A GMR Read Channel for Helical-Scan Tape Recording

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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
Track Width Variation Limits Areal Density

track center

head motion

tap motion

track angle

helix angle

differential head height

track center spacing

track width , \( \mu m \)

mean: 10.95 \( \mu m \)

std. deviation: 0.53 \( \mu m \)

histogram of 800 measurements

head 3 recording

width

width

\( w = 11.7 \, \mu m, \sigma = 0.19 \, \mu m \)
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.
During its life of 2500 hours, the head travels around 200K miles (320,000 km) in intimate contact with the tape

Head-to-tape speed: 55 mph to 90 mph (90 km/h to 145 km/h)
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 $\text{Al}_2\text{O}_3\text{TiC}$ and $\text{Al}_2\text{O}_3\text{SiC}$ 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

technology layers on silicon

gap

head-to-tape velocity

hard bearing materials: $\text{ZrO}_2, \text{Al}_2\text{O}_3\text{TiC}, \text{Al}_2\text{O}_3\text{SiC}$
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 Al₂O₂SiC (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/cm², $\delta = 200$ nm).
  – flux guide that has not been optimized for boundary domains.

• Impulse response (not step response) shown and compared to partial response impulse responses

• Equalization and Viterbi detection shown for BPRS recordings
The effect of tape thickness on attainable resolution

\[
P W_{50} = 2\sqrt{(d + a)(d + \delta + a) + \frac{g^2}{4}}
\]


Partial Response Pulses

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

Partial response frequency spectra for baud rate of 100 Mbit/sec
PR2 Equalization

![Diagram of PR2 Equalization process](image)

- **Record and playback process**
  - $c_k$ (input)
  - $y(t)$ (output)

- **Equalizer**
  - $q(kT)$ (input)
  - $y(t)$ (output)

- **Experimental channel**
  - $1 + 2D + D^2$ (filter)
  - $a_k$ (input)
  - $p(t)$ (output)

- **Ideal class II system**
  - $y_{ideal}(kT)$ (input)
  - $T_s = 1\text{ ns}$

- **Raw signal**

- **Equalized impulse response**

- **GMR channel impulse response**

- **Time, ns**
  - $-50$ to $50$
PR2-equalized pseudo-random sequence
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.