TERABYTES FOR EVERYMAN:

TAPE SUBSYSTEM DESIGN FOR PC AND TV

Hans F. Hinteregger
hfh@newton.haystack.edu

MIT Haystack Observatory
+1-508-692-4764

Westford, MA 01886

16 October 1996

THIC Meeting
Ellicott City MD

ABSTRACT:

A linear digital magnetic tape recorder about the size of a VHS cassette capable of sustaining at least 250 Mb/s for 4 hours [> 0.5 TB capacity] could be mass-produced to sell with 100% profit for $250.

Assuming the 4 cubic inch tape volume of VHS, 3480, DLT packages, a volume density of at least 1/8 TB/in^3 is implied, which can be achieved with today's SVHS-like 9 μm QIC tapes, 50 kbpi linear density, and 3.2 μm trackwidth/pitch supportable with today's [disk] MR head designs. A linear drive with only 3 moving parts, 2 identical rotor/hubs and 1 head-or-guide actuator is assumed. MIT Haystack Observatory is prepared under contract to collaborate in such a new drive design, in particular, given our "know-how," to develop edge-guides that guarantee "perfect" passive tracking [non repeatable head-to-track misregistration < 0.1 μm p/p].

TERABYTES FOR EVERYMAN:

Tape Subsystem Design of PC and TV

A linear digital tape recorder -- no larger than a VHS cassette and capable of sustaining at least 250 Mb/s for 4 hours, that is, of storing more than 1/2 terabyte -- could be designed to sell with 100% profit for $250.

Such a product, developed without further hesitation, could compete in the PC multimedia market within 2 years and could become the de facto standard digital VCR that will - sooner or later - replace the analog standard, VHS.

However, because it is digital, such a product is inherently a general-purpose mass storage device. It should in no way be limited to a particular digital video format or 'compression' scheme. It could record SD digital video uncompressed in D1 format or 'raw' [as it goes to 3 (R,G,B) D/A converters on its way the screen] for example.

It would also be cheap 'enabling technology' for all sorts of organized [scientific, medical, communications, surveillance, entertainment] and individual [personal artistic video/audio generation, animation] applications that require very high data rates and capacities -- applications that obviously exceed the bandwidth, capacity, and/or storage economy limitations of disk drives, be they magnetic or optical.

TB tape complements GB disk and MB RAM in the storage hierarchy. At 1/1000th the cost per bit and 1000 times the volume density of disk, tape storage is extraordinarily cost-effective. The literal, hence all-purpose, compression of tape storage is far more than is possible and necessary to force-fit hours of digital video onto a disk [DVD included] or into an existing over-the-air television channel.

Given the 4 cubic inch tape capacity of common packages such as those for VHS, 3480, and DLT, a volume density requirement of at least 0.125 terabyte per cubic inch is implied -- which can be achieved with today's key tape and head component technologies. For example, with a 9 µm SVHS-like tape, 50 kbpi linear density, and 3.2 µm track pitch.

The high track density in this example can be supported with today's Thin-Film[write]/MagnetoResistive[read] (TFMR) flying or pseudo-contact head designs -- which continue to be developed for disk drives [to sustain a furious 60% per year areal-density growth rate for another 5-10 years]. Serendipitously, we have found that this narrow-track disk-head technology can be applied directly and reliably to true-contact recording on modern tape -- without significant head wear or performance loss due to pole-tip recession or clogging. A flat-lapped 'row-bar segment', suitably wrapped, can be used to achieve speed-independent output to at least 8 m/s, which is proof of true contact [1].

Given a high channel-density [about 200 per inch] wafer layout [mask set] for such heads, a 20-channel 0.1"-long chip could be produced for example. Such a chip would be about the same size, and therefore have roughly the same mature-process cost, as today's single-channel disk slider, perhaps $20.

A linear drive of extreme simplicity must be designed for lowest production cost [of order $30]. Nevertheless, superb [passive] tracking performance -- nonrepeatability less than 1/10 track pitch p/p, 0.15 µm 0/p -- is needed to reliably support a 3 µm track pitch. We anticipate development of a drive design with only 3 moving parts -- 2 [identical, passive] rotors [hubs of supply and takeup tape packs] and 1 'inchworm-like' head-array [or edge-guide] actuator.

MIT Haystack Observatory is prepared under contract to collaborate in such a necessary new tape drive and/or new [removable] tape package design. In particular, given our analysis and understanding of an existing edge-guide [2], we may be uniquely qualified to efficiently develop the consumer-product edge-guides that guarantee the 'perfect' passive tracking that will permit tape track pitch to be greatly reduced, quite likely to below 1 µm with today's most advanced tapes and head technology that should be in commercial volume production in 3 years.

References

[1] H. Hinteregger, S. Müftü, "Contact Tape Recording with a Flat Head Contour", *IEEE TRANS MAG*. Vol.32,No.5, pp.3476-3478, September 1996.

[2] B. Bhushan, H.F. Hinteregger, A.E.E. Rogers, "Thermal considerations for the edge guiding of thin magnetic tape in a longitudinal tape transport", *Wear,* Vol 171, pp. 179-193, 1994.

Hans F. Hinteregger received B.A. and Ph.D. degrees in physics from MIT in 1964 and 1972 respectively and has been at Haystack Observatory since 1967 at the time of the first very long baseline interferometry (VLBI) experiments. He pioneered the geodetic/astrometric application of VLBI by introducing means to accurately measure group delay (by coherently sampling a wide spanned bandwidth). Since 1975 his work within the Haystack VLBI Group has focused on the development of the extreme wideband digital tape systems required by VLBI. The latest version of this system (Mark IV) has demonstrated 1 Gb/s operation with sixty-four 16 Mb/s channels [using two headstacks of the author's 1985 design].

APPLICATIONS OF

SUSTAINED HIGH DATA RATE RECORDING:

- 'EVERYMAN'S' UNCOMPRESSED SDTV: 0.25 Gb/s x 4hr ➡ 0.5TB

  HDTV: 1.00 Gb/s ➡ 2 TB

- ADVANCED FIBER COMMUNICATION LINK
  1 of many WDM Channels, Each @ 8 Gb/s = GB/s

  WHAT WILL LOG/MONITOR THIS TRAFFIC?

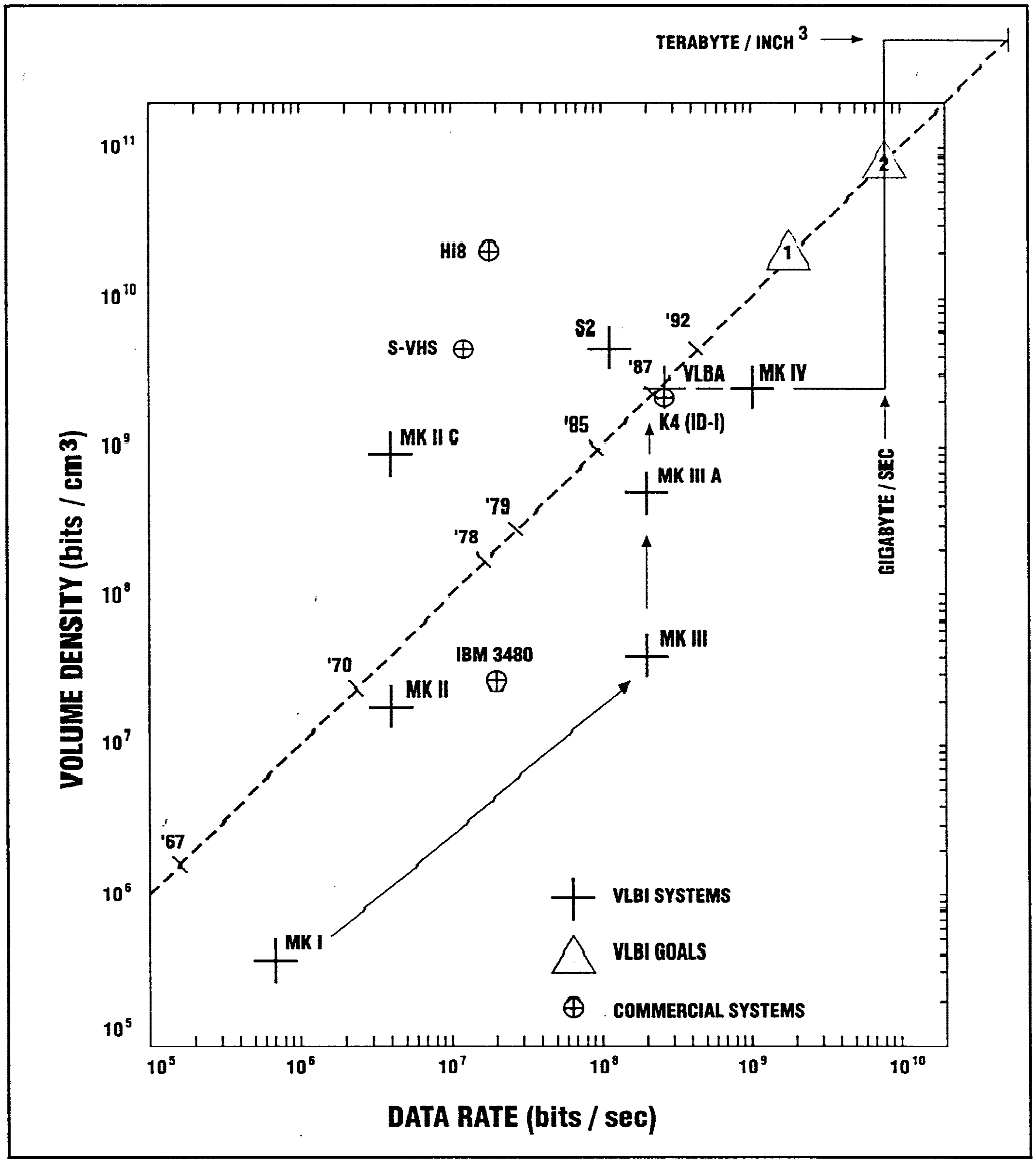
- DATA INTENSIVE SCIENCE, for example:

  VLBI (Very Long Baseline Interferometry)

  ➡ now VLBA (Very Long Baseline Array)
  .128 Gb/s x 10 stations, full-time operation
  ➡ 14 TB/day, recorded and processed

  ➡ 1997 goal #1 a) Gb/s operation, "Mk4"
  b) full-time array ➡ > 100 TB/day

  ➡ 2000 goal #2 a) GB/s operation
  b) full-time array ➡ 10^{15} B/day = Petabyte/day



In the 25-year history of VLBI, data rate has grown by more than three orders of magnitude to one gigabit/second in the Mark IV system. A further hundred-fold improvement in bandwidth and density is now a technically-realistic goal.

VLBI RECORDING GOALS:

0. AT LEAST GIGABYTE/SEC PEAK RATE

➡ NEED CHEAP, FAST, NUMEROUS CHANNELS

EXAMPLE: 576 CHANNELS x 18 Mb/s per channel

1. GIGABIT/SEC FULL-TIME SOON

[VLBA-LIKE OPERATION]

➡ NEED .044 TBYTE/in^3

[MK4/VLBA now at .0055 TB/in^3

2. GIGABYTE/SEC FULL-TIME

➡ NEED .355 TB/in^3

[TB/in^3 LIKELY BY 2000 AD]

- VISUALIZE TB/in^3: for example

10^{12} BYTES/in^3 = 4,000 Layers/in ➡Tape Thickness (TH)

x 12,500 Tracks/in ➡Track Pitch (TP)

x 20,000 Bytes/in ➡Bit Length (BL)

- TB/in^3 VIABLE SOON (by 2000 AD)!

Thickness (1/4 mil):	TH = 6.35µm
Track Pitch:	TP = 2µm
Bit Length @ 160 Kbpi:	BL = 0.16 µm

- 1/8 TB/in ^{3} VIABLE <u>NOW!</u>

TH = 12.7µm	S-VHS-like Tape
TP = 4µm	Disk TF/MR Head
BL = 0.32µm	80 Kbpi

WHAT DENSITY IS NEEDED?

- 4 hours @ 0.25 Gb/s = 0.5 TB
- For 4 in^3 CAPACITY per (VHS,DLT,3480) PACKAGE,

VOLUME DENSITY = .125 TB/in^3

IS ADEQUATE!

<u>WHAT'S NEEDED? IN ORDER OF PRIORITY FOR VLBI</u>

1. **HEAD-ARRAYS:**
   - THIN FILM ➡ HI HEAD DENSITY.
   - MR-READ ➡ HI TRACK, LINEAR DENSITY.
   - PC/CONS.PROD. COMMONALITY ➡ LOW COST.
2. **ELECTRONICS** [MANY-CHANNEL]:
   - ADVANCED COTS [DISK] Ics FOR VLBI;
   - NEED SIMPLIFIED, LOWER-POWER, MULTI-CHANNEL CHIP FOR CONS. PROD.
3. **TAPE:**
   - MR HEAD ➡ PRESENT VLBI TAPE [SVHS-LIKE] CAN SUPPORT 8x to 16x INCREASE IN TRACK DENSITY, 10 KTPI @ 75 KBPI.
   - ADVANCED TAPE ➡ 2-3x LINEAR DENSITY, 25-40 KTPI.
4. **LINEAR DIGITAL VCR ARRAYS:** $250, ≥ 250 Mb/s per drive
   - LINEAR DRIVE COULD OBSOLETE HELICAL VCR IN DIGITAL APPLICATIONS.
   - DRIVE DESIGN SHOULD BE <u>TOP</u> PRIORITY FOR PC/TV CONSUMER PRODUCT

SUPER RESULT w IBM TF/MR DISK HEAD on TAPE:

[EVALUATION sponsored by NSIC]

BETTER SNR OBTAINED WITH 3.8 μm MR HEAD
THAN WITH 38 μm STD VLBI FERRITE HEAD

➡ MR READ-TRACKWIDTH SHOULD GO to 2 μm

➡ TF WRITE-TRACKWIDTH SHOULD GO to 5 μm

➡ TRACK DENSITY x8 with PRESENT VLBI TAPE
go from 576 to 4608 tpi (64 passes x 72 channels)

➡ **FULL-TIME GIGABIT/SEC VLBI PRACTICAL SOON**

NO NEW TAPE EXPENSE SOON

NO INCREASE IN SHIPPING EXPENSE

REDUCED HEAD REPLACEMENT COST

ESSENTIAL FOLLOWUP SUCCESS!

<u>FLAT ROW-BAR CONTOUR WORKS VERY RELIABLY:</u>

GOOD SPEED-INDEPENDENT CONTACT [tested to 8 m/s]

SPACING-LOSS DOES NOT INCREASE WITH SPEED

PREVENTS HEAD WEAR:

NO INCREASE IN MR RESISTANCE OBSERVED AFTER > 2000 HR SHUTTLE, SO NO WEAR [<4 nm] DETECTED

>> 5000 HR PROJECTED WEAR LIFE
[BUT HEAD MIGHT FAIL FOR OTHER REASONS]

MAINTAINS PERFORMANCE:

NO SIGNIFICANT LOSS OF RESPONSE AFTER >2000 HR SHUTTLE.

LESS THAN .5 dB CHANGE AT 4.5 fc/μm IMPLIES < 4nm SPACING CHANGE.

Proposed Monolithic Quad 'Peregrine' VLBI Head-Array

Technology	Thin-Film, 'Merged' MR + 1W
MR	Magnetoresistive Read
IW	Inductive Write
Format	Quadruple 16-channel 'Peregrine' (64 channels on one chip)
Head Pitch	150 µm (x16)
Array Pitch	6600 µm (x4)
Read (Sense) Width	3.6 µm (reduced)
Read Gap Length	0.18 µm (MR to shield)
Write (track) Width	7.2 µm (reduced)
Write Gap Length	0.18 µm (reduced)
Contour	Flat, both corners hard $A\ell_2 0_3 - TiC$, wrapped 1°, for bi-directional contact to 10 m/s

Linear Density	≥2.25 fc/µm with S-VHS-like tape ≥4.5 fc/µm with W-VHS
Media	3M5345/Sony D1K 900Oe S-VHS-like tape, also compatible with 1800 Oe W-VHS-like tape

TF/MR HEAD ARRAY for CONSUMER PC/TV RECORDER

- SIMILAR TO 3M/ Seagate 'PEREGRINE'

- 16 OR 32 CHANNELS ON 1/2" TAPE
  (MONOLITHIC ROW-BAR SEGMENT)

- EXPECT 16-CH CHIP $\frac{MATURE}{PROCESS}$> HI-VOL COST ~ $20

- 256 Mb/s = 32 MB/s AGGREGATE RATE

  ➡ 16 CH x 2 MB/s/CH, @80Kbpi ➡5 m/s SPEED
  or 32 CH x 1 MB/s/CH, ➡2.5 m/s

- TODAY'S TF/MR DISK HEAD DESIGN:
  MR READ SENSEWIDTH ~ 2µm
  TF WRITE TRACKWIDTH ~ 4µm

BASIC ADVANTAGES OF THE LINEAR (Longitudinal) TAPE DRIVE

- MECHANICAL SIMPLICITY:
  2 MOVING PART SPOOLER POSSIBLE,
  1 MOVING PART HEAD-ARRAY ACTUATOR
  ➡ BEST 'INTRINSIC' MANUFACTURABILITY

  ➡ SHOULD HAVE COMPETITIVE EDGE AS *LOWEST-COST* DIGITAL VIDEO RECORDER

- PARALLELISM:
  EASILY SUPPORTS *MANY CHANNELS* (Heads),
  HENCE VIRTUALLY ANY AGGREGATE DATA RATE,
  WITHOUT ADDED COMPLEXITY.

  ➡ CAN CONFIGURE SYSTEM WITH AND/OR USE SIMULTANEOUSLY AS MANY CHANNELS AS BANDWIDTH (Aggregate Data Rate) OF APPLICATION REQUIRES.

PC/TV CONSUMER DRIVE REQUIREMENTS

- LINEAR DRIVE, MAXIMALLY SIMPLIFIED

  ➡ 3 MOVING PARTS: 2 REEL MOTORS
  1 HEAD-ARRAY ACTUATOR

- 'PERFECT' SLIDING EDGE GUIDE

  ➡ PASSIVE (NO SERVO NEEDED TO STAY ON TRACK)

  ➡ VERY CLOSE TO HEAD ARRAY

  ➡ MIT HAYSTACK UNDERSTANDS DESIGN,
  WANTS CONTRACT TO DEVELOP

  < 100 nm p/p NONREPEATABILITY EXPECTED

- DRIVE MECHANICS MASS-PRODUCTION COST: under $30