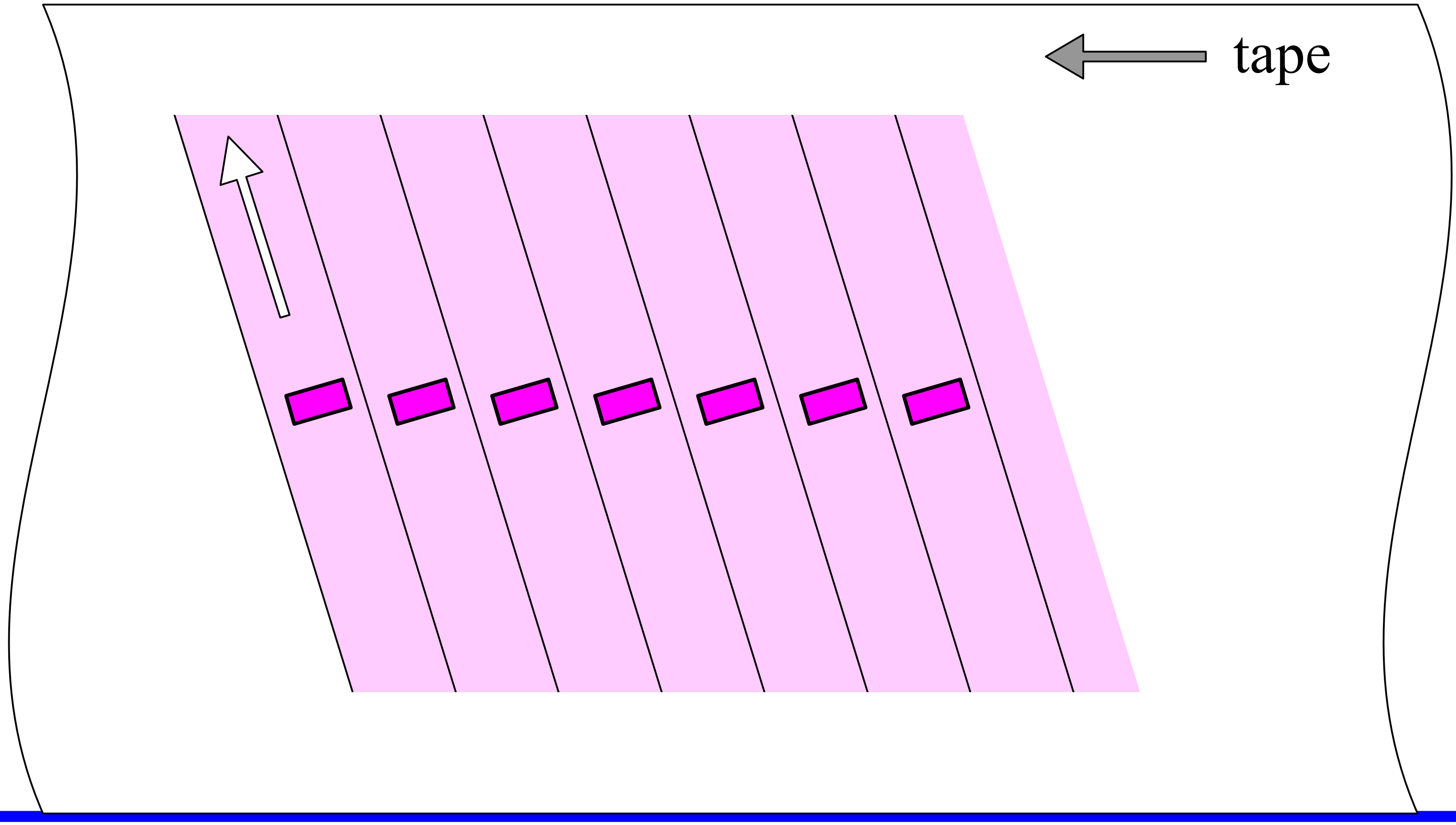
Azimuth, Non-tracking

2 scans per track, Tp << Tw < 2Tp



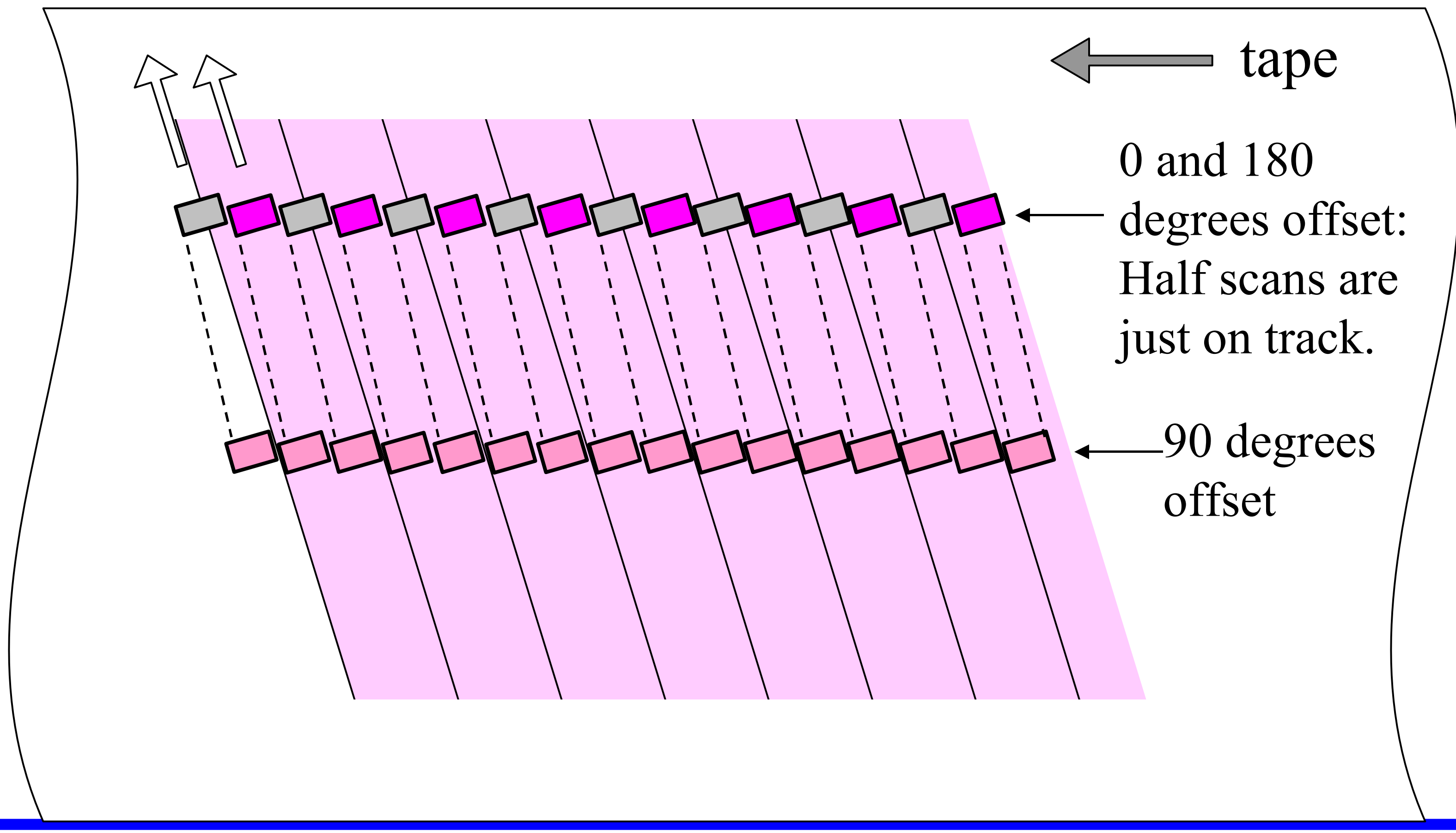
Non-azimuth, Tracking

1 scan per track, Tw << Tp
Maximum Tracking Margin = Tp/4

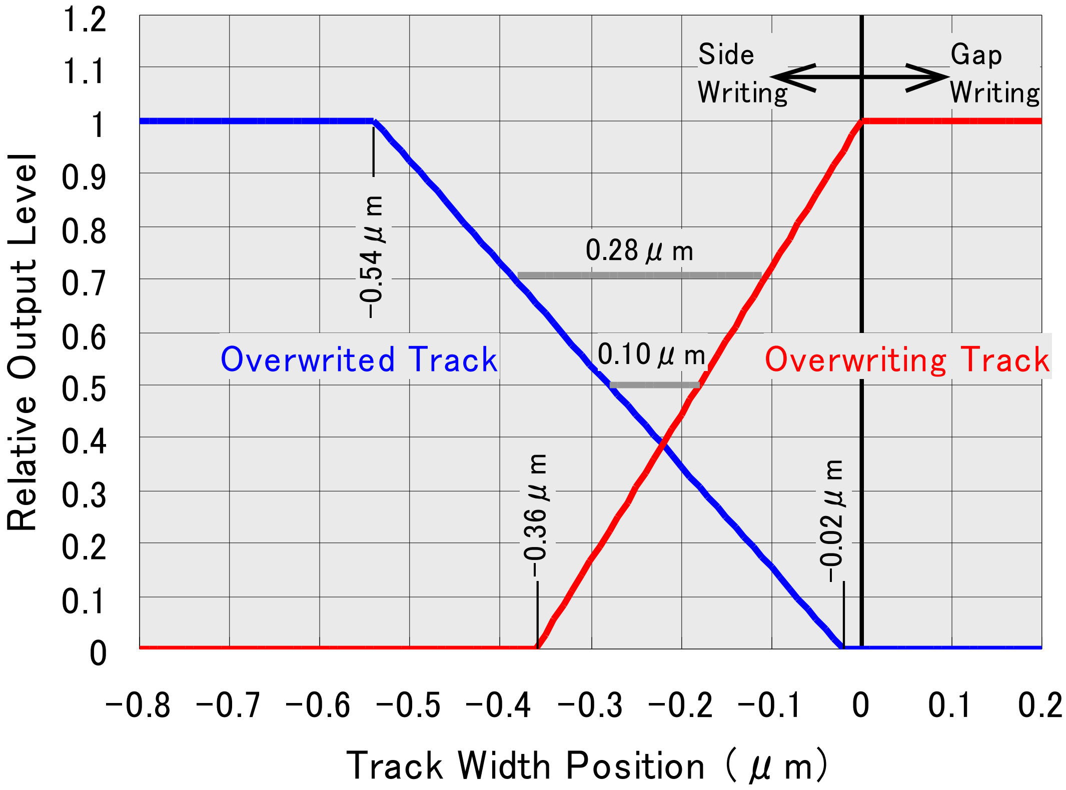


Non-azimuth, Non-tracking

2 scans per track, Tw < Tp/2



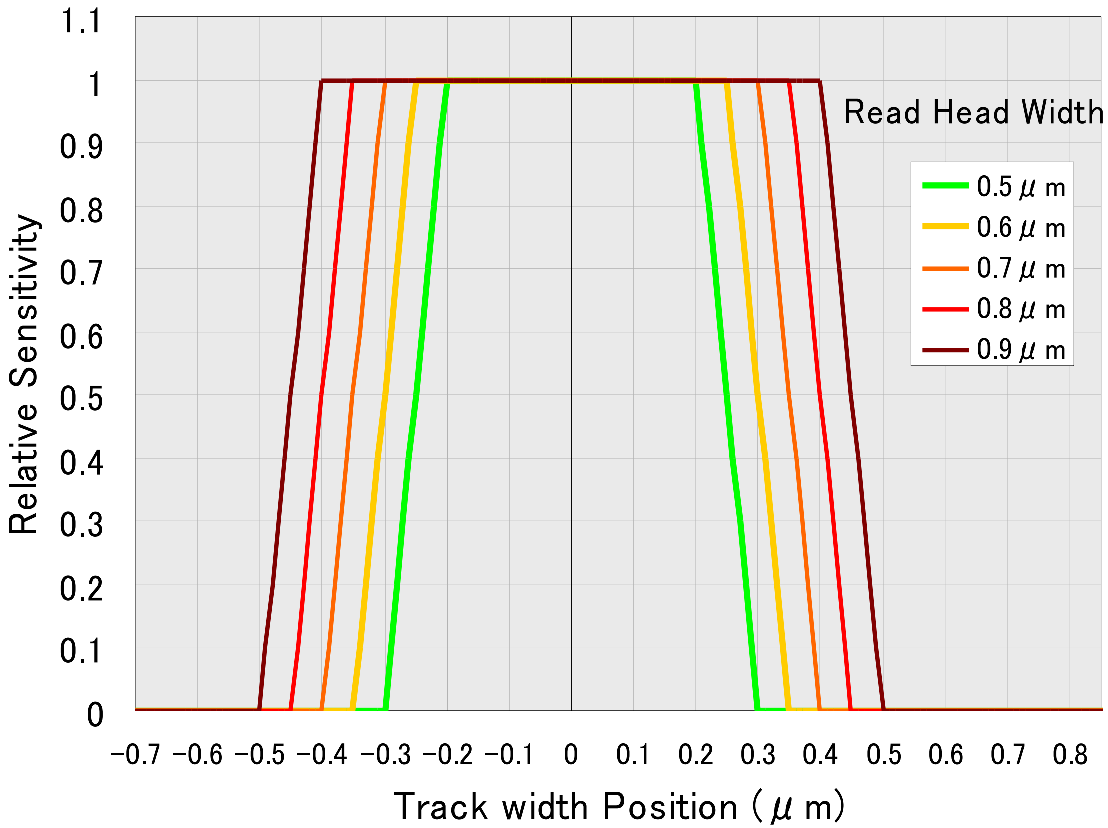
Output Model of Track on Tape



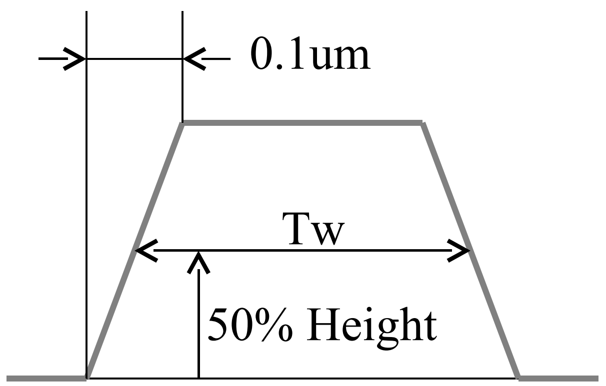
Between the tracks, there are erase bands written by fringing magnetic force from the edge of the write head.

These curves were obtained by analyzing the MFM data of actual tape patterns.

Sensitivity Model of Spin-valve Head

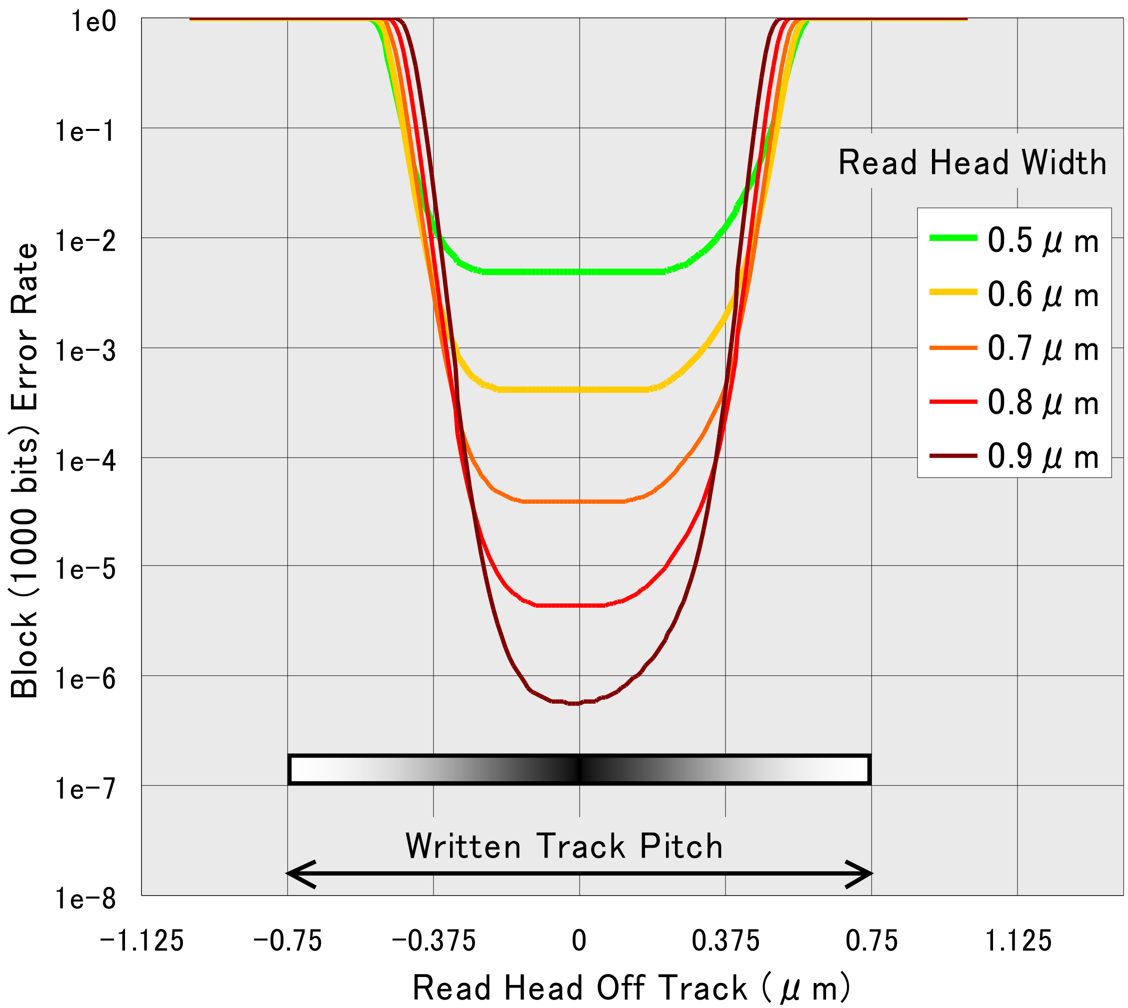


Tw: effective track width



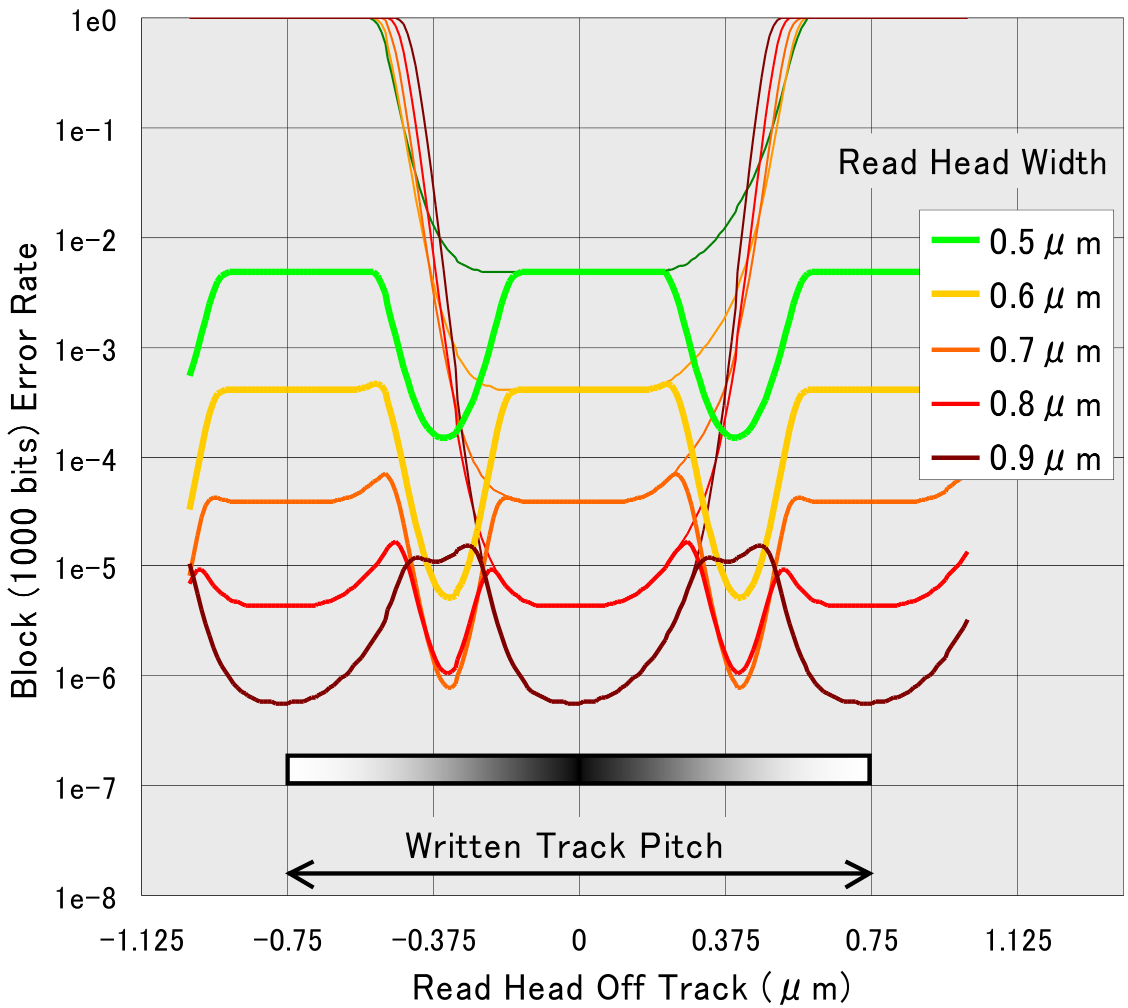
Inferred from track profile data. Those were read as recording tracks with width of 0.8µm and 2µm.

Error-rate Off-track Characteristics



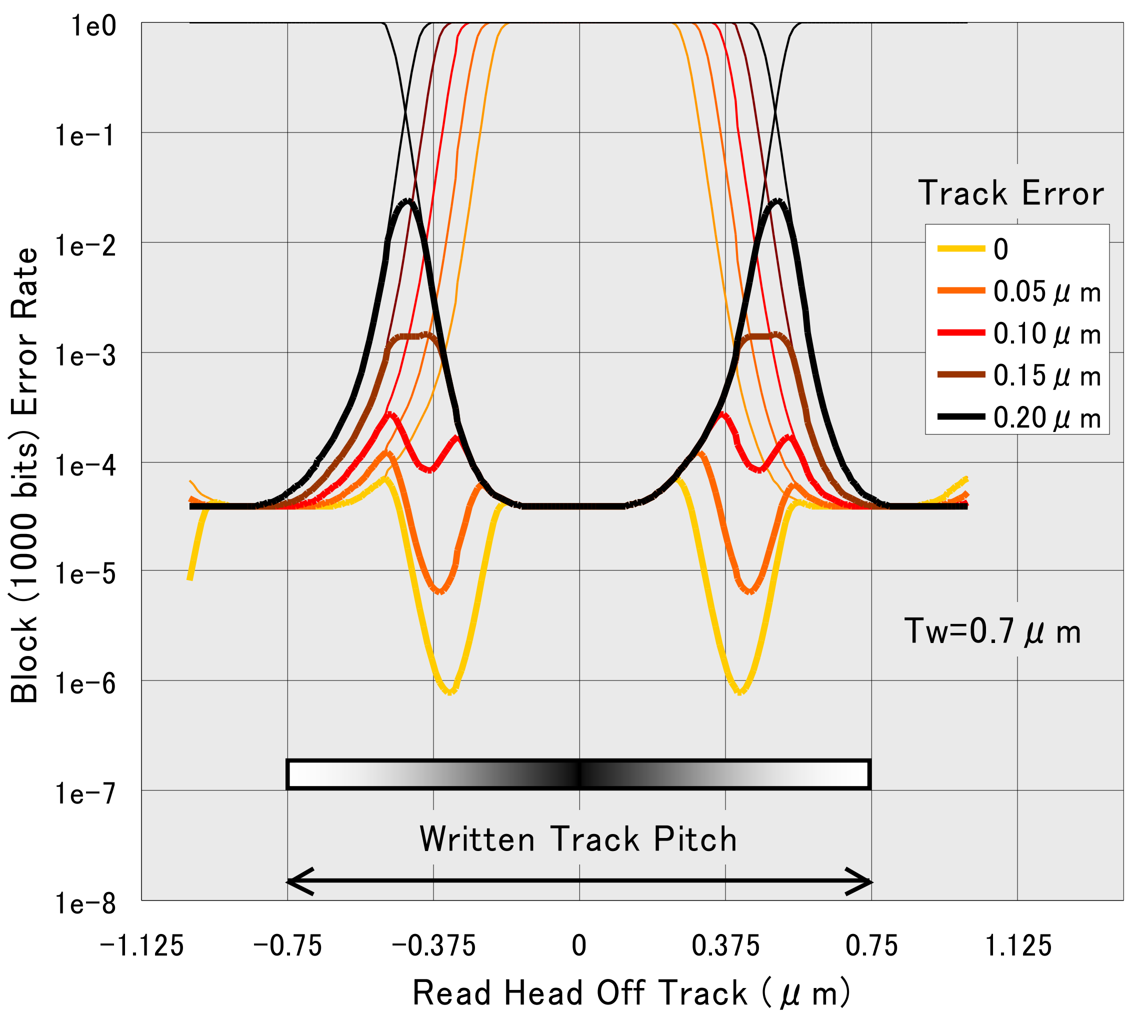
EQ:PR4
Coding:24/27
SNR:17dB

NANT Error-rate Off-track Characteristics



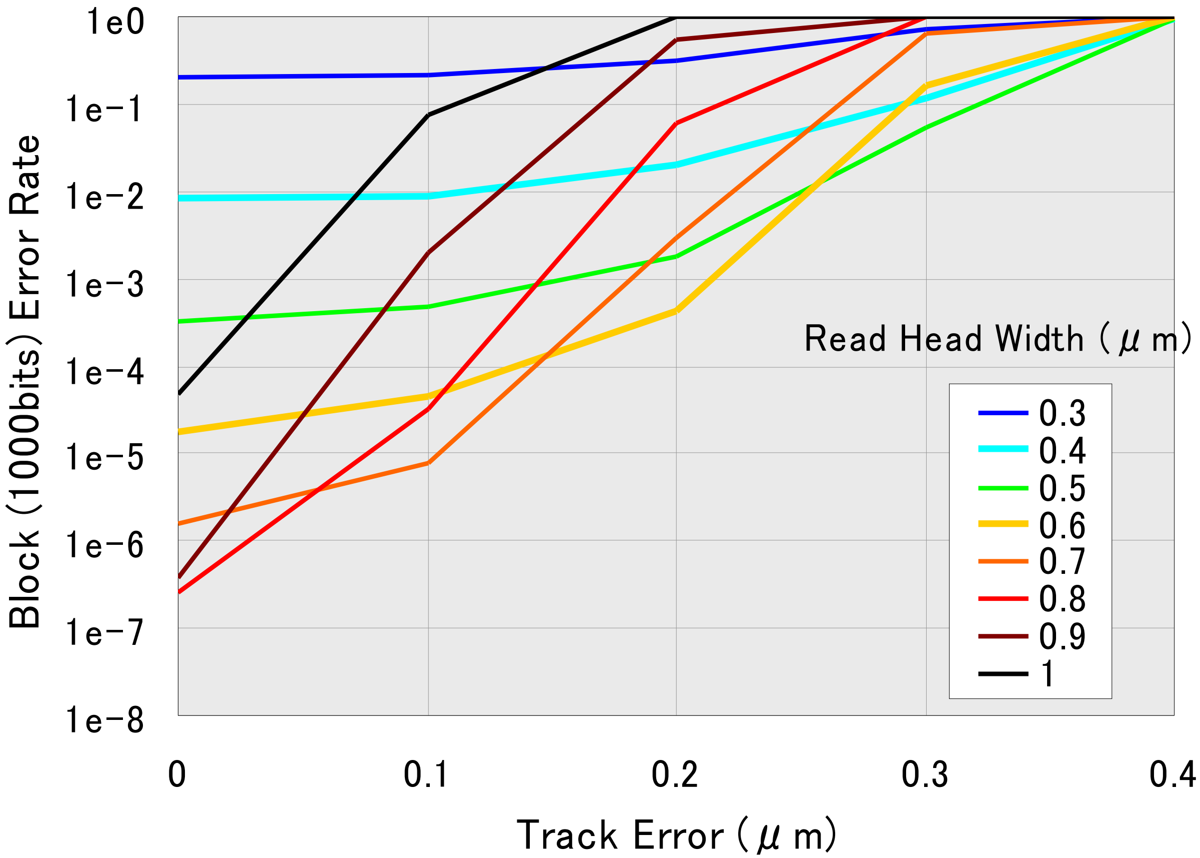
EQ:PR4
Coding:24/27
SNR:17dB

NANT Error-rate Track-error Characteristics



EQ:PR4
Coding:24/27
SNR:17dB
Tw=0.7µm

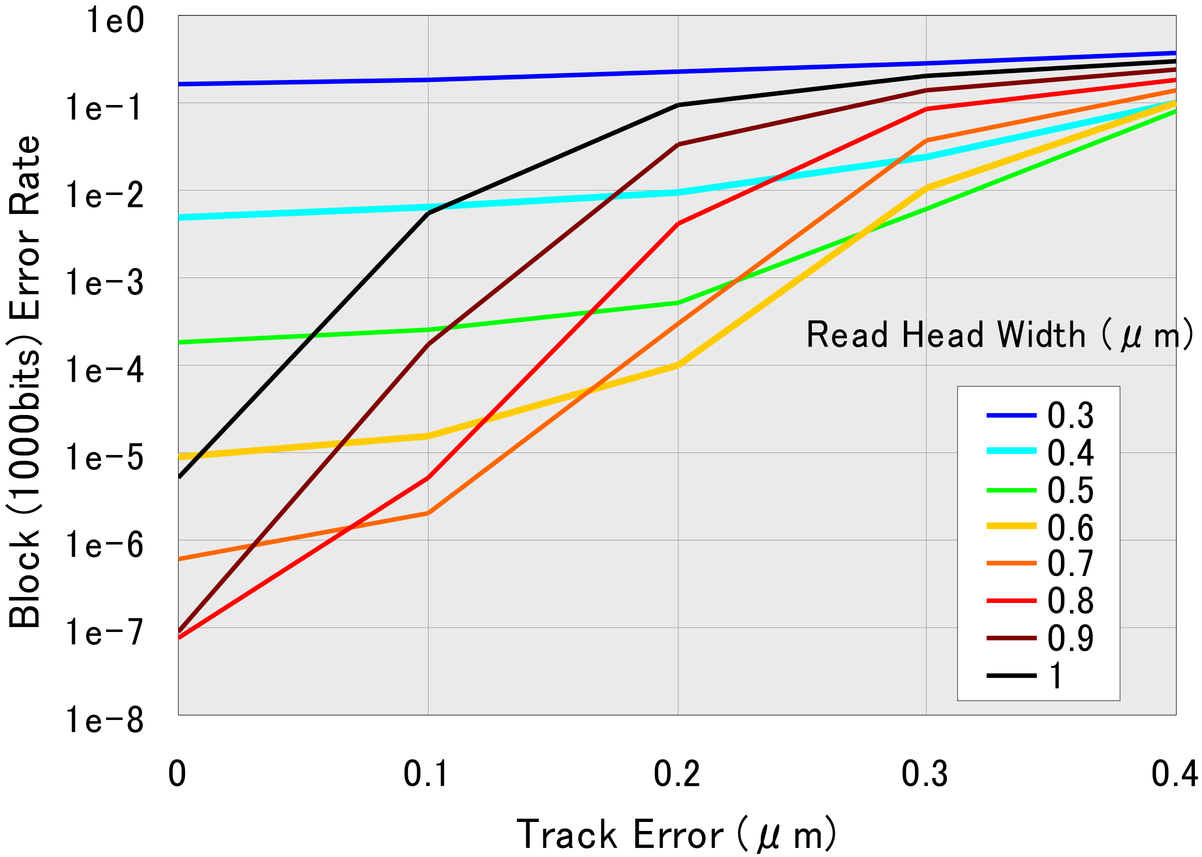
Worst-Phase Error Rate at SNR* of 18dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

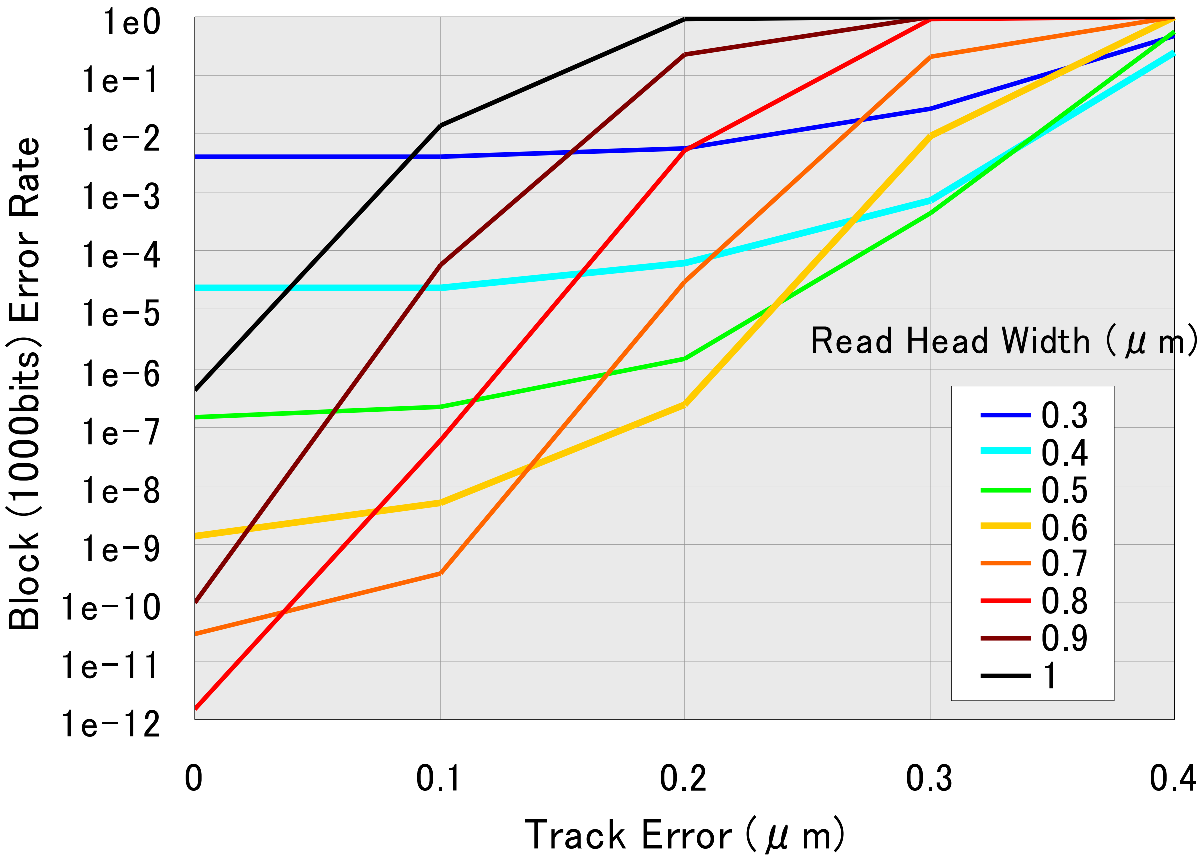
Average Error Rate at SNR* of 18dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

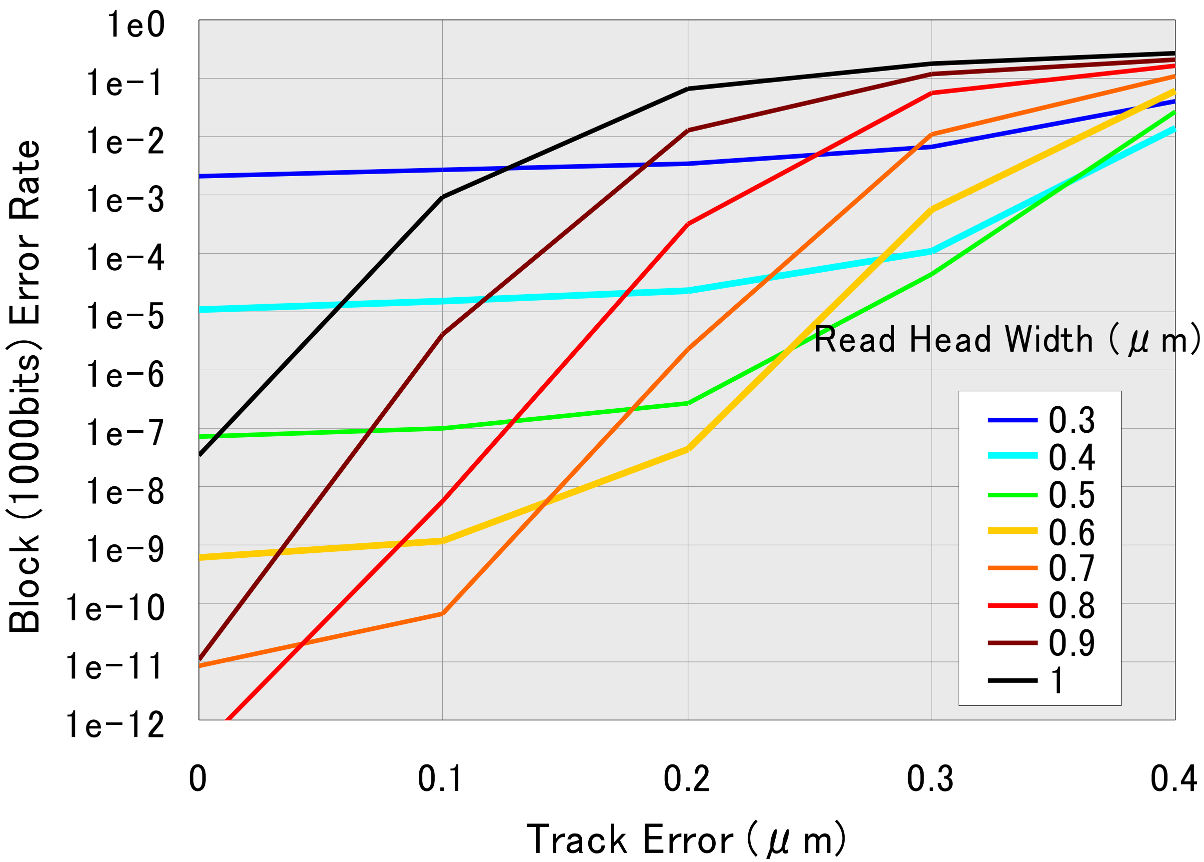
Worst-Phase Error Rate at SNR* of 20dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

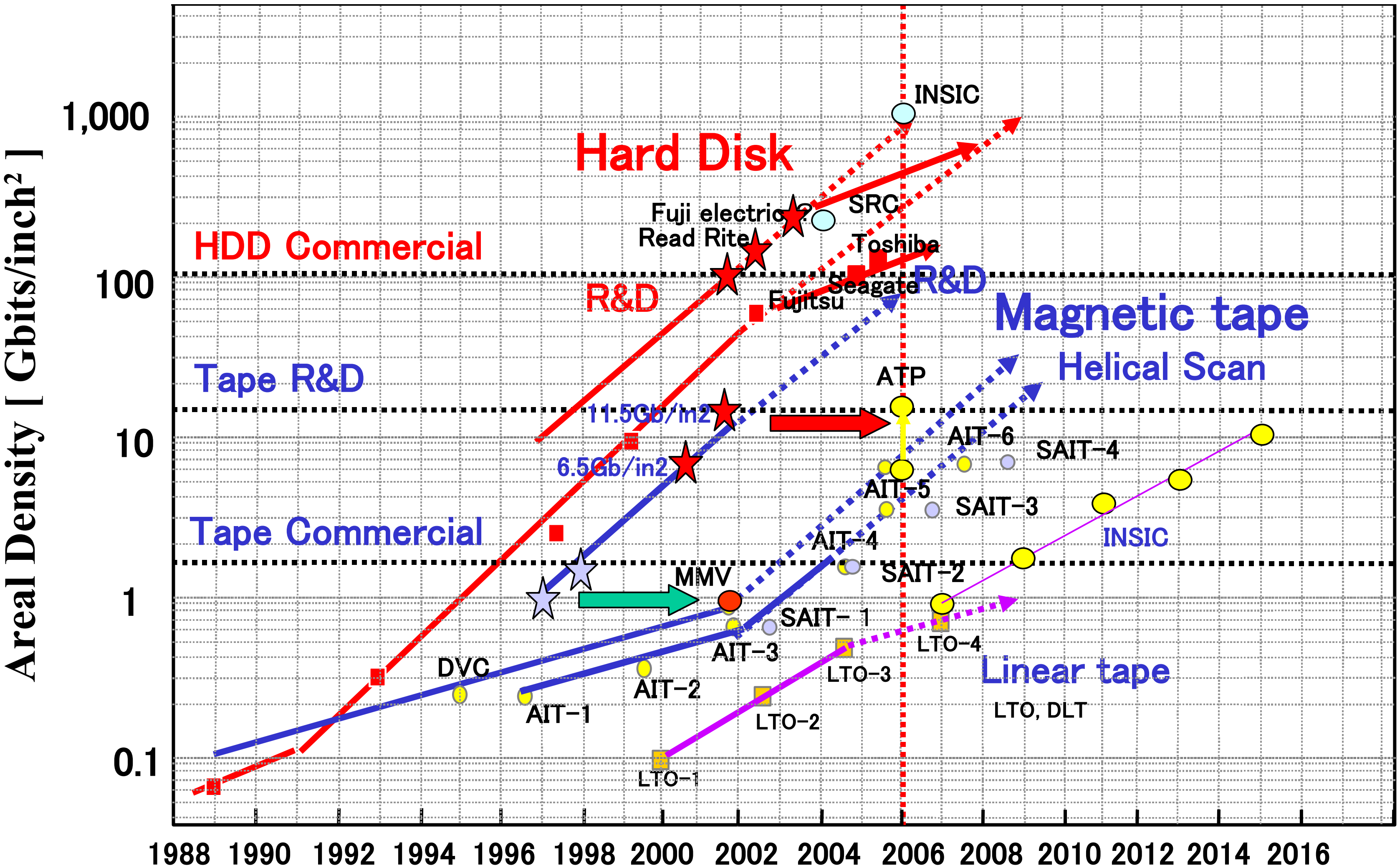
Average Error Rate at SNR* of 20dB



* SNR at center tracking using 0.7μm head

EQ:PR4
Coding:24/27

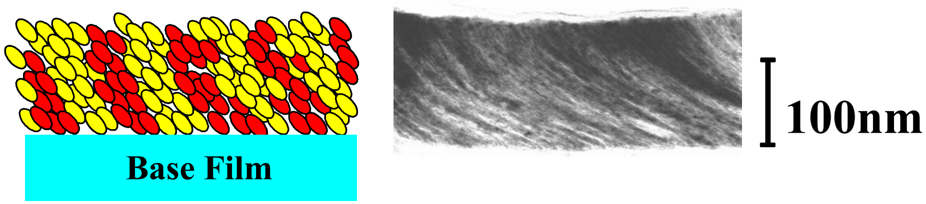
Trend and Prospect of Areal Density



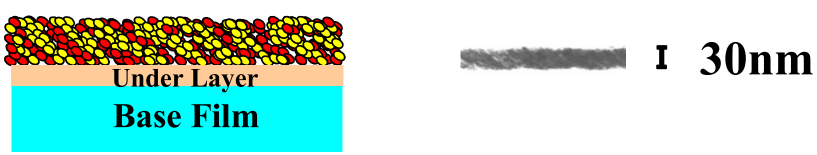
蒸着テープにおける記録密度向上

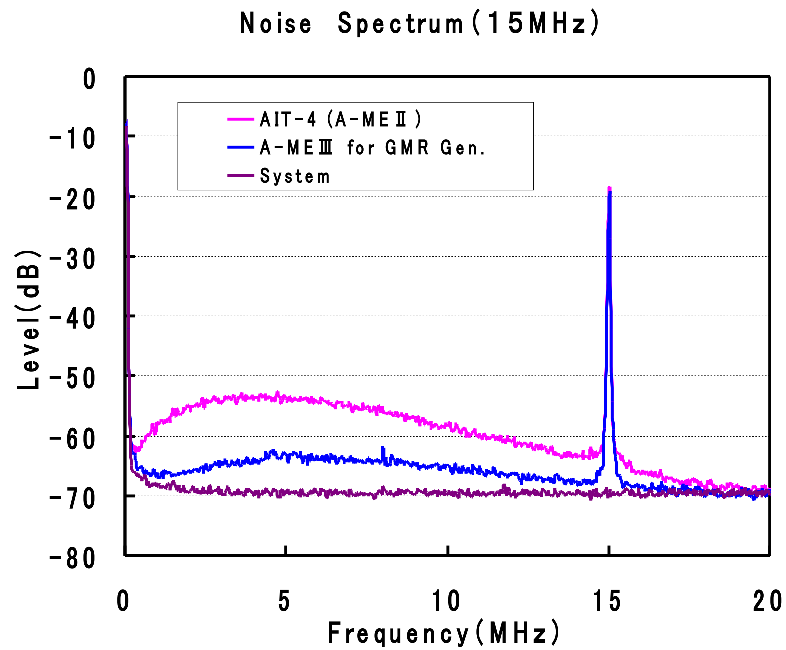
- Thinner Magnetic Layer
- Finer Magnetic Particle with Under Layer
- Smooth Surface

Conventional A-ME Ⅰ (DVC, AIT1~3)



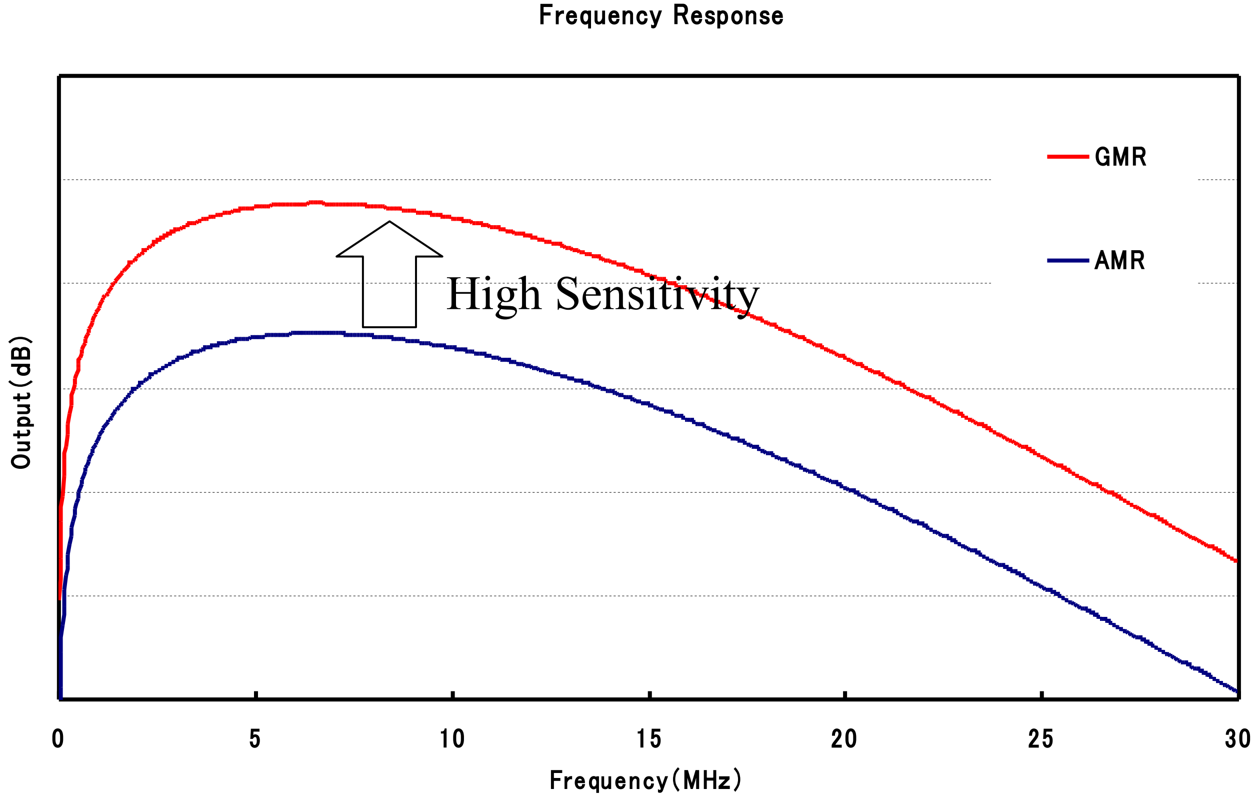
A-MEⅢ For GMR Generation





Co crystallites
CoO crystallites

High Sensitivity Read Heads for Tape System



V = 3.5m/s

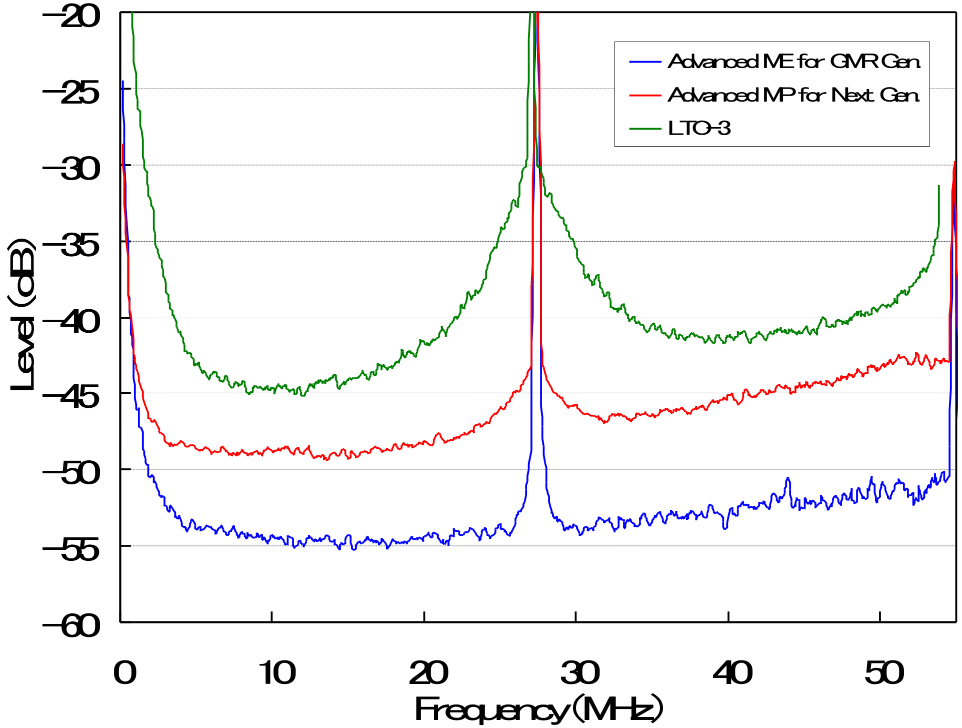
Anti-Corrosion GMR	+12.6dB
AMR	0dB

Difficult to use conventional GMR in Tape Systems

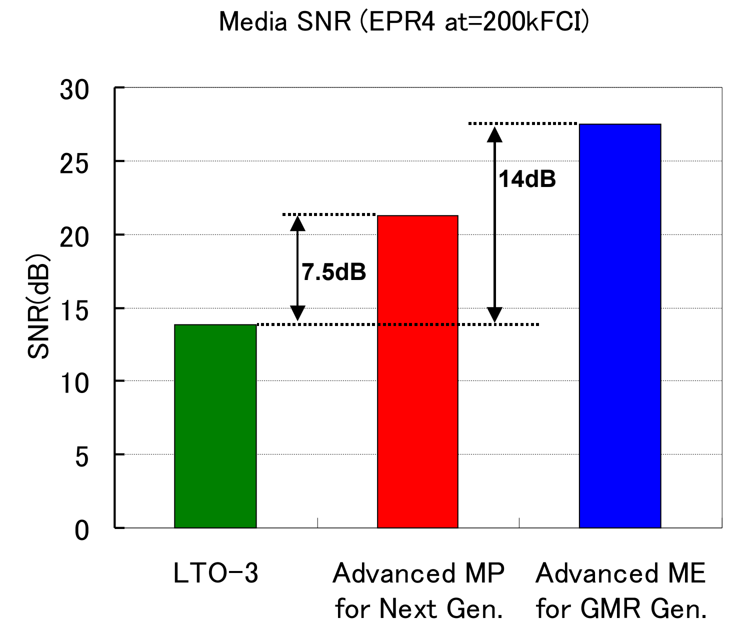
(Corrosion of GMR Element)

⇨ ✓Anti-Corrosion GMR Element

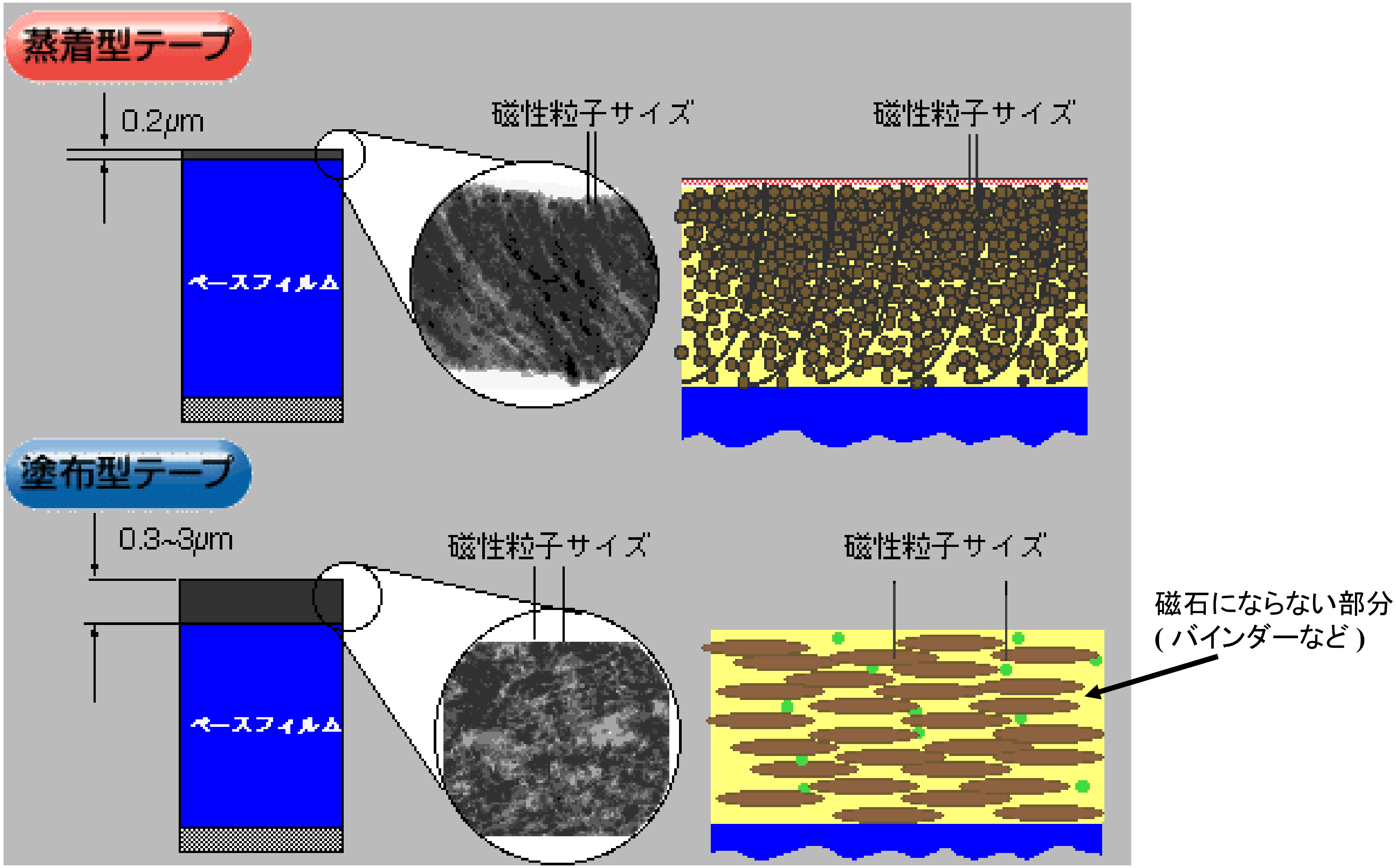
High Performance Magnetic Tapes



Read Head : Tw=0.8μm, Shield to shield=0.18μm, v=13.4m/s



テープの記録密度向上



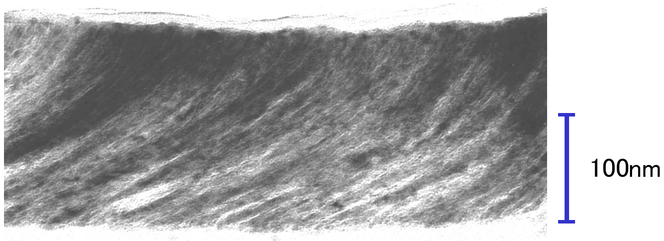
磁性粒子サイズ＆充填率 → 蒸着テープの方が高密度化に有利

Demonstration of 4.5Gbit/in^2 and 11.5Gbit/in^2

Properties of evaporated tapes (ME-1,ME-2)

	ME-1	ME-2
Remnant Magnetism	300 kA/m	221 kA/m
Thickness of Magnetic Layer	33 nm	28nm
Mrt	10mA	6.2mA
Coercive Force	116kA/m	102kA/m
Magnetic Layer	Co-CoO	

AME



AMEⅢ

Properties of spin valve heads (GMR-1, GMR-2)

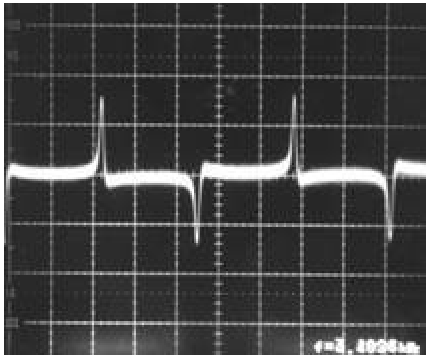
	GMR-1	GMR-2
Track Width	0.8um	0.45um
Distance between Shields	0.18um	0.12um
Stripe Height	0.8um	0.5um
Element Type	Spin Valve	

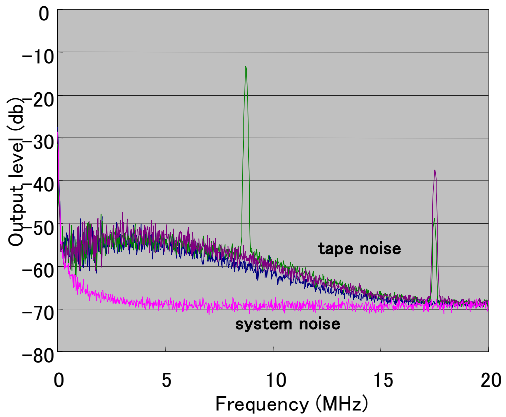
Demonstration of 4.5Gbit/in^2 and 11.5Gbit/in^2

□4.5Gb/in.^{2} （磁性層厚：33nm ）

22.2kTPI ； 203kBPI

2001/01 新聞発表

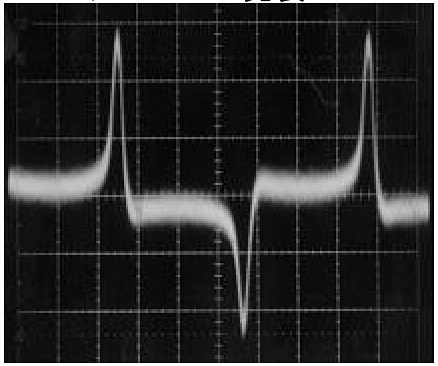


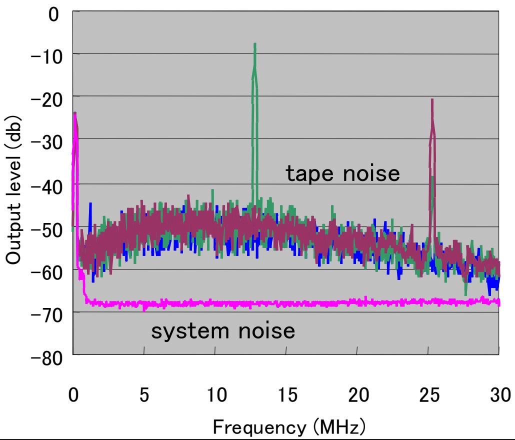


□11.5Gb/in.^{2} （磁性層厚：28nm ）

39.5kTPI ； 290kBPI

2001/08 TMRC 発表





磁気記録テープとして、

世界最高の記録密度を達成！

Isolated pulse of reproduced output signal

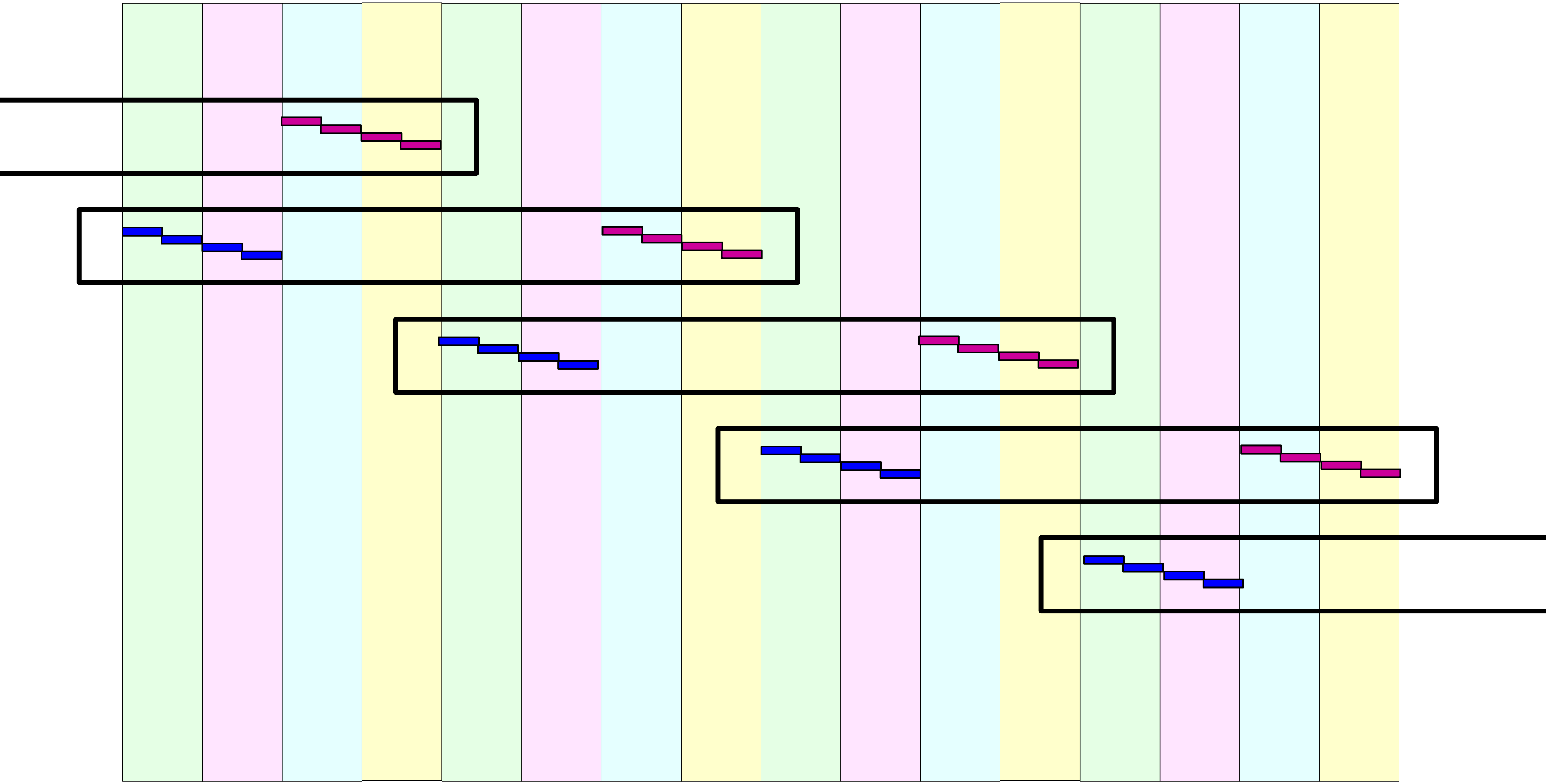
Spectra of signal and media noise

T.Ozue, M.Kondo, Y.Soda, S.Fukuda, S.Onodera and T.Kawana;"
11.5Gb/in2 Recording Using Spin-Valve Heads in Tape Systems,IEEE Trans. on Magn. Vol.38,No1,pp136-140(2002)

4.5Gbit/in² 、*11.5Gbit/in²* を適用すると．．．

	Inductive	GMR-1	GMR-2
Areal density(Gbit/in2)	0.7	4.5	11.5
Track Density(kTPI)	4.6	22.2	39.5
Linear density(kBPI)	155	203	290
Mrt of media(mA)	60	10	6
SNR(dB)	18	26	18
Capacity(AIT cassette)	100GB	640GB	1.6TB
Capacity(S-AIT cassette)	500GB	3.2TB	8.2TB

テラバイト / 巻　級の容量が可能



Dynamic Tracking

- To control head position during reading dynamically by using actuator.
- To enable to trace narrow track even when the track is not straight.