# A GMR Read Channel for Helical-Scan Tape Recording

**Kurt Hallamasek**
**Ampex Data Systems**
**1228 Douglas Ave, Redwood City CA 94063-3199**
**Phone: +1-650-367-3639 FAX: +1-650-367-3639**
**E-mail: Kurt_Hallamasek@ampexdata.com**

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# Joint effort with

Michael BOOTS,

Frederic SOUCHON,

Rachid Hida,

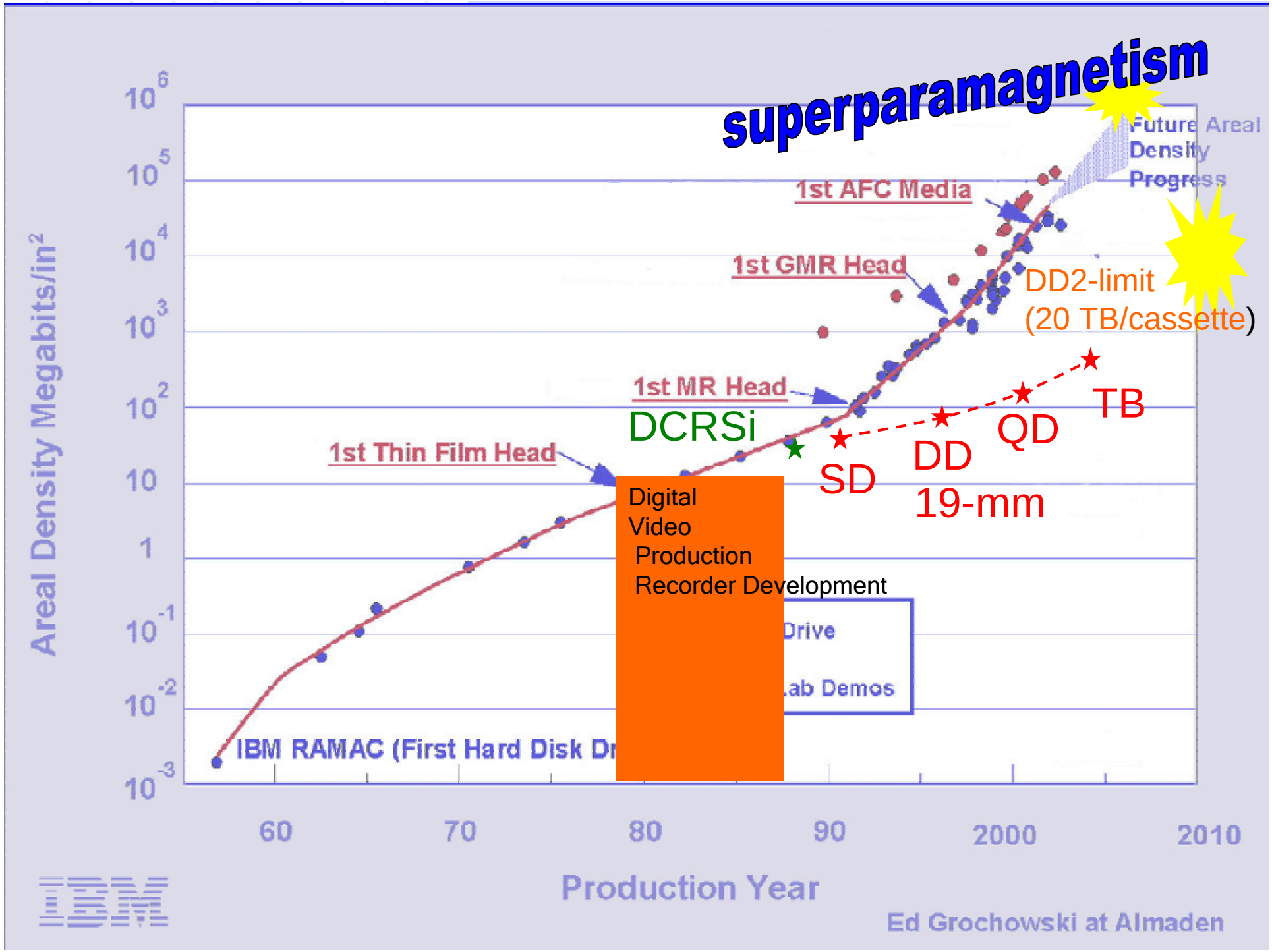
Marie Panabière,

Jean-Baptiste Albertini,

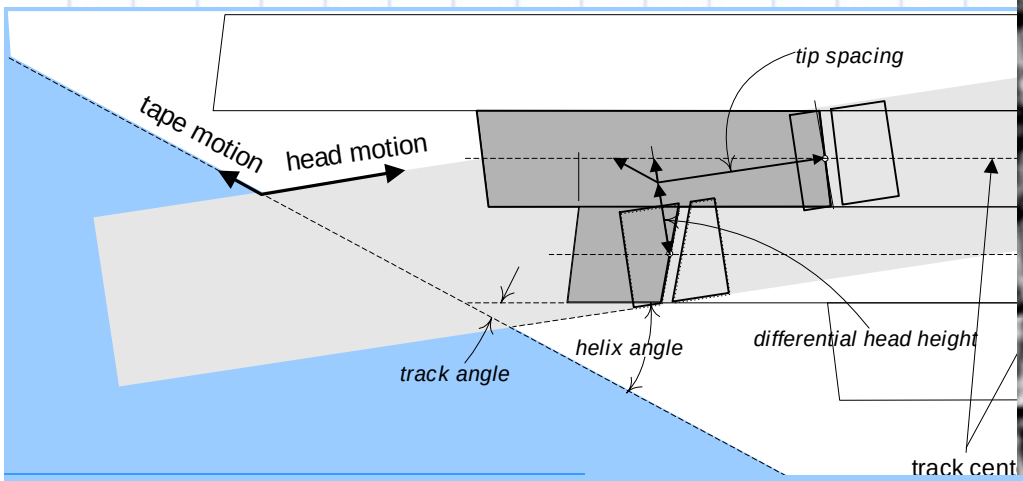
Bernard Viala

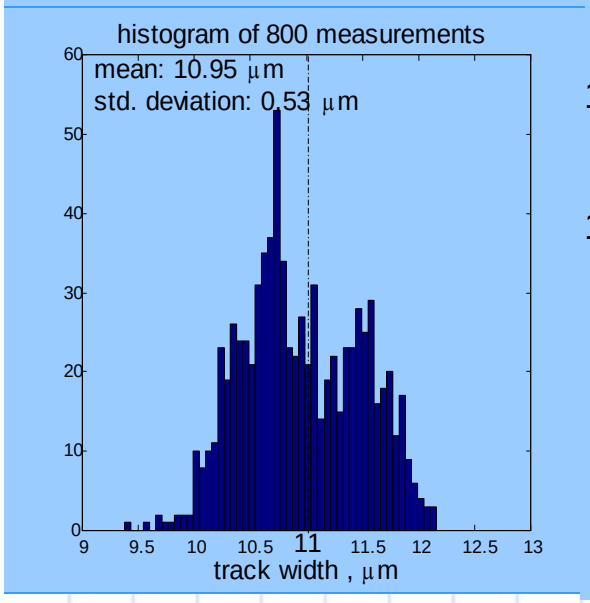
# Outline

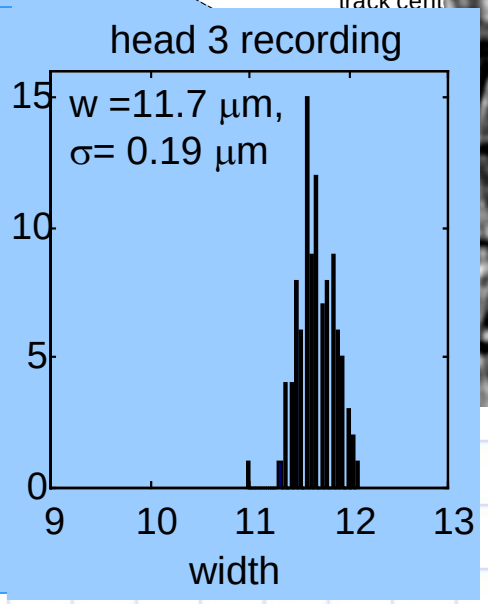
- Brief perspective of Ampex helical-scan recorders in a hard-drive world
- GMR heads for Helical-Scan Recorders
  - recipe for advances given by hard drive technology
  - wear and backward compatibility are dominating design constraints
- A GMR head design
  - addressing wear and head life
- A magnetic record channel
  - Pseudo Random Data Playback
  - Simulation of a PR2 channel
- Conclusion

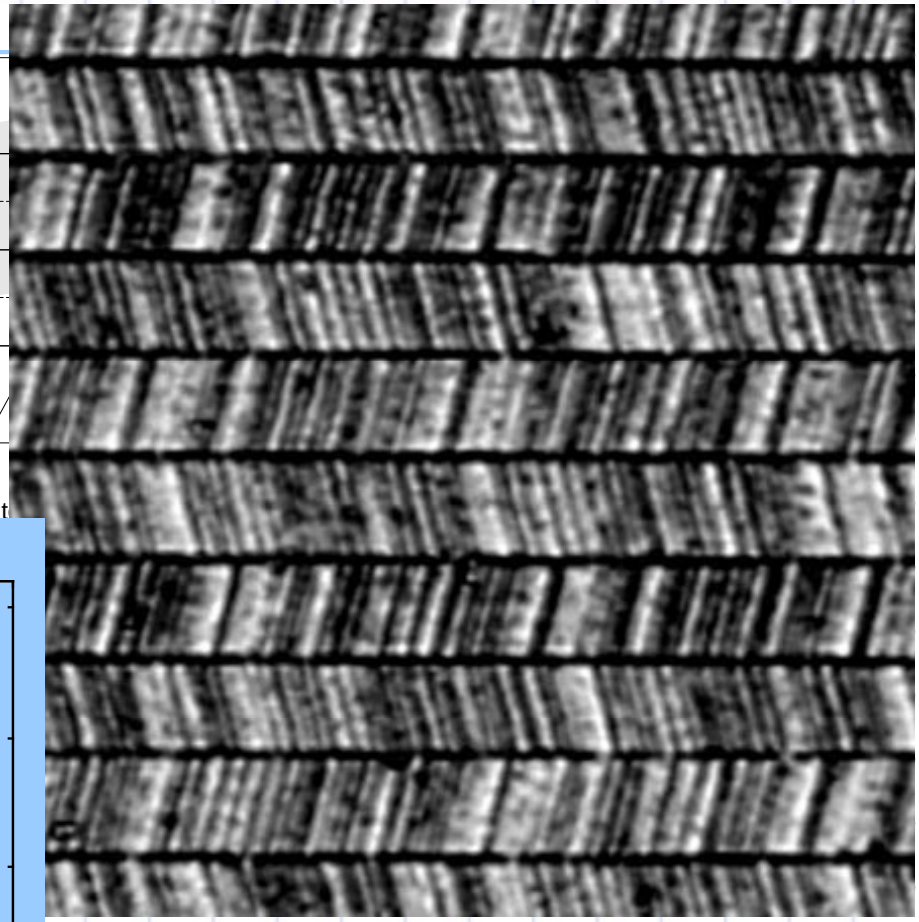

superparamagnetism
Future Areal Density Progress
1st AFC Media
1st GMR Head
DD2-limit
(20 TB/cassette)
1st MR Head
DCRSi
TB
QD
DD
SD
19-mm
1st Thin Film Head
Digital
Video
Production
Recorder Development
Drive
Lab Demos
IBM RAMAC (First Hard Disk Dr
Areal Density Megabits/in²
Production Year
Ed Grochowski at Almaden

# Track Width Variation Limits Areal Density

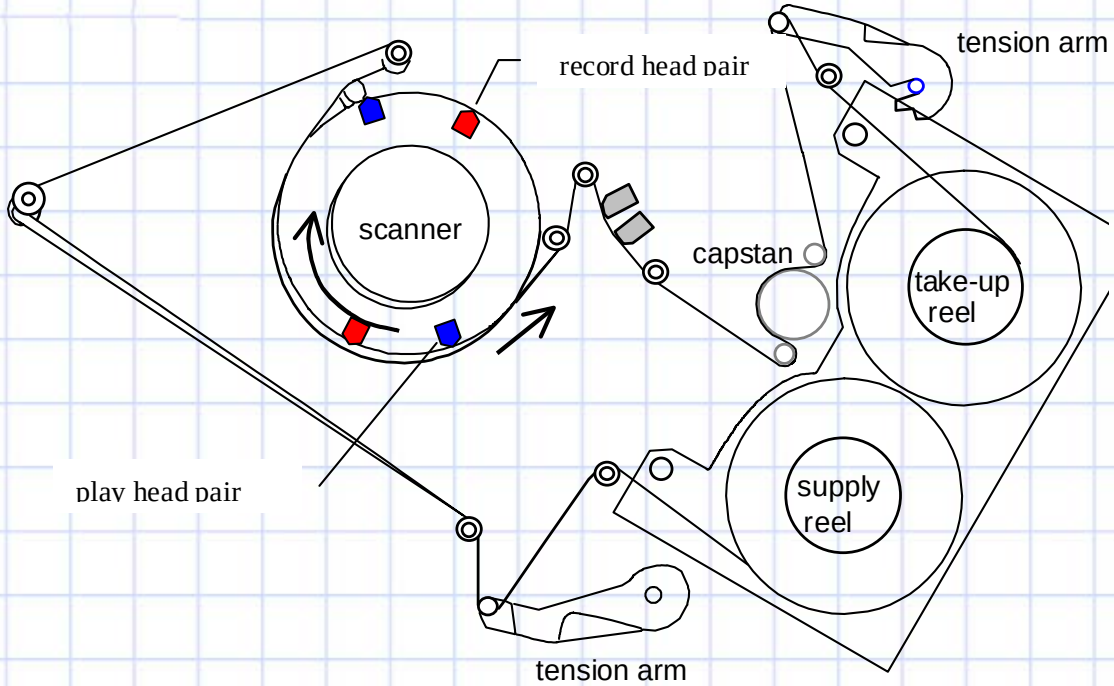


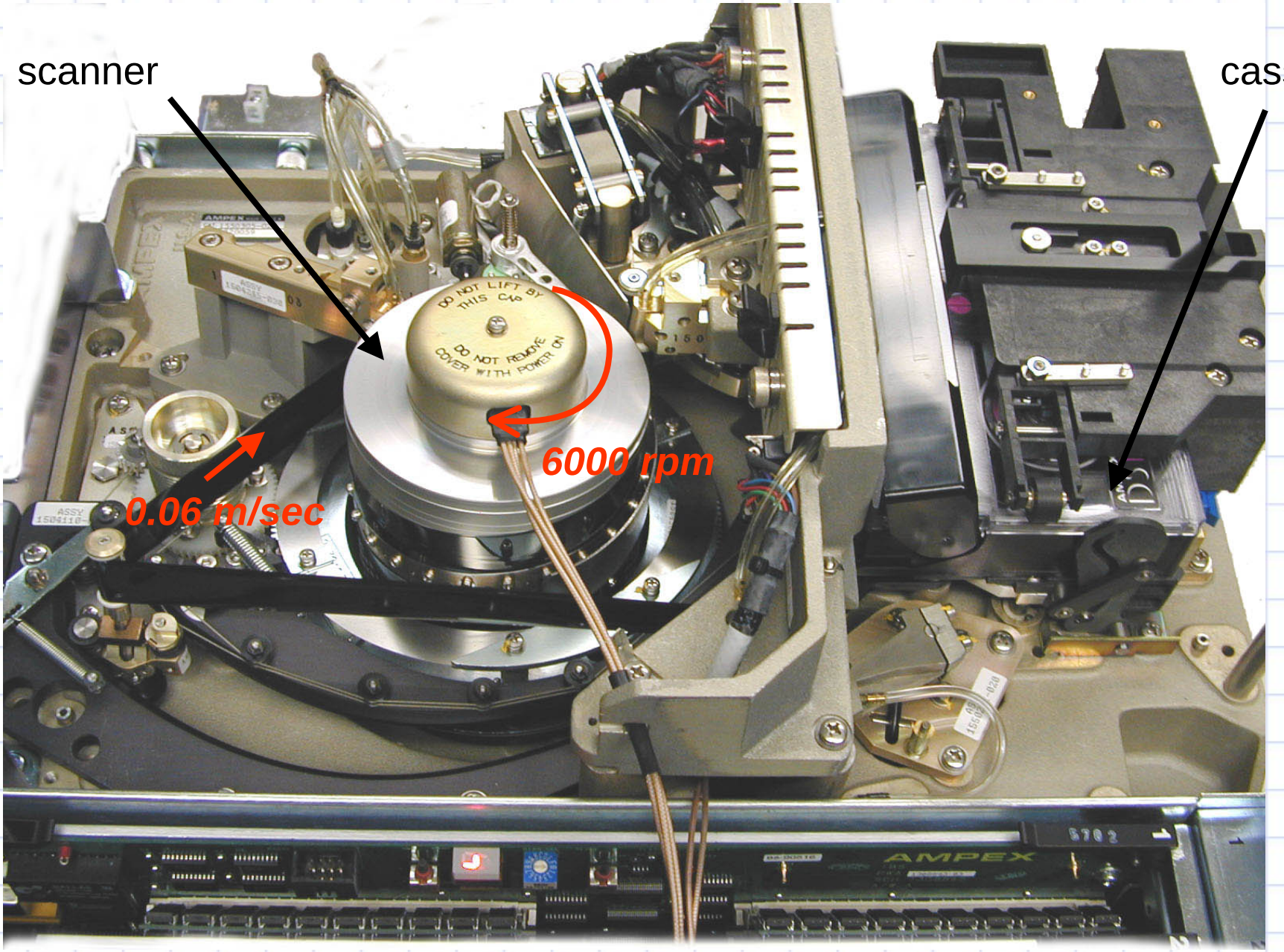



# Helical-Scan Recording

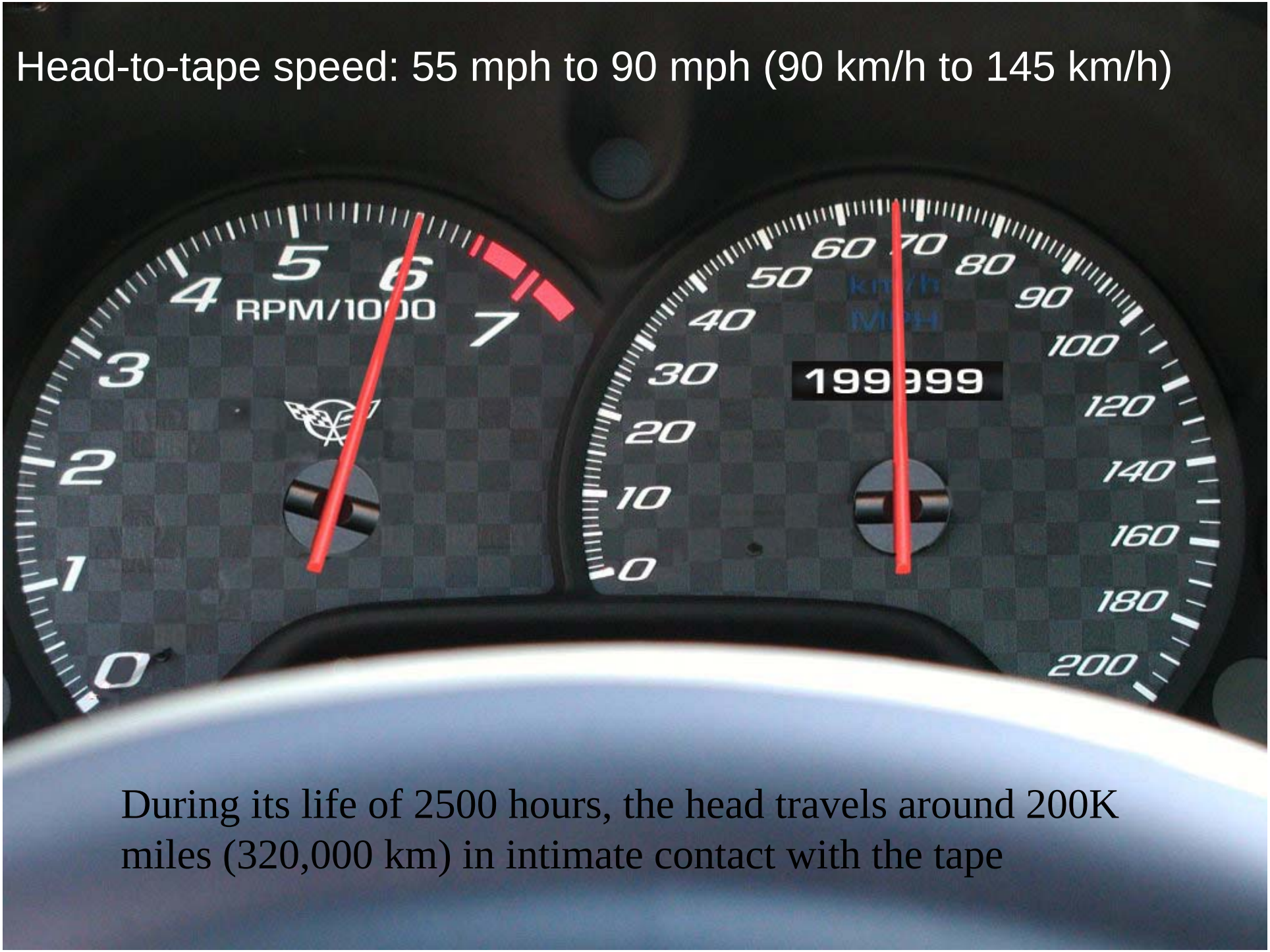



- low tape speed *(fast time-to-data)*
- high head-to-tape speed *(high data rate)*

Helical-scan recording is contact recording at high head-to-tape speed.



Head-to-tape speed: 55 mph to 90 mph (90 km/h to 145 km/h)



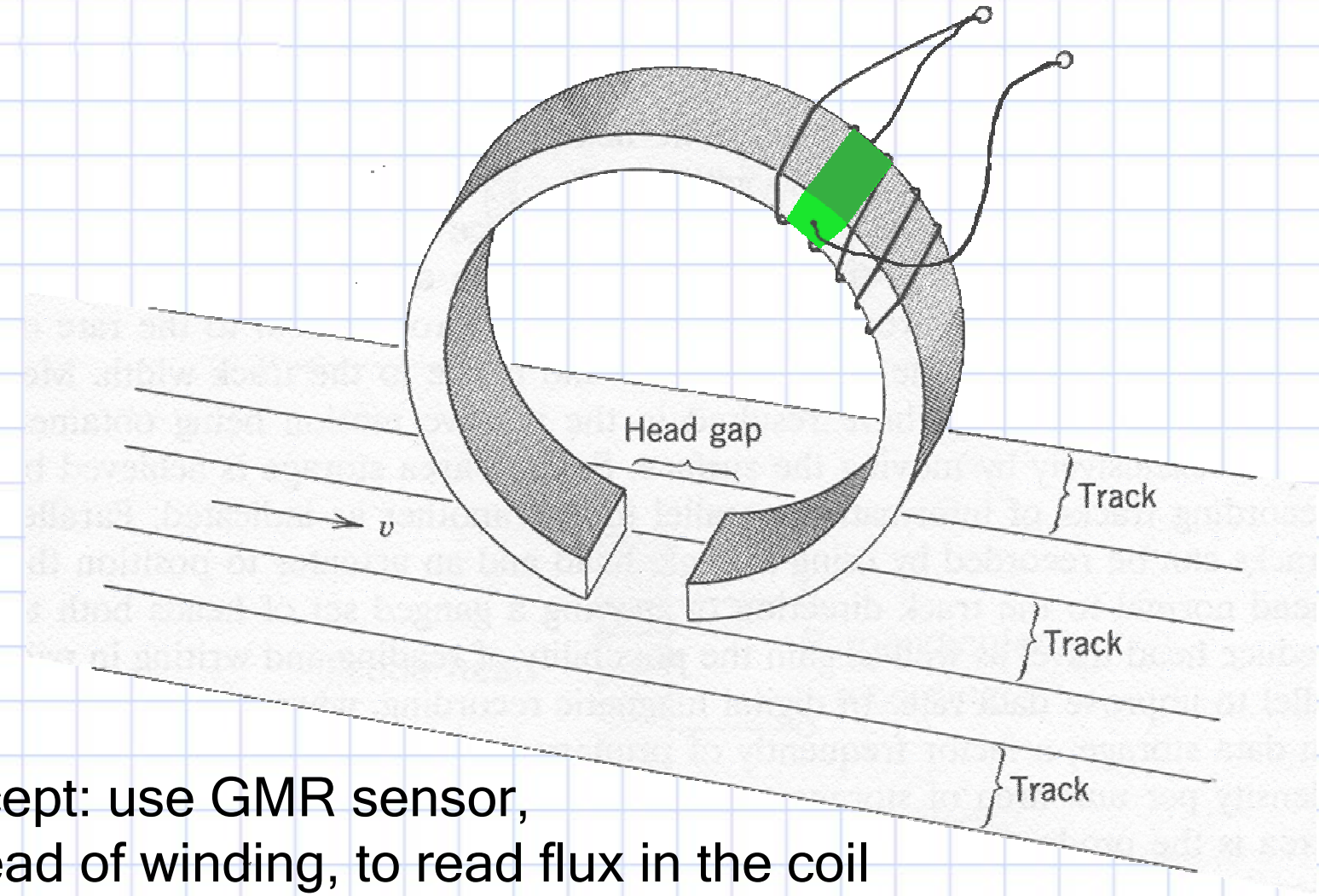

During its life of 2500 hours, the head travels around 200K miles (320,000 km) in intimate contact with the tape

# GMR heads for Helical-Scan Recorders

To date, no rotary-head tape recorder products use GMR heads.

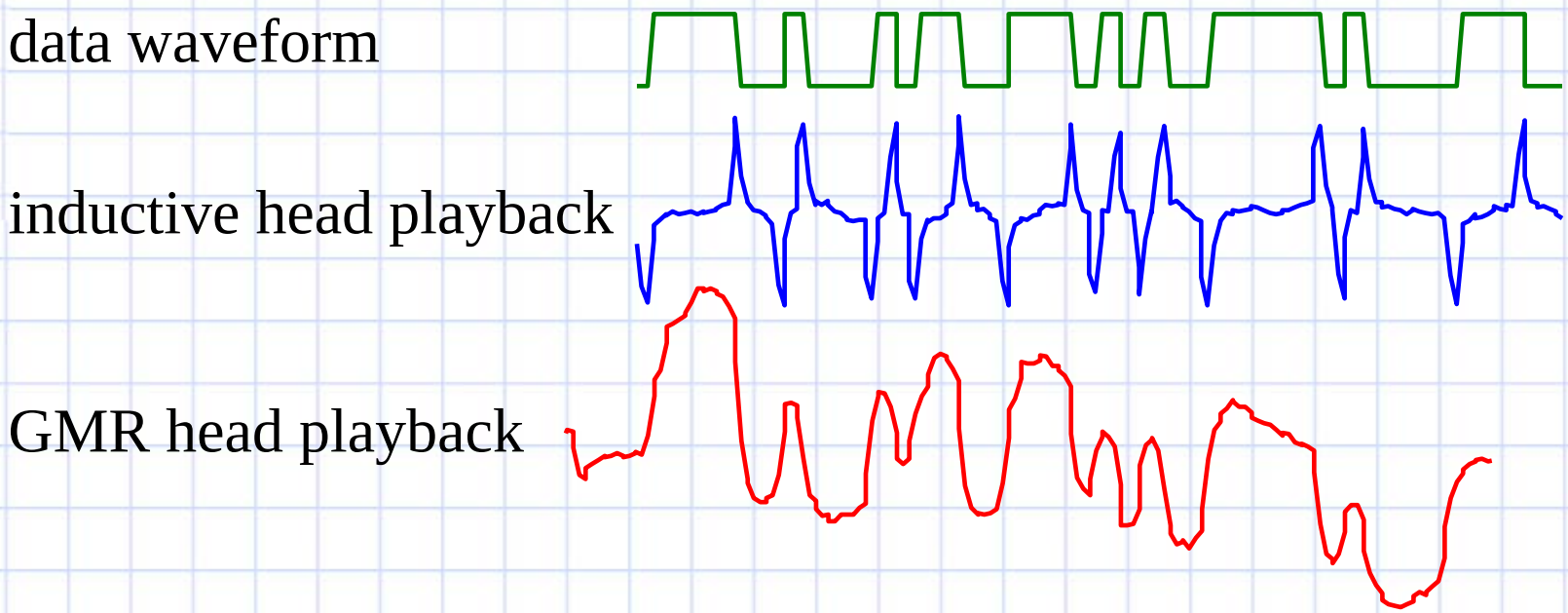
- Heads in helical-scan tape drives are subject to thermal spikes, electro-static discharge, and wear.
- A large dynamic sensing range is required to read previous-generation tapes.
- A flux-guide design
  - protects the sense element from wear and ESD.
  - frees the GMR sensor geometry from the dimensional constraints of fitting the sensor in the head's gap

# GMR Flux Guide Topology



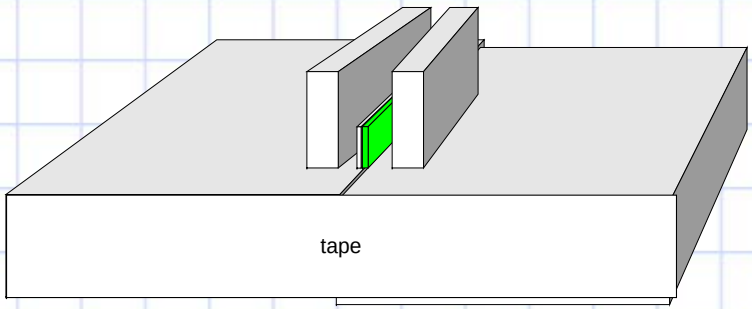

Concept: use GMR sensor,
instead of winding, to read flux in the coil

# Flux-Guide GMR playback waveforms



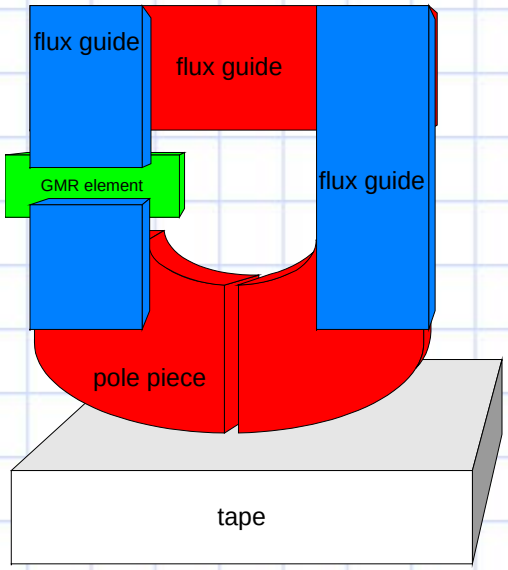

- *class IV family of partial response not ideal*

## sensor-in-gap GMR design




+ high output
+ high bandwidth
- sensitive to ESD
- wear destroys geometry
  (.5 micron stripe height,
  5 micron wear in 5000 hours)

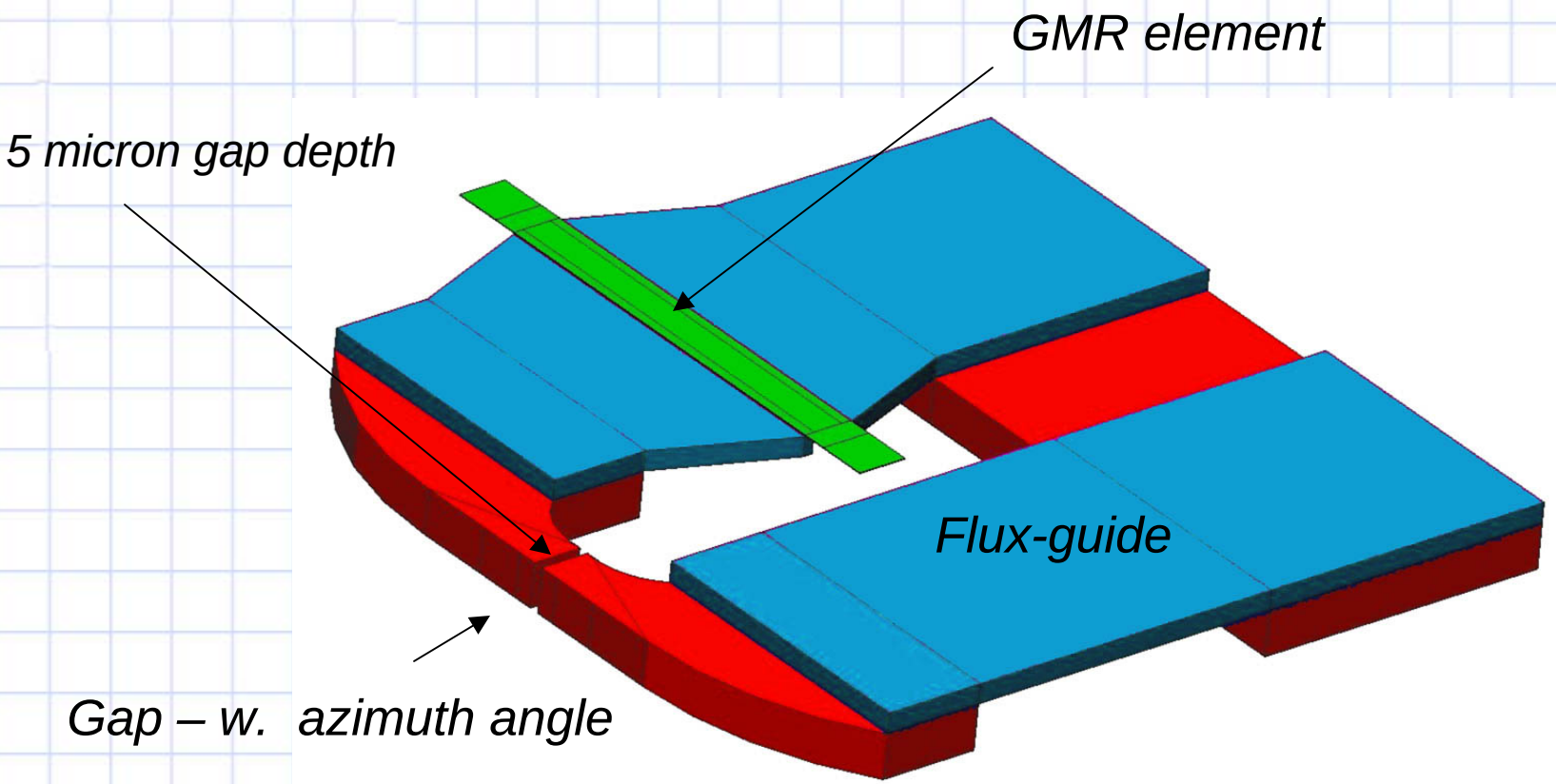
## flux guide GMR design




+ wear improves performance
+ insensitive to ESD, corrosion

- flux guide is lossy

# The Flux-guide GMR Sensor

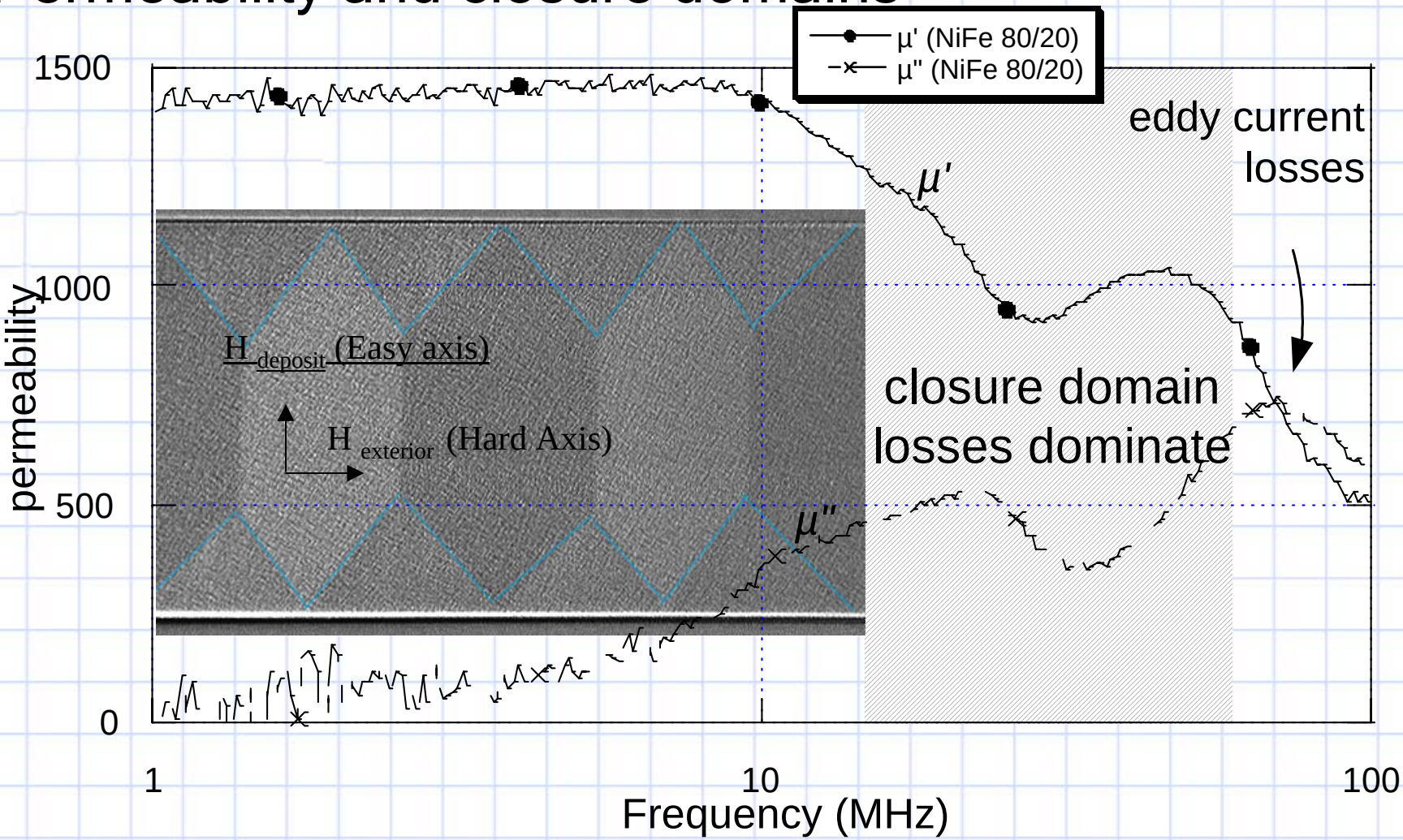



The angle at which the wafer was cut from the crystal relative to the crystal's <111> plane therefore defines the azimuth angle of the gap

# Flux Guide Design for Efficiency

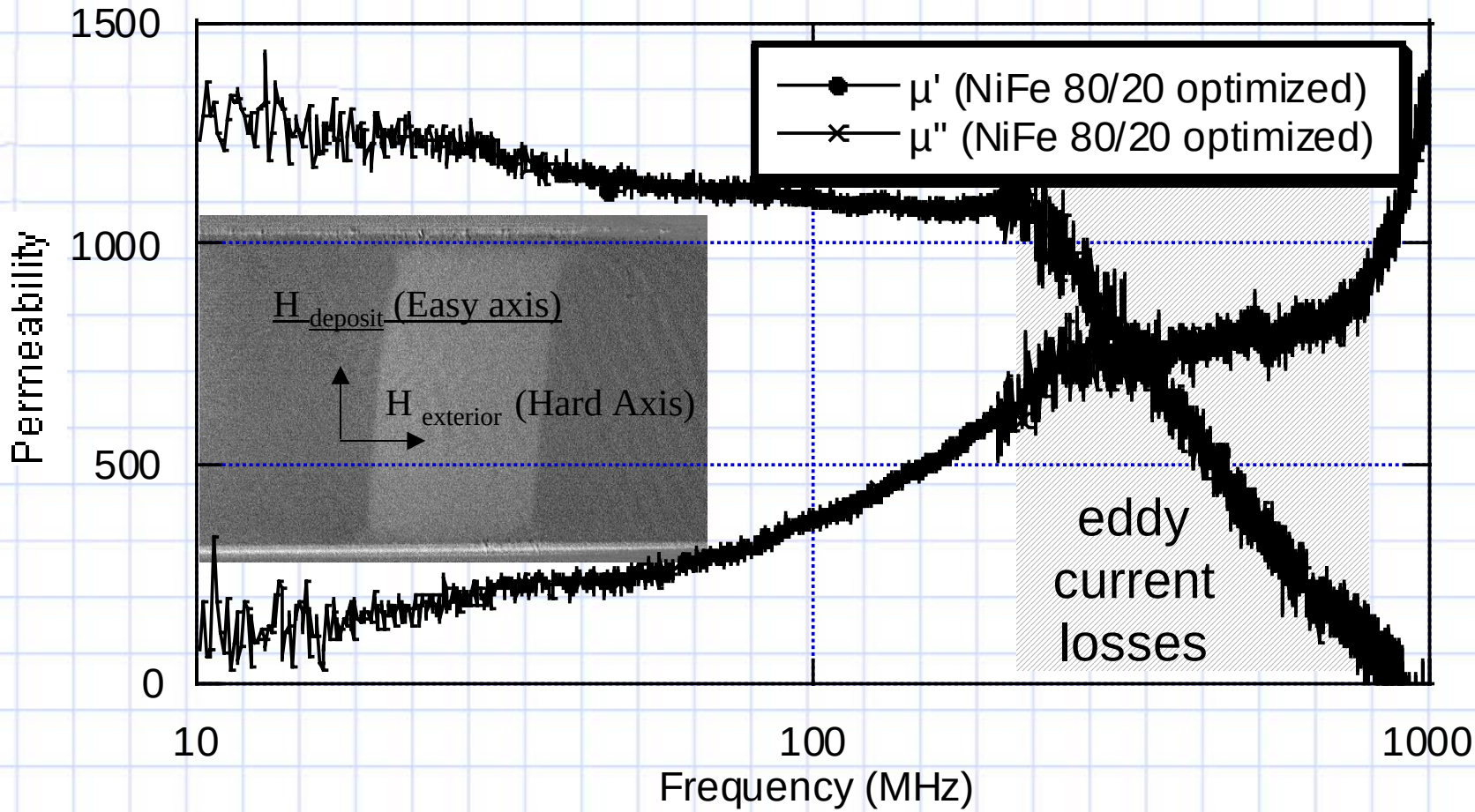
- Two loss mechanisms are considered:
  - Eddy current losses, minimized with a multi-layer flux guide design. In a multi-layer $Fe_{20}Ni_{80}$ structure, these losses set in around 100 MHz.
  - Closure domain losses, predicted by domain edge curling theory, depend on the guide geometry. They set in around 30 MHz typical flux guide structures.
- Optimization of the layer geometry and using an even number of layers gives a permeability > 1000 at frequencies to 100 MHz

# Permeability and closure domains




Permeability spectra for 1 μm thick $Ni_{80}Fe_{20}$ on 100 μm wide stripe and corresponding domain structure.

# Optimized domain structure by thin multi-layers



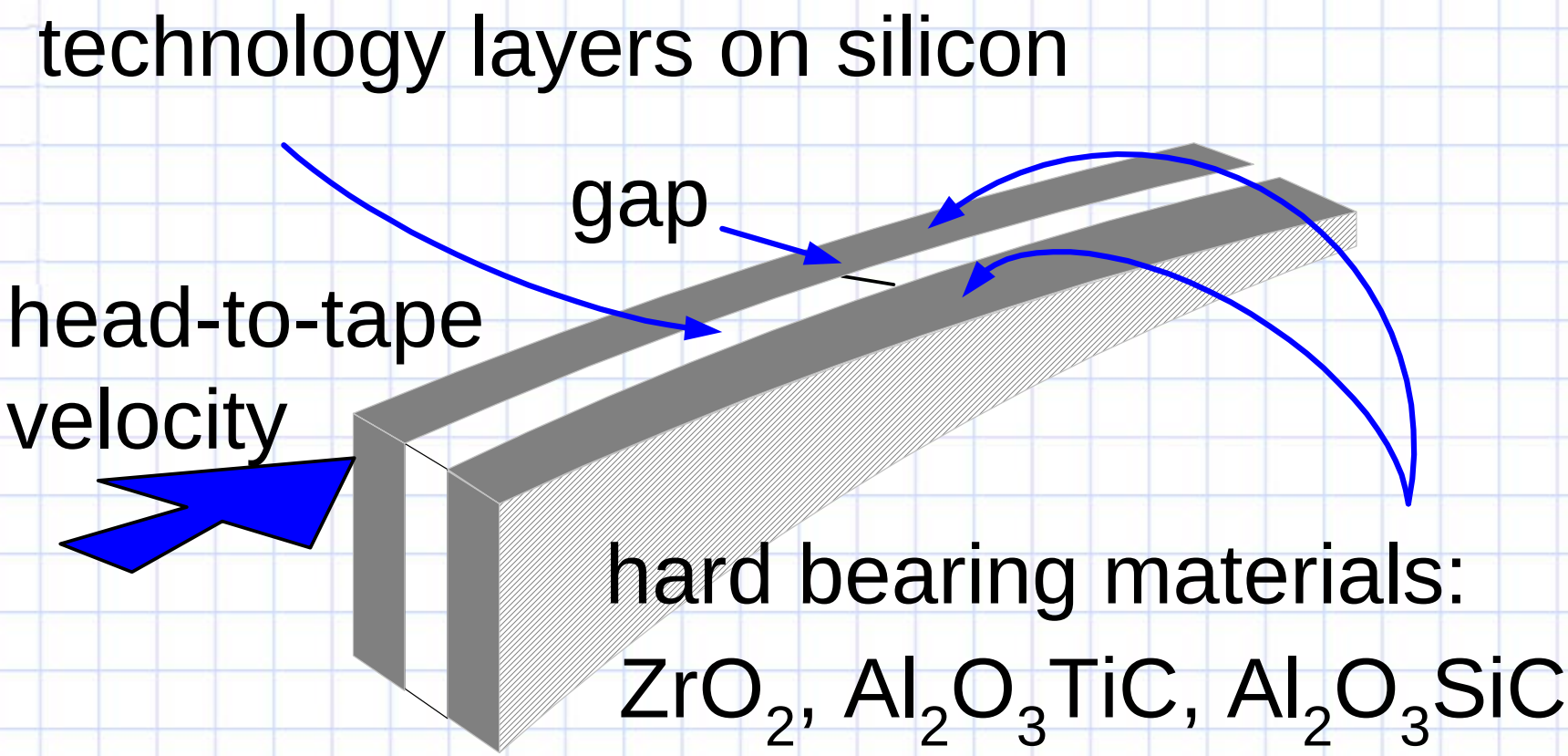

Permeability spectra for 1 μm optimized $Ni_{80}Fe_{20}$ bi-layer lamination on 100 μm wide stripe and corresponding domain structure.

# Bearing Structure for Head Life

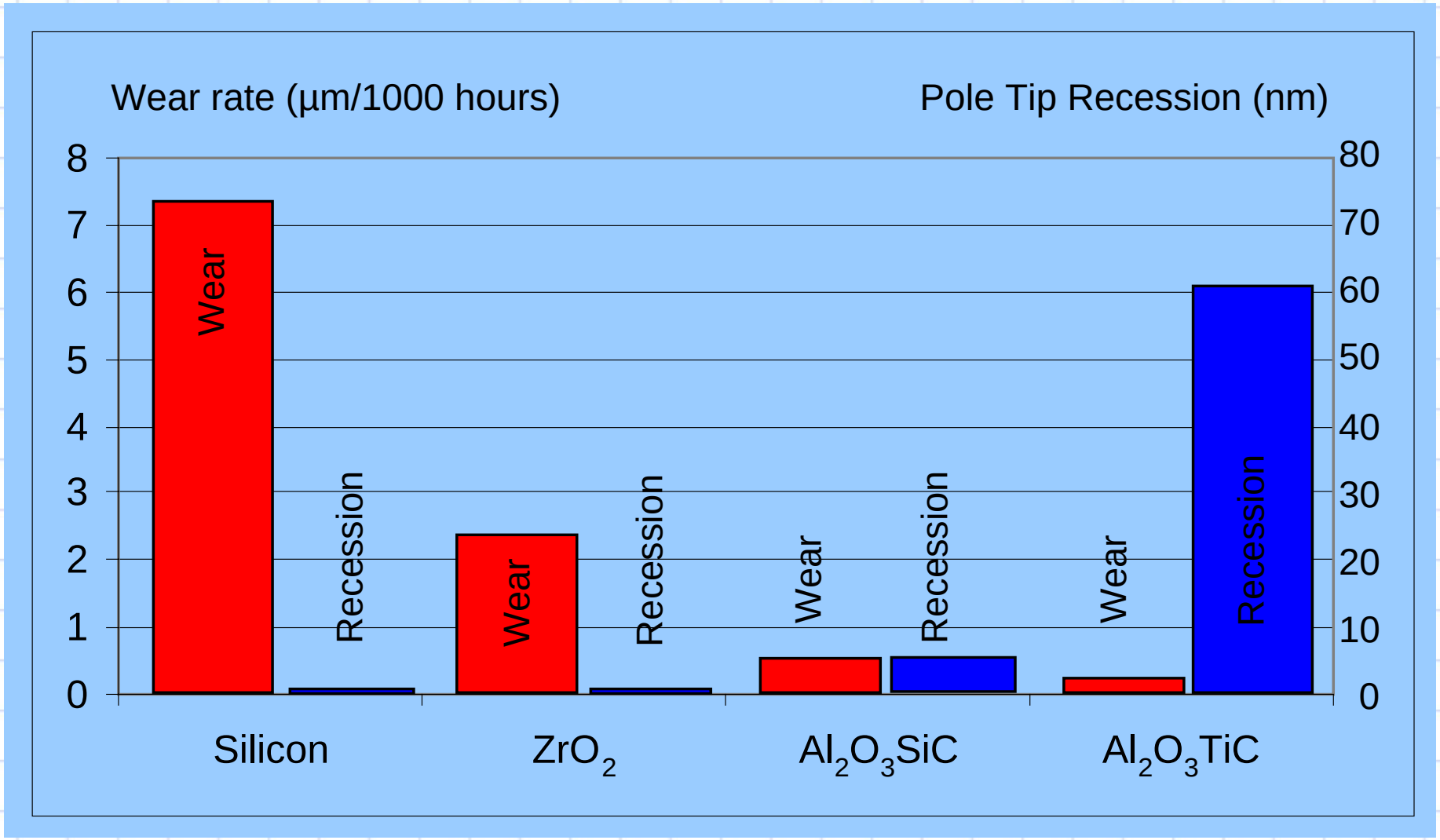
- Even recessing the GMR element in a flux guide structure built on silicon does not adequately protect it from wear. The silicon technology structure is sandwiched in a wear resistant bearing structure.
- Zirconia and the ceramic composites $Al_2O_3TiC$ and $Al_2O_3SiC$ were evaluated for pole-tip recession and head wear.

- Head life in excess of 5000 hours is predicted based on wear rates and gap depth of prototype head.

# Bearing structure for long head life



# Wear rate and pole tip recession

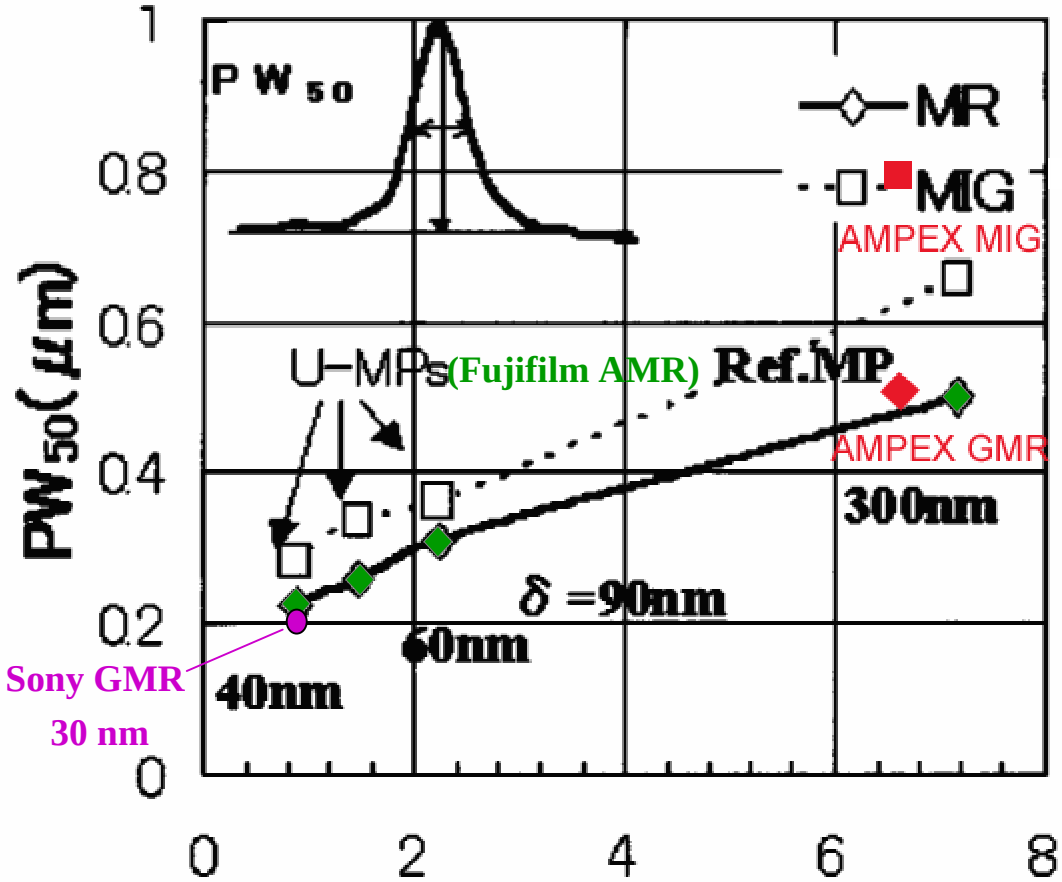



Wear rate and pole tip recession shown side-by-side for each material.
Wear is given in µm, recession in nm.
The best wear/PTR combination is with the composite ceramic $Al_2O_2SiC$ (Greenleaf's WG-300).

# The Flux-guide GMR channel

- Results shown for a head with 4.5 μm pole width.
  - Results on conventional MP tape (Fuji ATOMM, $M_r\delta$=6.5 memu/cm$^2$, $\delta$=200 nm).
  - flux guide that has not been optimized for boundary domains.
- Impulse response (not step response) shown and compared to partial response impulse respones
- Equalization and Viterbi detection shown for BPRS recordings

# The effect of tape thickness on attainable resolution



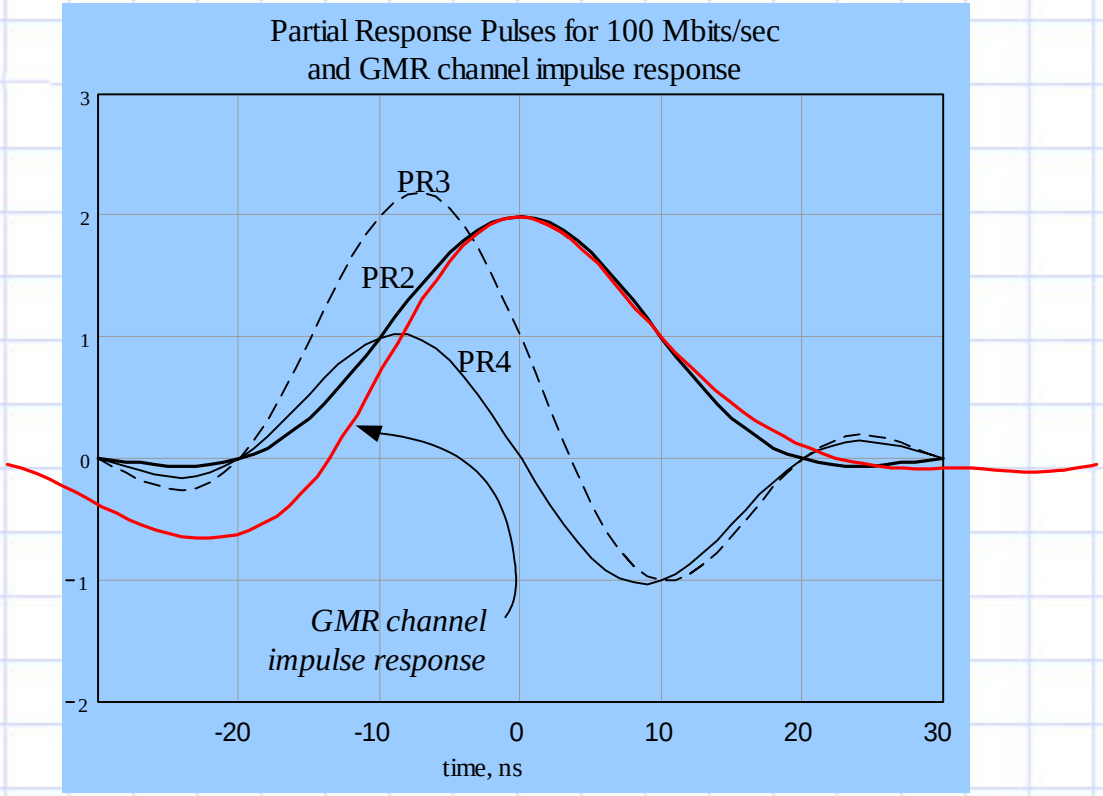

$$PW_{50} = 2\sqrt{(d+a)(d+\delta+a)+\frac{g^2}{4}}$$

**(b) $PW_{50}$ vs Mr・δ**


K. Ejiri, T. Sugizaki, R. Taguchi, K. Majima, K. Muto, T. Uehara, and H. Okuda, "Investigation of Particulate Media With an Ultra-Thin Magnetic Layer Suitable for MR Heads on a Rotating Drum," IEEE Trans. Magn., vol. 37, pp. 1605 -1608, July 2001

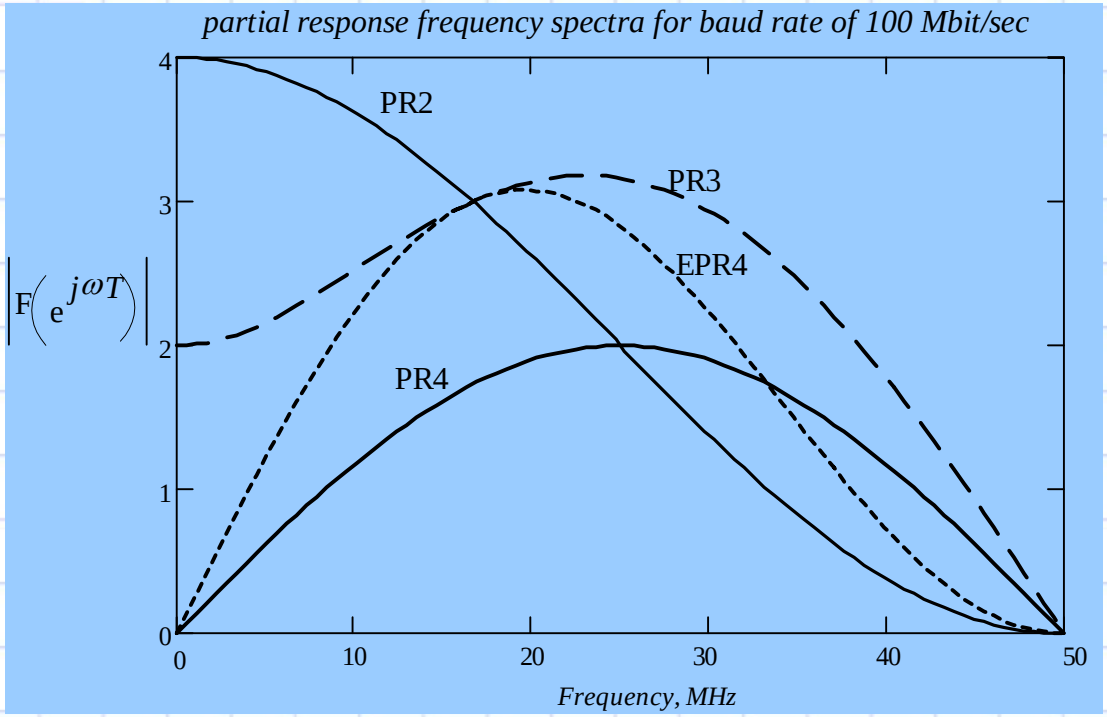
T. Ozue, M. Kondo, Y. Soda, S. Fukuda, S. Onodera, and T. Kawana, "11.5 Gbit/inch recording using spin-valve heads in tape systems," IEEE Trans. Magn., vol. 38, pp. 136–138, January 2002.

# Partial Response Pulses

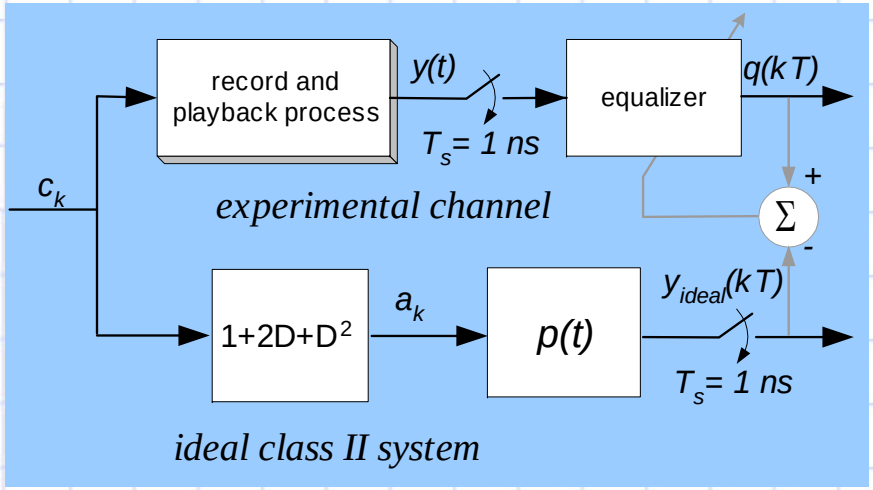


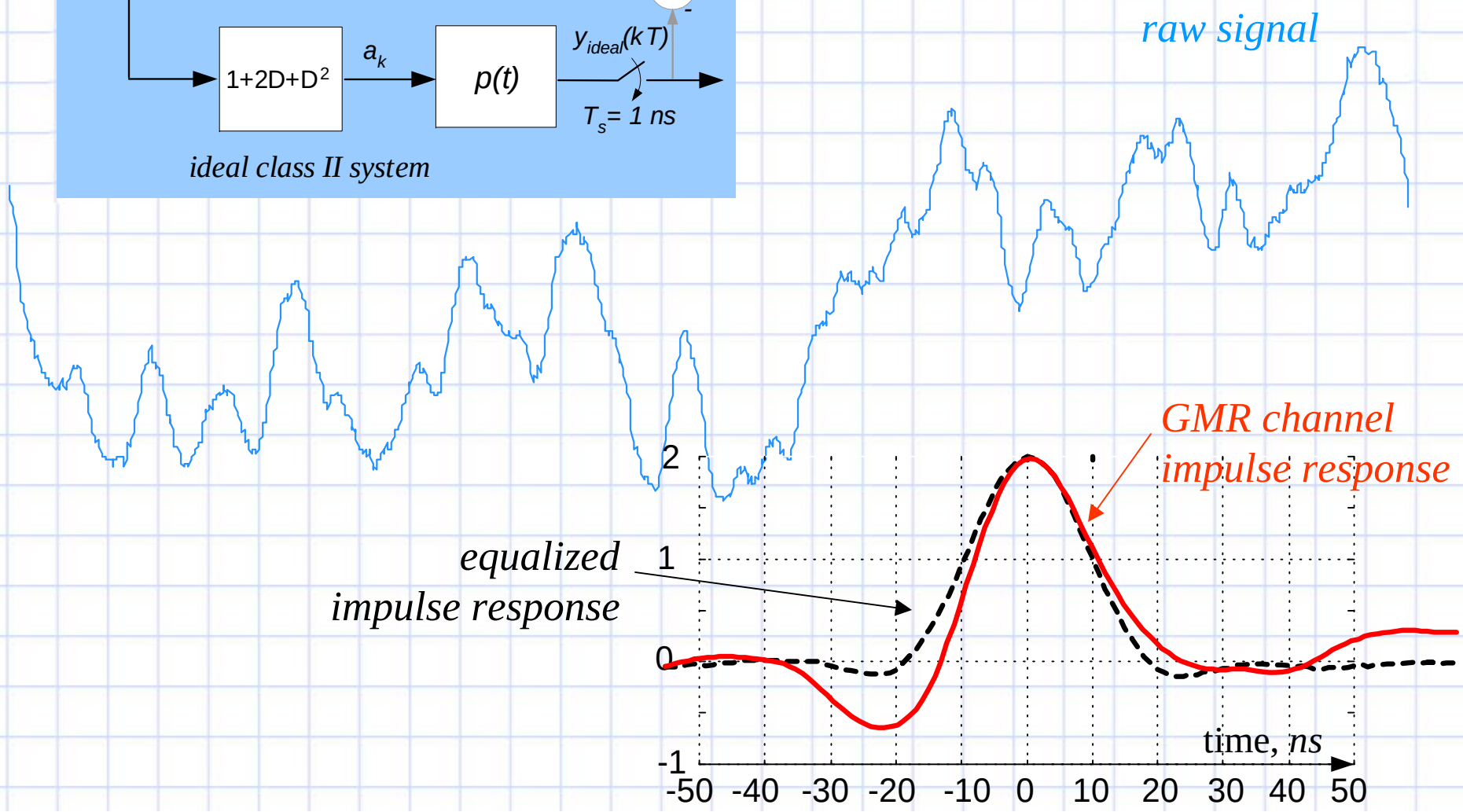

- Pulse response not confined to one bit cell
- Pulse has integer values at sample time

# Partial Response Spectra

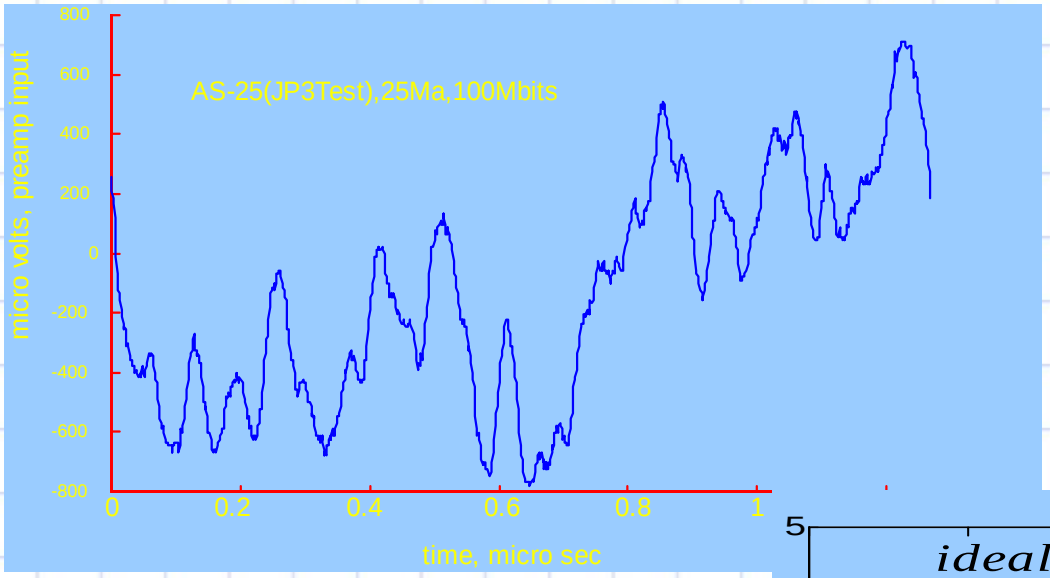


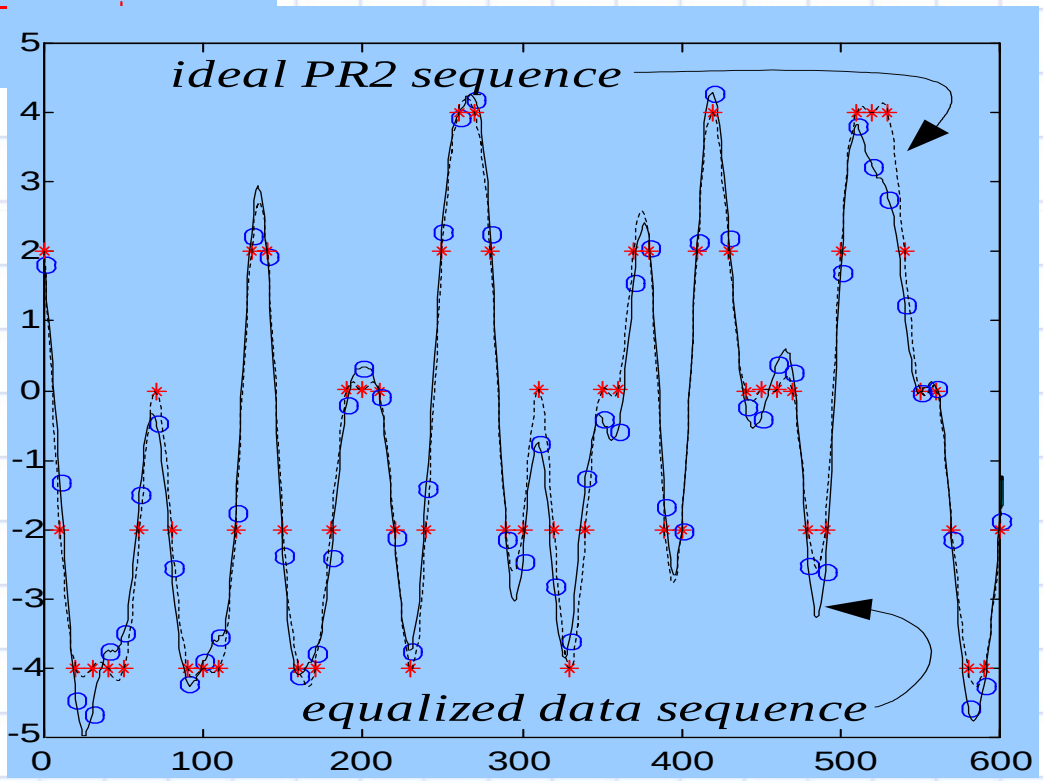
# PR2 Equalization



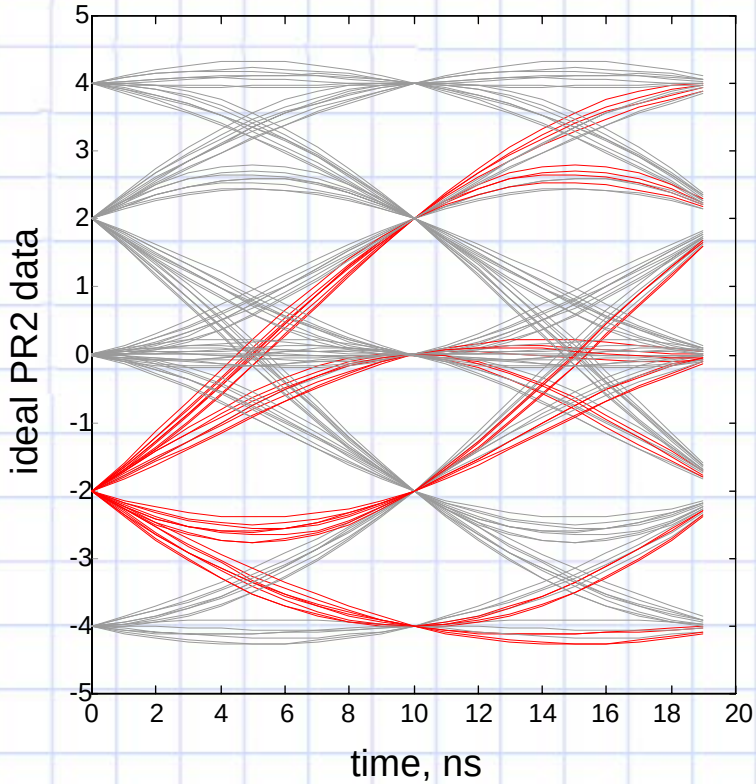



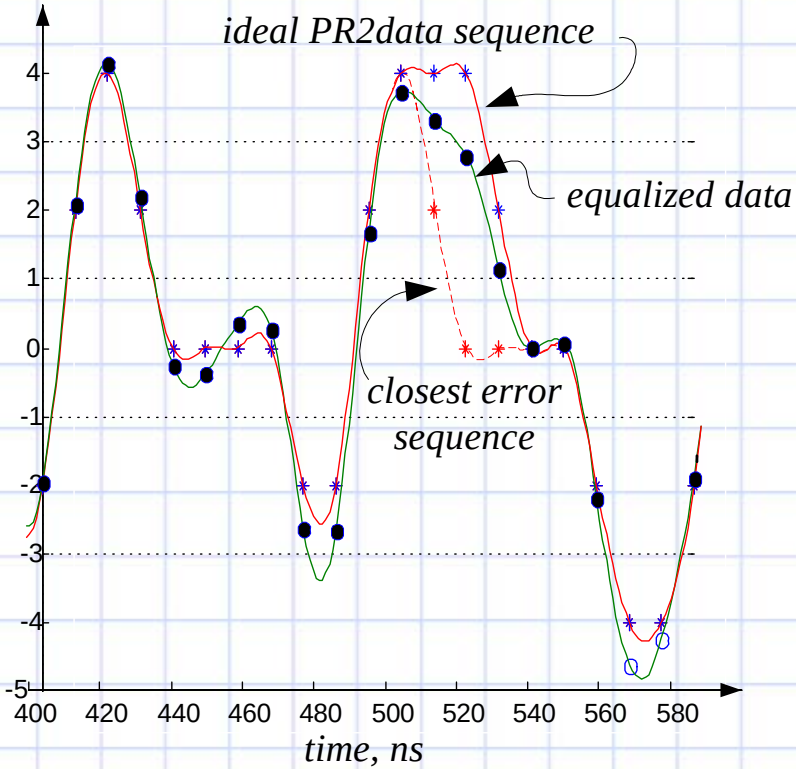
# PR2-equalized pseudo-random sequence



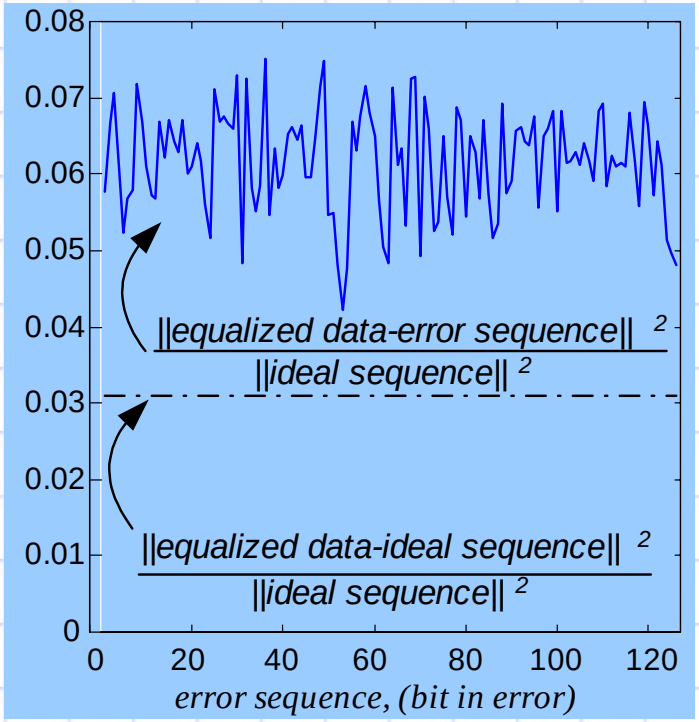
# Sequence Detection

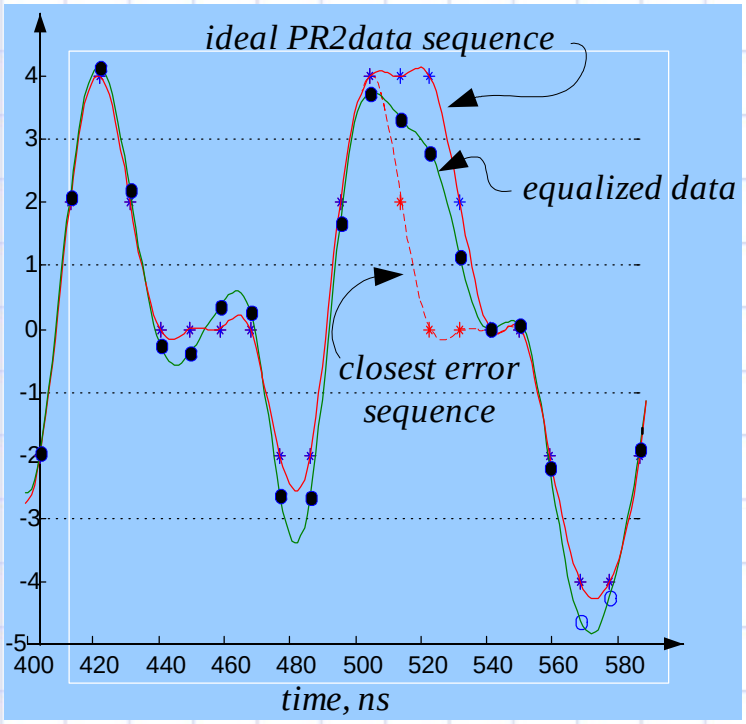



Sequence detection was simulated for a channel operating at 3.3 kbit/mm and a data rate of 100 Mbit/sec. No errors were detected in 38 repetitions of a 127 bit sequence.

# Viterbi detector performance




•Data is detected without errors

# Conclusion:

- A flux-guide design makes GMR technology practical for helical-scan recording
  - protects the sense element from wear, ESD, corrosion
  - frees the GMR sensor geometry from the dimensional constraints of fitting the sensor in the head's gap.
  - Can be adapted to TMR and CPP-mode sensors.
- Class II Partial Response is suitable for the flux-guide GMR head. Equalization and detection of a pseudo-random sequence recording is shown for a class II channel.