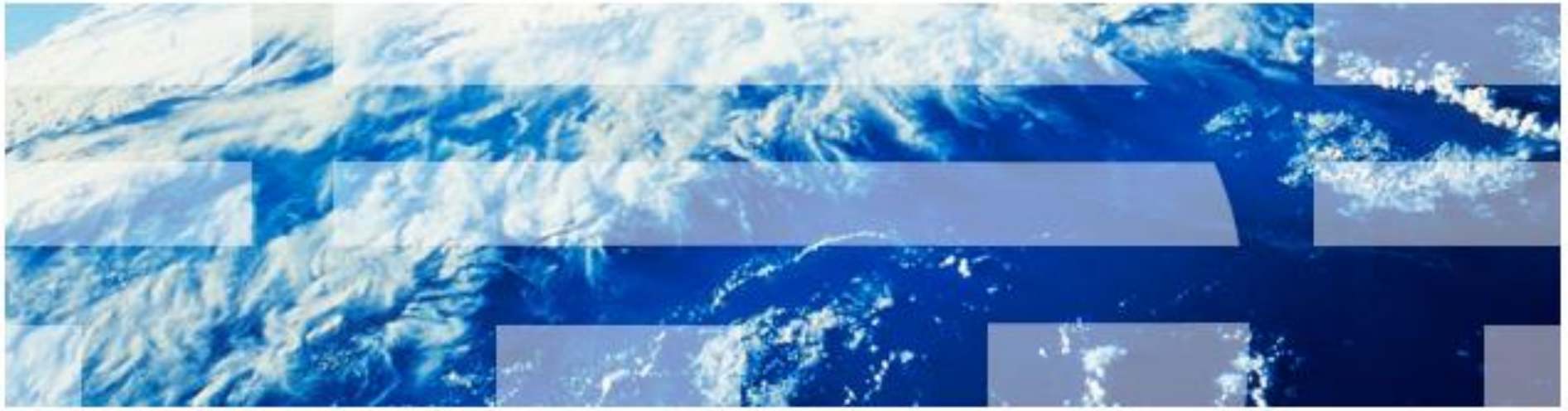
G. Decad, R. Fontana – IBM Systems
September 18, 2017

Tape Storage Roadmap for Cost Effective Cloud Backup and Archive



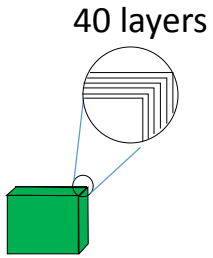
Tape Drive and Tape Cartridge Capacity Roadmaps

- AGENDA
  - The Tape Storage Bit Cell – The potential for areal density growth
  - Roadmaps
  - Tape Technology Development

- KEY POINTS
  - Tape Drive and Tape Cartridge Roadmaps continue to support capacity doubling (within the same form factor) or 2X in a 24 to 30 month cycle for 2+ generations
  - Conversely, HDD roadmaps support drive capacity doubling (within the same form factor) or 2X in a 48 month to 60 month cycle assuming continuation of 10% density increases and platter increases from 7 to 9.
  - Tape Roadmaps are sustained by investments in strong technology development efforts for readers, writers, tracking, and media.

The Bit Cell Environment Today

NAND 3D TLC
40 layers
3 bit/cell
84 nm x 84 nm
3000 Gbit/in ^{2}

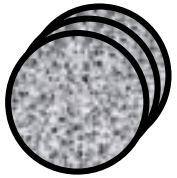


7 TB 12” wafer, 440 12 mm x 12 mm dies, ~ 256 Gb/die

HDD
58 nm x 11 nm
1000 Gbit/in ^{2}

10 TB 3.5” Drive, 7-8 platters, ~ 1.4TB/platter

Optical BD-XL
3 layer
land recording
180 nm diameter
75 Gbit/in ^{2}



1.2 TB Cartridge, 12 disks, ~ 0.1 TB/platter

LTO TAPE
~3200 nm x 47 nm
4 Gbit/in ^{2}

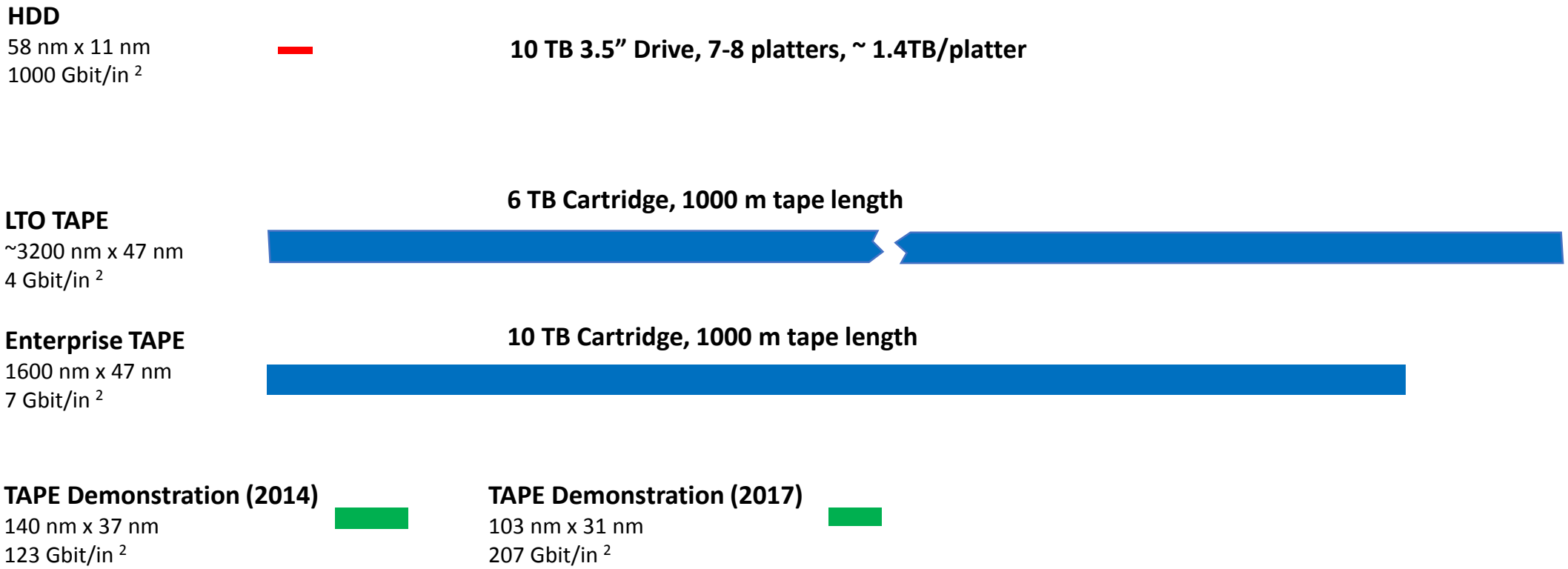
6 TB Cartridge, 1000 m tape length

Enterprise TAPE
1600 nm x 47 nm
7 Gbit/in ^{2}

10 TB Cartridge, 1000 m tape length

Technology Demonstrations – A Key Indicator for Future Component Capacity Increases

- Tape demonstrations suggest that 16X areal density improvements are realizable.
- Tape technology builds on established HDD technology to increase areal density and hence cartridge capacities
- Tape demonstration areal densities are still 5X lower than present day HDD densities
- Tape has “runway” for capacity improvement



IBM Tape Strategy

- **Tape Technology Pipeline - IBM Development/Research**
  - Large research investment @ IBM Zurich laboratory
  - 2017 technology demonstrations – 300+ TB cartridge capacity
- **Develop a common core technology**
  - Drive technology value into Enterprise
  - Leverage technology into LTO when industry is capable
- **TS11xx Enterprise Tape product line**
  - Reliability, Performance and Function differentiation
  - Enterprise media cartridge with reuse
- **LTO Midrange product line**
  - Open Tape Streaming product family
  - Full Automation Product support – 1U to HD Frames
  - LTO Consortium driven development/function
- **Software - LTFS**

2017 Tape Technology Demonstration
IBM Research Zurich / Sony Storage Media Solutions Corporation

- Advanced sputtered media (CoPtCr)
- Linear Density – 818 kbpi
- Track density – 246 ktpi
- 1-sigma PES – 6.5 nm
- Areal density – 201 Gbit/in^2
- Potential cartridge capacity for 1100 m tape -- > 300 TB

This demonstration shows that tape technology has the potential for significant capacity increases for years to come

Tape Drive Roadmaps -- LTO and Enterprise

IBM Tape Drive History and Roadmaps

LTO

LTO Generations	LTO-6	LTO-7	LTO-8	LTO-9	LTO-10
New Format Capacity (Native)	2.5 TB (L6)	6 TB (L7)	Up to 12 TB (L8)	Up to 25 TB (L9)	Up to 50 TB (109)
Other Format Capacities (Native)	1.5 TB (L5) (800 GB L4 R/O)	2.5 TB (L6) (1.5 TB L5 R/O)	6 TB (L7) (2.5TB L6 R/O)	Up to 12 TB (L8) (6 TB L7 R/O)	Up to 25TB (L9) (12 TB L8 R/O)
Native Data Rate	160 MB/s	300 MB/s	Up to 360MB/s	Up to 432 MB/s	TBD

LTO-11,12,13,…

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2011 2012 2014 2015 2017

Enterprise

TS1100 Generations	TS1140	TS1150	TS1155	TS1160	TS1165	TS1170
Max Native Capacity (m type)	4 TB (JC)	10 TB (JD) 7 TB (JC)	15 TB (JD) 7 TB (JC)	Up to 20 TB (JE) 15 TB (JD) 10 TB (JC)	Up to 30 TB (JE) 15 TB (JD) 10 TB (JC)	Up to 40 TB (JF) 30 TB (JE) 15 TB (JD) 10 TB (JC)
Native Data Rate	250 MB/s	360 MB/s	360 MB/s	Up to 500 MB/s	Up to 500 MB/s	Up to 1000 MB/s
Attachment	FC-8	FC-8	FC-8, 10 GigE (RoCE, iSCSI)	FC-16, 25 GigE (RoCE, iSCSI)	FC-16, 25 GigE (RoCE, iSCSI)	FC-32, 25GigE (RoCE,iSCSI)

TS1180, 90, 100,…

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Any statements regarding IBM's future direction and intent are subject to change or withdrawal without notice, and represent goals and objectives only.

Enterprise and LTO Comparisons

Common Elements

- Core Recording Technology
  - Head, data channel, media
  - Generally newest technology goes into Enterprise first
- Data Reliability
  - Both systems same high BER - identical ECC, channel, dataflow
  - 1E20 spec for Enterprise
  - 1E19 spec for LTO (lower for media variances of multiple LTO vendors)

Enterprise Differentiation

- Capacity/Roadmap and Media Up-format (i.e. reuse)
- Performance and Access
- Interfaces / Attachments
- Reliability (drive)
- Reliability (cartridge)
- Encryption – end to end

Enterprise Differentiation – Capacity and Media Reuse

- Enterprise has the highest single cartridge capacity and roadmap maintains the capacity advantage
- Enterprise supports media up-formatting, allowing previous generation media to be re-used at higher capacities and data rates on future drive models.
- Enterprise supports field drive model upgrades

- Advantages
  - Improved density / reduced library frames reducing overall system cost
  - Higher capacity and performance over time on existing media reducing media/storage costs
  - Maintaining footprint with future storage growth
  - Drive models may be upgraded at reduced cost and upgrades may be expensed

Drive marketing Name >> Models Name		TS1155 drive 3592 55F(FC) 3592 55E (eth		TS1150 drive 3592 E08(FC)		TS1140 drive 3592 E07 (FC)	
Tape Cartridge Name	Format	Capacity	Data Rate	Capacity	Data Rate	Capacity	Data Rate
JD (Data) JZ (WORM)	JD J5A 15TB	15 TB	Up to 360 MBps				
JL (short JD)	JD J5A 15TB	3 TB	Up to 360 MBps				
JD (Data) JZ (WORM)	JD J5 10TB	10 TB	Up to 360 MBps	10 TB	Up to 360 MBps		
JL (short JD)	JD J5 10TB	2 TB	Up to 360 MBps	2 TB	Up to 360 MBps		
JC (Data) JY (WORM)	JC J5 7TB	7 TB	Up to 300 MBps	7 TB	Up to 300 MBps		
JK (short JC)	JC J5 7TB	900 GB	Up to 300 MBps	900 GB	Up to 300 MBps		
JC (Data) JY (WORM)	JC J4 7TB	4 TB (R/O)	Up to 250 MBps	4 TB	Up to 250 MBps	4 TB	Up to 250 MBps
JK (short JC)	JC J4 7TB	500 GB (R/O)	Up to 250 MBps	500 GB	Up to 250 MBps	500 GB	Up to 250 MBps

Technology Strategy for Higher Capacity Tapes

- Focus on aggressive track density scaling, i.e. TPI increases

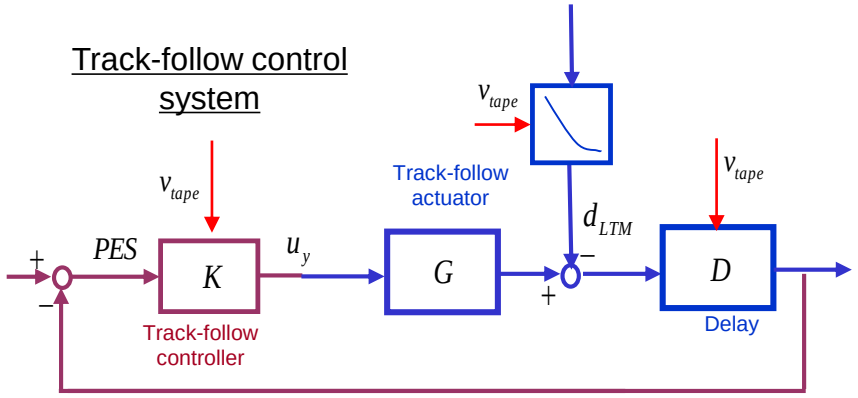
Implications

- Narrower tracks require advances in track following of position error control
- Narrower tracks require higher sensitivity read sensor to maintain output signal from written transition
- Smaller bit cell requires improved media (smaller particles) to retain SNR
- Smaller particles use higher anisotropy to retain bit stability requiring improved writer structures
- Enhancements in signal processing to compliment SNR requirements.

New H∞ track-follow control system

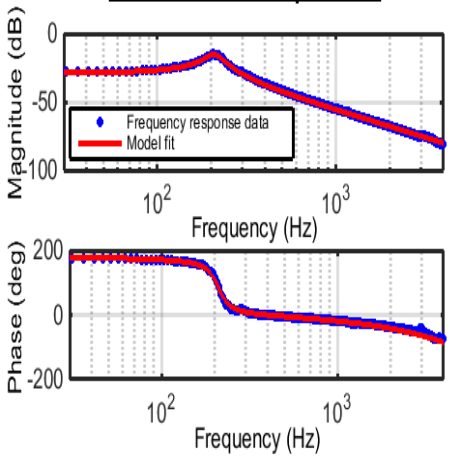
- **Key features**
  - Prototype high bandwidth head actuator
  - A speed dependent model of the system delay is used for control design
  - The tape speed is used as a parameter to select the controller coefficients
  - Disturbance rejection is enhanced at the frequencies of the tape path disturbances

Track-follow control system



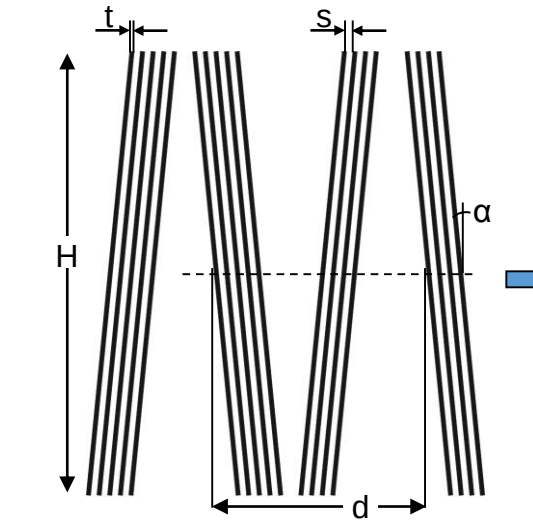
High Bandwidth Actuator

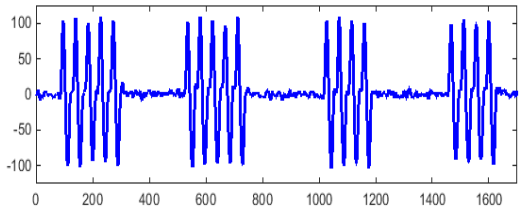
Actuator Response



Servo pattern design for high areal density demo

- Main design goal: nm-scale positioning fidelity
- Increased azimuth angle ⇨ increased resolution
- Increased pattern density ⇨ increased servo bandwidth and resolution





Standard LTO Pattern
H = 186 µm, t = 2.1 µm, s = 5 µm
α = 6°, d = 100 µm

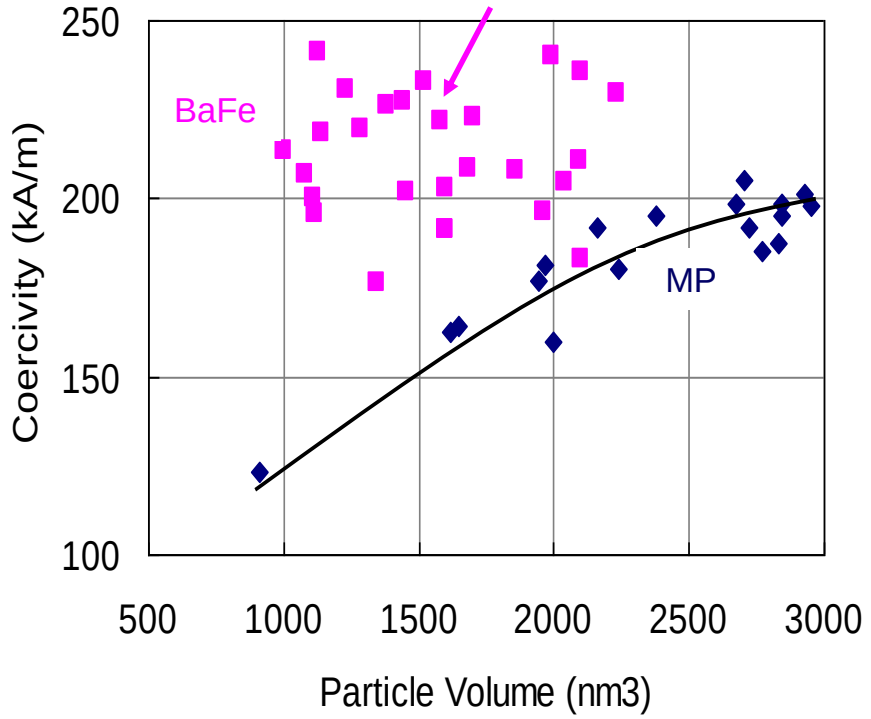
Demo Pattern
H = 23.25 µm, t = 1.0 µm, s = 2.4 µm
α = 24°, d = 52 µm

4x angle
2x rate

Compatible with Future 16 Data Band Tape Format

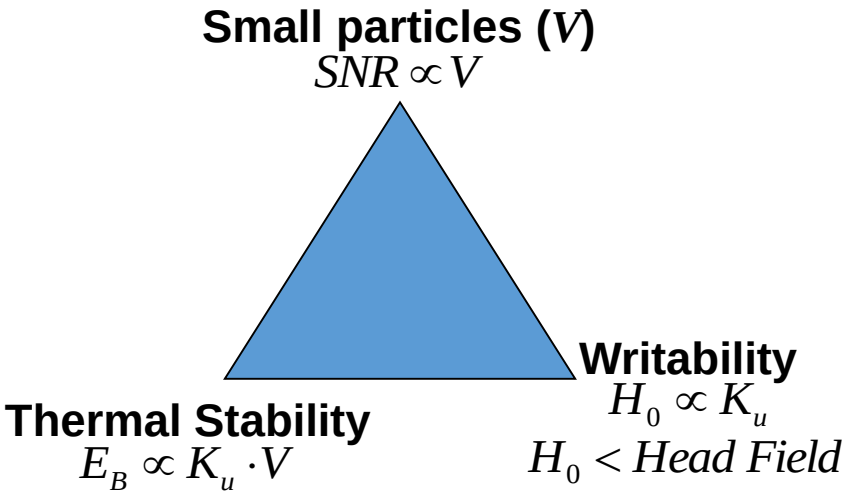
Advanced BaFe Media Technology (2015 Tape Demonstration)

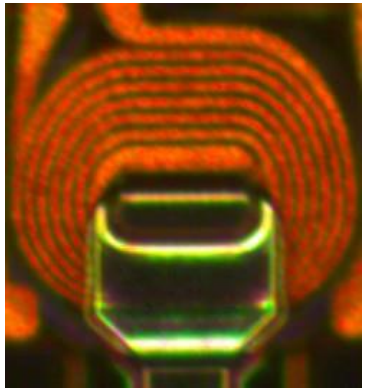
- BaFe Media Improvements
  - Smaller particles for SNR improvement
  - Increased coercivity for archival life improvements

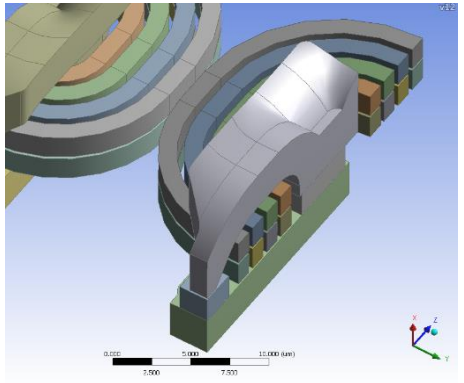


Enhanced Write Field Head Technology

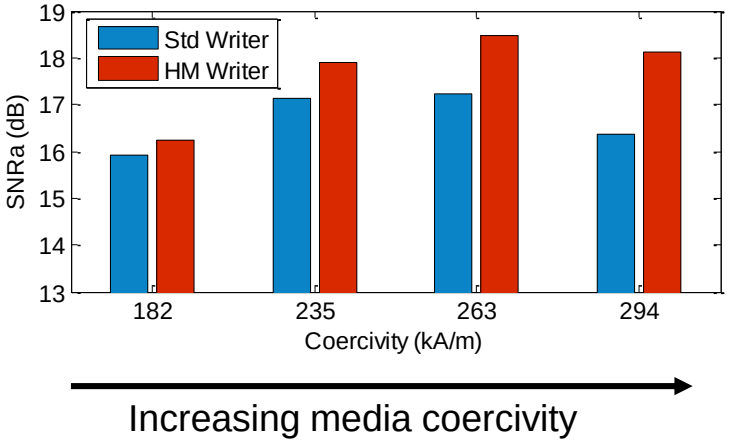
Magnetic Media “Trilemma”:



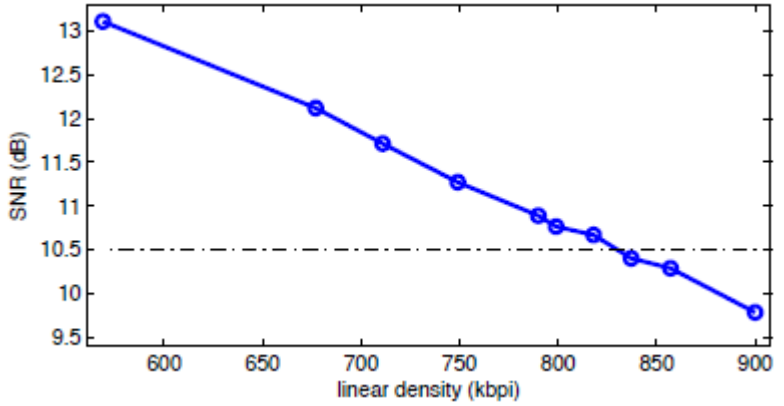




IBM developed a **new high moment (HM) layered pole write head** that produces much larger magnetic fields enabling the use of smaller magnetic particles



Advanced Media Effort (using enhanced writer)



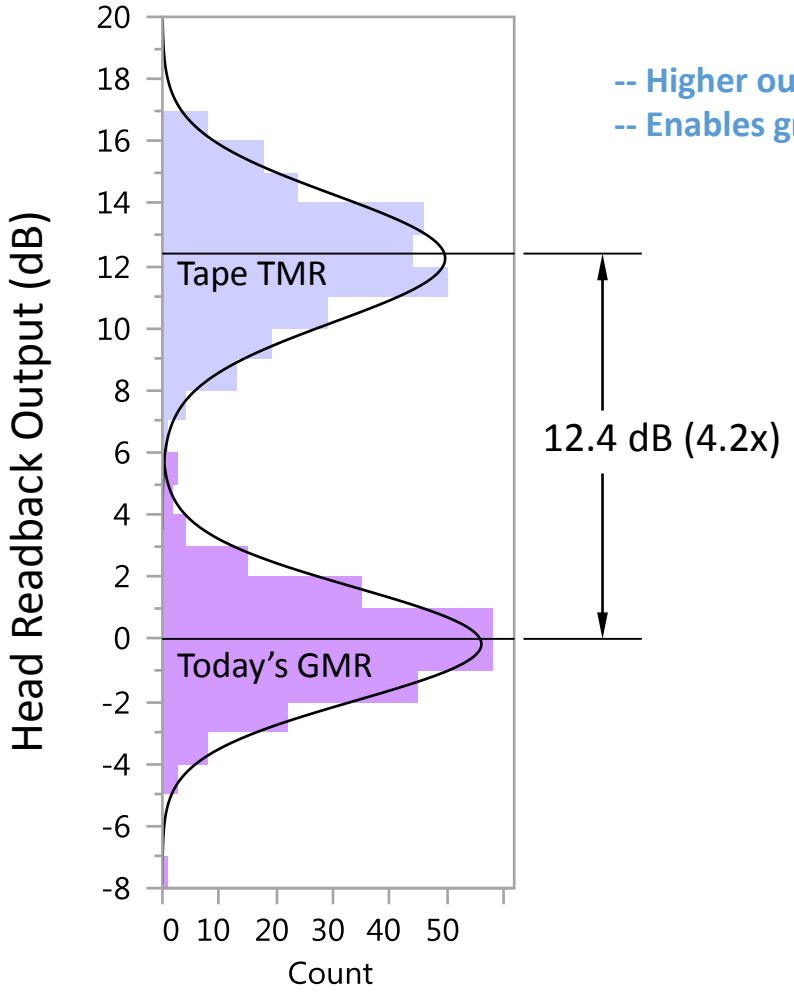
← SNR limit

← Byte error rate limit

- Advanced sputtered CoPtCr media supports a linear density of **818 kbpi** with a 50nm experimental reader
- IBM has introduced TMR head technology in 2017 to further exploit both BaFe media attributes and CoPtCr sputtered media attributes

The TMR Sensor

- TMR Sensor introduced into TS1155, July 2017
- Higher sensitivity sensor required for narrow bit cell strategy
- TMR* gives > 4x more signal than GMR when tested under similar conditions



-- Higher output gives better reading performance
-- Enables growth beyond 10-15 TB cartridge

Same test platform
Same size populations
Same track width, bias
Same tape type
Similar spacing

Summary

- Tape progress in drive roadmaps and cartridge capacity is supported by continued investment in technology
- Enterprise drive strategy emphasizes capacity, reliability, and media-up conversion
- LTO drive strategy benefits from Enterprise characteristics; but delayed by 18 – 24 months
- IBM research and development efforts are presently demonstrating the necessary technology for narrow track (higher areal density) magnetic recording
- Tape has an assured “runway” of 4X to 6X in capacity increase over present day Enterprise and LTO components