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To: Distribution

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Subject: Evaluation of Phase-2: Five Supplementary Tests

Summary

This report summarizes the results of 5 additional tests on a Phase-2 Partial VLBI Prototype TFMR Head Assembly composed of 3 1" rowbars provided to Haystack Observatory by Seagate Corp. as part of the Thin-Film Array Project sponsored by the NASA Commercial Projects Office.

Good digital and analog measures of performance were obtained with all i.e., ~20 magnetoresistive (MR) elements tested, including now 5-um-wide as well 12-um-wide sensors.

The write performance of phase-2 inductive thinfilm (TF) heads was found to be about 3 dB less severely compromised than in phase-1 tests even though gaplength in this "partial" prototype is still 1000 nm. The reasons for this are not understood.

Adjacent-channel write-crosstalk is surprisingly high; why is not yet understood; detrimental effects on digital channel performance have not been observed at 80 ips but need to be investigated at 160 and 320 ips.

Write and direct overwrite performance of TF writers was found to be co-optimized at Iop = 20 ma for thin 900 Oe VLBI tape at 56Kfci and results in a typical 10^{-5} raw error rate regardless of whether direct overwrite is used; 16 ma is enough to maximize bandedge response and maintain the lowest error rate on degaussed tape; 24 ma increases the error rate to over 10^{-3}.

A prerecorded Fuji H621 thick tape (27 μm), 6 times as stiff as thin VLBI tape (15 μm), was successfully read at 135 ips in both directions at 2.2 (10" H_20) and 1.1 N (5" H_20) tension, all with identical, stable analog and digital performance. The thick, lower-resolution tape was also recorded with a TF element at both 135 and 80 ips, optimally at 25 and 16 ma for minimum error rates of $1.5x10^{-5}$ and $4.5x10^{-4}$ at 33 and 56 Kfci respectively.

1. Introduction

Reported here are 5 additional sets of tests of a phase-2 partial VLBI prototype TFMR head assembly which complement the main contour geometry qualification tests described in Mk4 memo #269. The supplementary tests mostly confirm, repeat, extend, or slightly modify results or expectations from phase-1. Some of the new tests, 4] and 5] in particular, are not critical to the VLBI application as planned, but are nevertheless important. The following are the tests performed;

1] Digital MR reader performance, using prerecorded thin VLBI tape,
2] Write performance of phase-2 TF heads with 1 μm long write-gaps,
3] Adjacent-channel write-crosstalk,
4] Write/overwrite performance and optimization of long-gap TF writers, and
5] Thick VLBI tape tolerance: mechanical, read, and write.

2. Test Results

2.1 Digital Read Performance with 12 and 5 μm MR Elements

In these tests a thin (15.2 μm) VLBI test tape was read at 80 ips, one reader at a time, with an adequately large sampling of both 12 μm 'data' and 5 μm 'servo' MR readers. This tape was prerecorded with formatted random noise by a standard ferrite .33 μm gap headstack in '97 and it was used for phase-1 tests [ref. Mark4 memo #268].

In all, about 20 phase-2 MR heads were tested, including several 5 μm wide MR 'servo' elements.

- For 12 μm data readers, 10^{-5} to 10^{-6} raw error rate is typical, as is a bandedge signal-to-tape-noise ratio (S/TN) of 26 to 28 dB. As expected, both measures of performance are not significantly different from phase-1. MR data heads for phase-2 are 12 μm wide, identical in design to phase-1 elements except for slightly reduced element-to-shield distance (half-gap).
- For servo readers S/TN is, as expected, typically 4 dB lower than for the 12 μm data heads, still quite high at 22 to 24 dB. In spite of which, error rates rise to 1 to 2 x 10^{-4} for the 5 μm readers. The higher error rates observed with the 5 μm sensors are of little concern in the VLBI application, even if they imply that raw error rate performance is already limited by tape flaws. Though a better equalization/bit-detection 'read-channel' might well improve the observed raw error rates, all digital performance tests to date have been done using only the empirically fixed equalizer 'frozen' in the first successful phase-1 digital read tests in 2/98.

2.2 Less Write Performance Compromise in Phase-2 Long-gap TF Writers

The tests of phase-2, part-1 TF writers with 1000 nm long gap, show about 3 dB less write performance loss, with respect to a recording made with a standard ferrite 330 nm gap VLBI head, than the 6 db relative write-loss at bandedge (900 nm wavelength) found in phase-1 tests (Mark IV memo #268).

This apparent improvement is a pleasant, and perhaps puzzling, surprise with as yet no explanation. A better theoretical understanding is needed and more extensive write-performance testing is also warranted: Only 4 adjacent writers in one phase-2 array have so far been tested.

The 330 nm write gaplength specification for VLBI implementation is not likely to change because,

a) The long-gap short-wavelength write-loss is still significant, and
b) A short gap is needed for adequate resolution when the inductive head is used, as planned, as a high-speed reader in the field for monitoring (spot-checking) write performance.

2.3 Adjacent-Channel Write-Crosstalk

Tests in which up to 4 adjacent writers were simultaneously active exhibited significant write-crosstalk -- in which a fraction of an adjacent-channel's write signal is somehow added to the correct channel's write signal, resulting in a recording which is to some extent corrupted by the simultaneous activity of the adjacent write-channel.

Though no significant increase of error rate due to adjacent channel activity has yet been found, write-crosstalk levels measured with a spectrum analyzer are high enough to be of concern. I did not anticipate a write-crosstalk problem and assumed negligible mutual inductance in these co-planar TF head arrays especially in the phase-2 variety with its writers spaced more than twice as far apart as in phase-1, at a little less than half the current VLBI head pitch. The coupling mechanism is not yet known but needs to be understood; it may have more to do with perhaps improper configuration of the experimental electrical interface than with intrinsic properties of the head-array design. Whether the effect is more serious at 160 and 320 than at 80 ips should be determined. Anecdotally, the current VLBI heads/interfaces show poorer error rate performance in mode A than mode C at 160 ips, and more so at 320 ips, than at 80 ips where there is no difference between mode A (all heads active), and mode C (alternate write heads active); a similar write-crosstalk mechanism may be at work and also needs to be understood.

Fig 1

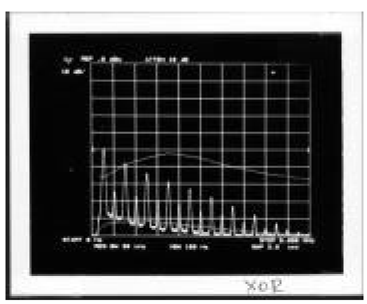


Fig 2

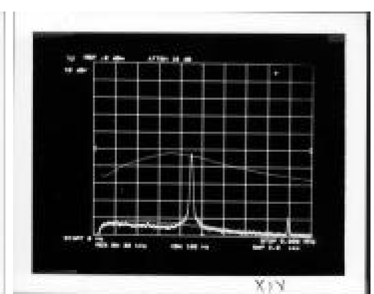


Fig 3

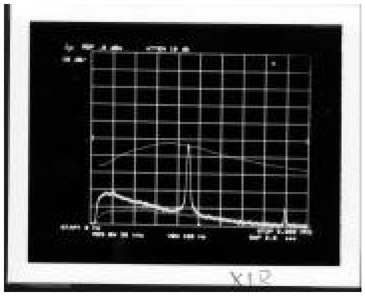


Fig 4

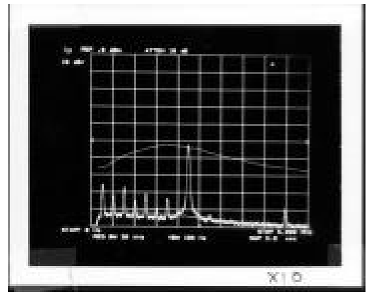


Fig 5

Figures 1, 2, 3 show the S/TN spectra for formatted Random, Zeros, and Ones, respectively. Figures 4 and 5 show the Ones S/TN spectrum with one-sided adjacent-channel random and zeros interference, respectively. The 1/9th bandedge parity pip at .25 MHz, which is due to the alternating-sign impulse-train component of the VLBI-formatted random interfering signal, is seen to be attenuated only 20 dB as write-crosstalk. The same frequency fundamental of the (almost) pure square-wave, produced by odd-parity NRZI-formatted Zeros interfering signal, is at 27 dB more highly attenuated as write-crosstalk, but peak interference to signal ratio in this case is only -22 dB compared to about -29 dB for random interference.

Note that an optimized read-channel would equalize the dominant tape-noise, whereas the equalizer actually used, as seen in the faint TN traces in the figures, attenuates the 1/9 bandedge tape-noise, hence also signal, about 10 dB with respect to 5/9 and 9/9 or 12 dB with respect to 7/9 bandedge. Though not optimized for random noise, this equalizer may therefore be more robust against low frequency or long-wavelength interference such as results, for example, from the relatively poor direct long-wavelength overwrite capability of these heads -- which becomes even poorer when write gaplength is reduced, as it should be.

2.4 Write/Overwrite Performance Optimization, Erase Capability of TF Writers

The magnitude of record current has a profound and highly wavelength-dependent effect on the recorded spectrum. Fig. 6 shows the superimposed read spectra of Random recordings made with a TF element with 16 and 37 ma, zero-to-peak write current. 16 ma is the lowest current at which the 2.25 MHz bandedge response is maximized; 20 ma is the highest; at 37 ma the bandedge response is attenuated 13 dB, whereas at 1/9 bandedge (1st parity pip, .25 MHz) the response is increased 10 dB. The bright trace is TN at 80 ips.

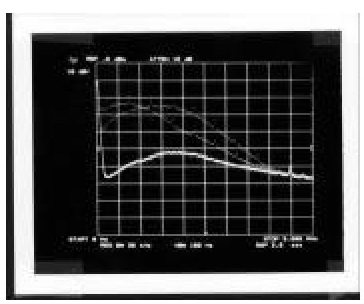
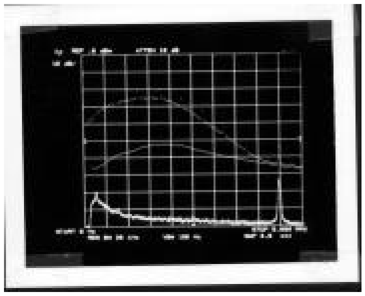


Fig 6



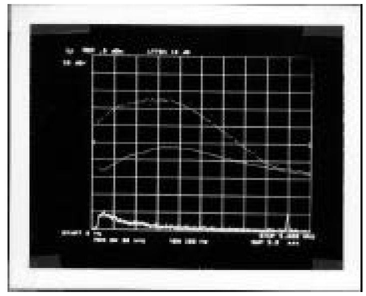


Fig 7 Fig 8

Erase Capability: The bright traces in Figs. 7 and 8 show the Erased-Signal (ES) to TN ratio, or ES/TN resulting from attempting to erase the 16 ma Random recording with Double-Density (DD) Ones at 16 and 37 ma respectively. 16 ma erase knocks the 1/9 BE pip down only 15 dB from 35 to 20 dB; 37 ma is 10 dB better providing 25 dB erasure of the 'stubborn' 1/9 BE signal. Note also that the DD Ones 'recording' made at 37 ma is 17 dB weaker than that made at 16 ma. As long as the TF head does not saturate,[1] selective-erase capability is improved by increasing current.

Fig 9

Fig 10

Write Current Optimization: The bright traces in Figs. 9 and 10 compare the Random spectra written at 24 and 20 ma respectively to the faint 16 ma spectrum. At 24 ma the tape is already substantially overdriven with error rate over 10^{-3}, whereas at 16 to 20 ma minimum error rate of typically 10^{-5} is achieved. The subtle clue to overdrive in the spectrum of Fig. 9 is that bandedge is slightly attenuated, by about 2 dB, at 24 ma. At 16 and 20 ma the bandedge response is identically maximized; the higher current produces a monotonically increasing relative output with increasing wavelength so that at 1/9 BE 20 ma drive produces 5 dB more output than 16 ma, but this results in no error rate improvement when writing on a bulk degaussed tape.

Direct Overwrite: At 20 ma direct overwrite of Random by Random does not result in a significant increase in error rate; at 16 ma direct overwrite error rate increases ~50%.

At 20 ma DD Ones erasure of a 1/9 BE = 8.1 µm recording is -16 dB while erasure of BE = .9 µm signals is -30 dB. Erasure is also cumulative; a second erase pass will knock the 1/9 BE signal down another 16 dB for example.

[1] Unlike our short-gap ferrite heads, which saturate before being able to heavily overdrive the 900 Oe tape.

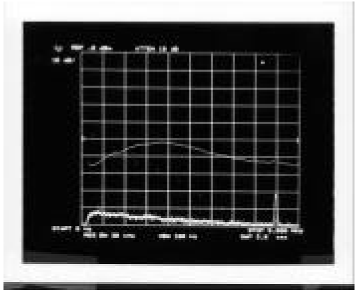


Fig 11

Fig. 11 is the 20 ma DD Ones S/TN with 18 dB C/TN at double BE and modulation noise ramping up to MN/TN = 7 dB at 1/9 BE, just like for Ones in Fig. 3.

2.5 Thick VLBI Tape Mechanical Tolerance, Read and Write Capability

In order to test the mechanical compatibility of thick tape with the 1.5 mm wide triple-flat prototype contour, playback of a prerecorded Fuji H621 tape was first attempted at 135 ips and 2.2 N tension. This resulted immediately in a stable eye pattern and a reasonably low error rate of 2.5×10^{-4} in spite of the highly attenuated low-frequency response in Fig. 12. At bandedge S/TN = 26 and TN/EN = 7 dB.

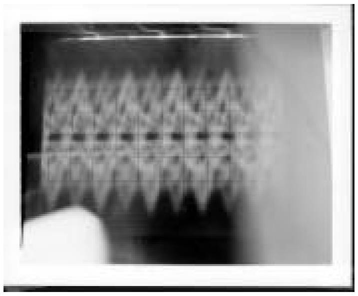


Fig 12

Identical performance was obtained in the opposite direction of tape motion and also at 1.1 N tension in both directions.

Best BER ~1.5×10^{-4} H621 w TF at 33 Kfci

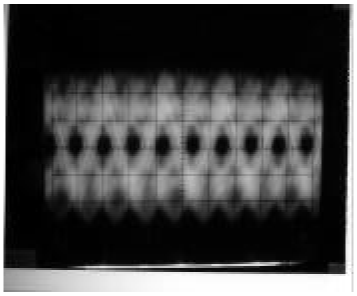


Fig 13 25 ma

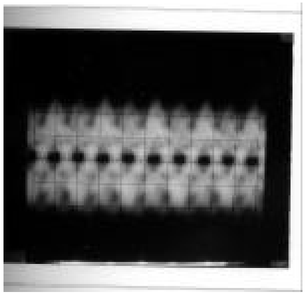


Fig 14 20 ma

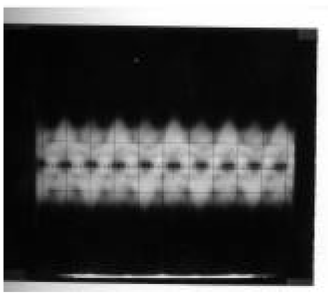


Fig 15 16 ma

Recording with a TF writer first at 33 Kfci (135 ips) and then at 56 Kfci (80 ips) was then attempted, in each case with trial write currents of 25, 20, and 16 ma. The corresponding eye patterns are Figs. 13, 14, 15 for 33 Kfci and Figs. 16, 17, 18 for 56 Kfci. Figs. 19 and 20 show S/TN spectra as the bright traces for the best write current, 25 ma for 33 Kfci and 16 ma for 56

Kfci respectively. Bandedge S/TN is 23 and 16 dB and error rate 1.5×10^{-5} and 4.5×10^{-4} respectively.

H621 w TF at 56 Kfci

Best BER ~ 4.5×10^{-4}

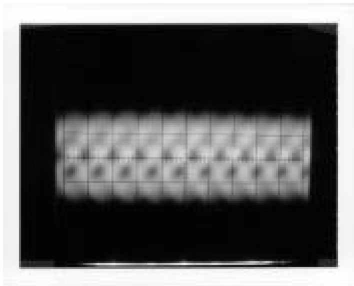


Fig 16 25 ma

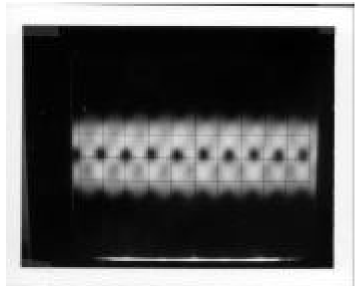


Fig 17 20 ma

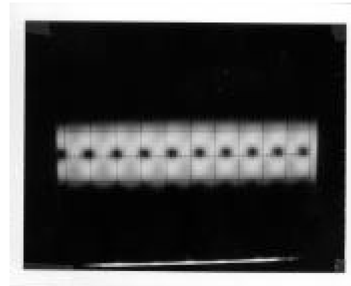


Fig 18 16 ma

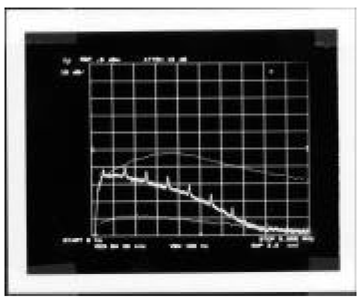


Fig 19
33 Kfci at 25 ma

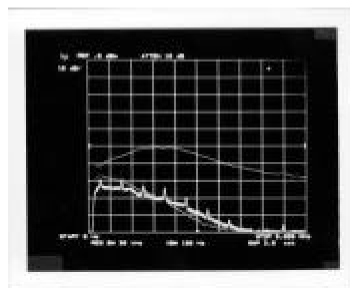


Fig 20
56 Kfci at 16 ma

3. Future work

As mentioned in 2.3, adjacent-channels write-cross-talk, which is observed to be significant but without detrimental effect on error rate at 80 ips, needs to be checked at 160 and 320 ips write speed. An electromagnetic model of the head and its experimental interface is needed to interpret the results and to properly design a parallel head interface for a full implementation prototype.