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Subject: Review of Feb-Aug '00 Notes: High-Speed Head and Interface Problems and Fixes

Introduction

This memo is a detailed recapitulation and review of my high-speed read and write problems-related work from Feb'00 through Aug'00. The successful highest-priority effort was to test adequately-modeled means of reducing severe high-speed read-crosstalk to acceptably low levels.

Severe high-speed write- and read-crosstalk problems had become evident by mid-'99. My preliminary experimental characterization of these problems and efforts to model them in 3 & 4 Q'99 were summarized in a Jan'00 internal memo – on which primarily the successful high-speed read-crosstalk reduction efforts were based. Efforts to more fully characterize, understand, and mitigate high-speed write-crosstalk were also undertaken – with somewhat less success, due in part to the less-tractable non-linear nature of the write and hence write-crosstalk processes.

Summary of Main Conclusions

The observed problems were found to be due generically to:

- a too-high-inductance standard head specification, and
- a current read-only head-interface design clearly not suited for 280 ips playback.

SP headstacks were found to be inferior to Metrum for reading at high speeds ≥ 160 ips:

- high-speed efficiency rolls off ~ 3 dB w/r Metrum at 160 ips bandedge, > 6 dB at 320 ips bandedge,
- channel-to-channel variation of SP efficiency is typically 5 dB, usually independent of wavelength -- compared to typically 2-3 dB at bandedge, but < 1 dB at long wavelengths for Metrum.

Standard SP headstacks also exhibited serious, but usually tolerable, write and write-crosstalk problems already at 160 ips write-speed. These problems were another major consequence of both the high variability and high frequency rolloff of efficiency. The 160 ips write-performance of several SP headstacks tested appeared more degraded, due to the combined effects of large efficiency variations and 160 ips write-crosstalk, than the 320 ips write-performance of a standard Metrum headstack which was less degraded nearly solely by (somewhat higher) 320 ips write-crosstalk.

Because 320 ips write-performance of standard SP headstacks was known to be unacceptable, the high-speed write-performance of an experimental $\frac{1}{2}$ -inductance $\frac{1}{2}$ -depth-of-gap SP headstack was investigated in 4Q00 and reported in memo #286. This experimental SP headstack was found to have acceptable 320 ips write-

performance. However it was at best only comparable to that of a standard-inductance and depth-of-gap Metrum headstack. The experimental SP headstack's 320 ips write-performance observed, though comparably degraded, was better than the 160 ips write-performance of any of the several standard SP headstacks reported on in this memo #285. Similarly specified 1/2-inductance and 1/2-depth-of-gap Metrum heads are expected to have much better 320 ips write-performance with little or no degradation due to write-crosstalk and/or poor, highly variable and frequency-dependent, efficiency.

The main recommendations resulting from the detailed work of this memo # 285 are for

1. lower-crosstalk, higher-SNR (1/2-inductance, 1/2 depth-of-gap) specs for new headstacks, and
2. design of new low-capacitance read-only head-interfaces to enable 280 ips processing.

These recommendations are discussed in memo #284.

Three specific revisions to new headstack procurement specifications,

1. inductance (turns) reduction,
2. efficiency increase (depth-of-gap reduction), and
3. improved minimum SNR (preferably tested at 280 ips)

are succinctly proposed in memo #288. This memo also reports good 80 and improved 160 ips read-performance observed so far in two recently May'01 delivered 1/2-inductance Metrum headstacks (which are considered to be 'worst-case'-efficiency test cases, due to their large standard, actually ~ 35 micrometer, depth-of-gap).

Summary of Additional Results and Conclusions

The main body of the detailed chronological review, which follows this section, also contains several other important additional investigations, results, and conclusions. These are briefly summarized here:

1. A standard Metrum headstack had acceptable 320 ips write-performance, with PER = 1 to 6×10^{-4} in read-crosstalk-free 80 ips playback. This range of error rates is within the formal digital performance specification, though considered 'marginal' with PER degraded by about a factor of 40 by 320ips write-crosstalk as compared to recordings written at 80 or 160 ips. Similar Metrum 320 ips write performance was found and judged typical in the work of 4Q00 described in memo #286, using both a Metrum triple-cap with Mk4 1000-ohm read-or-write interface, and a stepped Metrum stack with Mk4 1000-ohm write-only-interface.
2. Reduction of depth-of-gap from 35 to 10 um in Metrum sample WTF headstack increased efficiency (read SNR) by 5-6 dB. Similar gains have been observed in heavily worn Metrum stepped heads as reported in the past.
3. Metrum's experimental Wide Triple-Flat, WTF, contour was easily 'spoiled', but virtually 'unwearable' in normal operation. Optical observations of microindentations would have detected as little as 25 nm of wear, but no wear was detected after >2000 hours of tape shuttling, during which partially spoiled performance did not recover and finally began to further degrade. Later in 12/00 as described in memo #287, full 'recovery' of SNR-performance was demonstrated for a 2nd spoiled WTF-contour headstack: A proprietary wear-accelerating tape-lapping device and a tedious procedure recommended by Metrum were successfully used, but 'maintainability' of recovered SNR performance and stability remains unknown. It was decided not to 'implement' WTF for these reasons, as well as much higher price. The wear-accelerating device is simple and useful for contour restoration, and damaged-layer removal – but is recommended only for very cautious and expert use!

4. S/RX and S/WX (Signal/ReadXtalk and Signal/WriteXtalk) ratio as function of speed and frequency were measured with mode C, and 'Mixed mode A', MA (simultaneously-written interleaved 'ones' and 'random' channels), test recordings respectively. Digital PER performance is related to these analog measures of cross-talk, but not unambiguously so -- especially in the case of S/WX:
5. In SP but not in Metrum headstacks for example, Non-linear Transition Shift, NLTS, due both to high rolloff and variability of head efficiency, appeared to play the dominant error-producing and -compounding role at low 80 ips as well as high 320 ips write-speeds respectively. The several standard-inductance SP headstacks tested exhibited least-compromised write-performance at 160 ips with marginal $PER = 1-6 \times 10^{-4}$ in most, and higher out-of-spec but still processable $PER < 10^{-2}$ in a few channels. SP 80 ips write-performance was markedly poorer but processable.
6. Standard-inductance SP 320 ips write-performance in earlier tests was so poor as to be judged 'unprocessable' with $PER > 10^{-2}$ and high sync-loss rates. A 2000-ohm read-or-write interfaced SP stack yielded S/WX ~ 8 dB at the 9 MHz 320ips-bandedge, 4 dB worse than standard Metrum heads using 1000-ohm write-only or read-or-write interfaces (see memo #286); the halved L/R time constant did not 'fix' the write-crosstalk problem, but rather made it worse.
7. SP headstacks, unlike Metrum, required a tricky and fragile careful-compromise write-voltage determination, and also, much to my surprise, significant bandedge 'underdrive' in order to minimize error-rate. Because of the latter, SP stacks have greater write-crosstalk susceptibility for a given level of write-current cross-coupling.
8. We therefore strongly recommend careful determination and occasional re-checking of write-voltage such as to minimize error rates of worst channel(s) at 80 ips write-speed:
 - For Metrum headstacks, write-voltage is easier and less critical to properly determine. In all experience to date, write-voltage just high enough to fully maximize bandedge output of all channels within $\sim 1/2$ dB produces the lowest error rates. Slight 'underdrive' is tolerated gracefully; 'overdrive' is not.
 - For SP headstacks, the critical-compromise write-voltage was found to be such that bandedge output of all channels was 'underdriven' (below maximum) by typically 2 ± 1 dB.

Chronology

4feb00 minutes#41:

- High-speed read- and write-crosstalk and other problems: Summary document of my 1999 findings was distributed internally.
- Judged reading at 280 ips to be impossible with current-configuration Mk4-processor read-only head-interface -- primarily because this [capacitively overloaded] interface pulls resonance down to less than ~ 8 MHz, the 280ips-bandedge-frequency, where signal-to-read-xtalk ratio, S/RX, is thereby catastrophically reduced to ~ 0 dB.
- Mode A 320ips-write-crosstalk also degrades recordings. In essentially read-xtalk-free playback at 80 ips, at least one, typically two, orders of magnitude increase in PER w/r to 160 or 80 ips recordings are observed -- though tapes written by Westford's Metrum headstack with its 1000-ohm write-only interface at 320ips still, barely, passed the $PER < 6 \times 10^{-4}$ spec in 80 ips playback.

- Mode A written at 320 ips should be readable at 160 ips, better with Mk3 read-only interfaces that resonate at ~ 10.5 MHz than with as-is reduced-resonance Mk4-processor interfaces that resonates at ~ 7.9 MHz. Note, 160 ips readability of 320 ips mode A recordings has not yet been verified.
- Dan S. fielded mostly 1500 and 2000 ohm WO and RW interface variants. Do they reduce write-xtalk? Not yet directly tested by anyone! Should verify that these variants are at least not worse than the well-tested 1000-ohm interfaces at Westford. The latter appear now satisfactory for 320 ips data acquisition with standard Metrum heads -- provided read-crosstalk is reduced sufficiently in the recommended new read-only processor head-interface to be qualified for 280ips playback.
- Is 280 ips read (mode A playback) with current-standard heads and current-Mk4-standard processor interfaces feasible? Answer: NO! At least, new or extensively reworked processor read-only interfaces are needed to move resonance beyond 12 MHz -- as recommended in summary in memo #284.
- Does shallow gap (of experimental sample Metrum wide triple-flat headstack under test) lower high-speed read-crosstalk? Answer: Not much inherently -- unless new interface design moves resonance beyond 1.5 bandedge.
- Do reduced-turns (half standard inductance)headstacks reduce read-crosstalk? write-crosstalk? Answers to date of this review: Clearly YES in both theory and practice for the linear read-crosstalk! I have no good theory for the non-linear write-crosstalk. Only one experimental SP 35-turn 12-micron depth-of-gap headstack was write-tested in 4Q00 (details in memo #286): Write-performance of this half-inductance SP stack was better at 320 ips than that of several standard SP stacks at 160 ips (as reviewed here in memo #285). Nevertheless the improved $\frac{1}{2}$ -inductance SP stack's 320 ips write-performance was at best only comparable to that of standard-inductance Metrum headstacks. Thus, further improved 320 ips write-performance is expected with reduced-inductance Metrum stacks, but this expectation is still untested – high-speed read-performance tests of the 2 reduced-inductance Metrum stacks recently received have priority.

29feb00 minutes#43:

- Sample Metrum headstack (with standard-inductance, volunteered wide triple flat contour, and ~ 10 um shallow depth-of-gap) yielded S/EN ~ 27 -28 dB in first tests, a 5-6 dB output increase w/r standard initial depth-of-gap Metrum heads for which S/EN ~ 22 dB is typical at 160 ips (20 dB minimum is specified).
- I accidentally 'spoiled' part of the contour with momentary Q-tip pressure and high tension 'cure' for spacing loss and instability in part of the stack.

HFH 16feb00 Note:

Knowns

- 17-18 dB bandedge SNR at 80 ips can yield PER $\sim 10^{-5}$ if write-xtalk & write-nonlinearity [intersymbol interference] are not significant.
- Read-xtalk is proportional to head impedance, hence read-speed, for a given head-inductance and wavelength: 5 dB worse at 280 than at 160 ips.

- On Mk4 processor drives the head-interface emitter-follower is currently loaded, not just by its own capacitance and the head, but by a parallel load -- the grounded series combination of write-resistor and antiparallel isolation diodes. This use of for-read-only-superfluous write-components in the current 'Mk4 processor-head-interface configuration' was chosen by Dan as an expedient way to stabilize the preamps.
- The extra 4 pF of the grounded isolation diodes however lowers the resonance frequency from ~10.5 to 7.9 MHz -- which maximizes read x-talk at the 280ips bandedge! For reading at 280 ips, the preamp should be stabilized without extra capacitive or resistive loading of the emitter follower.
- The head/interface resonance frequency should be raised to at least 12 MHz, 1.5 times the 280 ips bandedge at ~ 8 MHz, to reduce the known enhancement of read-crosstalk near resonance to acceptable levels. This can be done by:
 1. reducing head inductance in replacement heads, and, as was shortly shown, by
 2. replacing, with a suitable lower-capacitance transistor to be identified, the current ~ 8 pF 3906 head-interface transistor.

Reduced 48->35 turns expectations; Read-crosstalk and Write-crosstalk tests

- 1/2 inductance of std. head implies 6 dB reduction in read-crosstalk [far from resonance]. Linear effect is quantitatively understood.
- If capacitance is fixed, 1/2-inductance increases resonance frequency by $\times 1.4$ -- therefore greatly reduces the easily-modeled strong enhancement of read-crosstalk near resonance by substantially increasing the distance between the highest-speed 280ips-bandedge and resonance.
- Read-crosstalk test: Compare spectra of unrecorded channels with recorded ones in a [cross-write-free] mode C recording. For standard 48-turn heads with Mk4 read-or-write interface or Mk3 read-only interface resonant at ~10.5 MHz, Signal to Read-Xtalk, S/RX, is only ~12 dB at the 320ips-bandedge, 9 MHz. This corresponds to + and - 35% worst-case 'instantaneous' interference voltage from both adjacent channels, each 25% of the time.
- Write-crosstalk test: Record 'Mixed mode A', MA, in which the even (odd) channels are independent random data and odd (even) channels are coherent 'all ones', a pure bandedge signal, under the conditions (speed, write-voltage) of interest. Compare the random with the ones spectra. The ratio of random to ones spectra is Signal to Write-Xtalk ratio, S/WX (except at bandedge, and only if random-to-ones write-crosstalk exceeds 'ones' noise-floor below the monochromatic bandedge 'ones' signal frequency). Heuristic expectation: reduced inductance --> reduced write-xtalk. But no plausible even only semi-quantitative theory for the non-linear write-crosstalk processes was developed.

Note: At 320 ips write-speed, S/WX of a 35-turn SP stack tested in 4Q00 was not better than S/WX of two 48-turn Metrum heads compared (using the same 1000-ohm write-only and read-or-write interfaces respectively). But the 320ips performance of the 35-turn SP stack in memo # 286 was better than several 48-turn SP stacks tested at 160 ips write-speed in this memo # 285.

19apr00 minutes#46 my progress report

- Demonstrated 8 dB reduction of 'mode A' read-crosstalk at 270ips-bandedge using a standard-inductance 48-turn Metrum headstack with a pair of modified Mk3 read-only head interfaces. Two critical modifications increased mode A S/RX from 'poor' 12 dB to 'good' 20 dB:
- The 100ohm/470pF version of the 'Ingalls' filter introduced by Alan Rogers in '89 was found necessary to prevent oscillation -- when both even and odd interfaces are physically connected for mode A read-capability. Replacement of the 'old' 270ohm/100pF by the 100ohm/470pF version reduced the resonance frequency from 11.5 to 10.5 MHz -- with only one odd or even interface connected as in most Mk3 field recorders.
- When a second interface was connected a 'co-resonance' peak appeared at even lower ~9.3 MHz frequency -- where S/RX went to ~ 0 dB. At the 7.5 MHz 270ips-bandedge S/RX was only 12 dB. Co-resonance at only 1.25 times bandedge is clearly not acceptable.
- Without the second interface connected (that is, removing the 8 pF load of the 3906 emitter followers on adjacent heads) S/RX > 20 dB was apparent. Thus reduction of interface capacitance was shown clearly to greatly reduce read-crosstalk by moving resonance further away, to at least 1.4 times bandedge frequency.
- Low-capacitance transistor candidates BF550 and BF824 were tried as replacements for 3906s in two interfaces and yielded 270ips-bandedge S/RX ~ 20 dB with co-resonance at ~ 12 MHz.

2may00 minutes#47 my progress report

- No magic bullet for 320-ips write-xtalk: Halving the L/R time-constant -- Dan used 2K instead of 1K or 1.5 K resistors in HartRAO's write-only interface, part of assembly under test at Haystack with a pair of standard SP headstacks -- did not improve S/WX ~12 dB at the 9 MHz 320ips-bandedge. This is about the same as Westford's Metrum head with the 1K interface. At 160 ips write-speed S/WX ~ 17 dB is much better in both cases. The 2K read-or-write interfaced head, capacitively loaded by the transistor, was even worse with S/WX ~ 8 dB at 320 ips, though at 160 ips S/WX ~ 17 dB was the same as for the write-only interface.
- A smaller ferrite bead, J.W.Miller FB73-085, suitable for incorporation in new 280-ips-qualified Mk4 read-only interfaces, was identified and successfully tested -- by substitution of the much larger beads that are part of standard Mk3 read-only interfaces -- but not yet part of VLBA/Mk4 interfaces. Mk3 interfaces -- even with lower impedance 'Ingalls' filter and low-cap BF550 transistors -- are typically unstable [oscillate] if the emitter wires do not pass through ferrite beads.
- BFT92, which is readily available, was identified for test as candidate substitute low-capacitance transistor for BF550, which is not.
- Wear test of Metrum sample WTF (Wide Triple Flat contour: 1 mm central 'headland' , 0.5 mm outriggers, 0.5 mm grooves, ~ 20 mm radius): Observe wear proportional to, ~ 1/40, of optically apparent shortening of diamond-shaped micro-indentations, so that observable 1 um shortening of indentation corresponds to ~ 25 nm wear detectability. No wear of WTF was detected (upper limit 25 nm) after 1000 hours of running at 270 ips (< 1 um in 40,000 hours). A microindented stepped head (with only a 0.3 mm headland) served as control; it actually wore 1/6 um in 200 hours, at least 33 times faster than WTF -- nevertheless equivalent to only 25 um in 30,000 hours, a very slow rate due to the enforced dry < 20% RH tape-path condition.

16may00 minutes#48

- **BFT92 was found to work as well as BF550** – and is now recommended for new 280ips-qualified Mk4 read-interface, along with small beads and lower impedance 100ohm/(470pF to 0.1uF) Ingalls filter.
- Tested this modified Mk3 interface with **35-turn 10 uH SP headstack** -- resonates with low Q at ~ 18 MHz, up as expected from ~ 12 MHz when mated to a 48-turn ~ 20 uH standard-inductance headstack.
- Verified **robust bidirectional contact and contact-stability** of this triple-cap SP headstack at 270, 135 ips and 7.5, 10, 12.5" vacuum.
- Verified $S/RX \geq S/EN = 17 - 21$ dB at 7.5 MHz, the 270ips-bandedge.
- **S/EN has large 5 dB spread, 16.5 to 21.5 dB at 135ips-bandedge.**
- SP output doesn't increase with speed as it should: S/EN at 270ips identical to 135ips, within +/- 0.5 dB. Difference, 270-135 ips, should be + 3 dB. Implies 3 dB efficiency rolloff from 3.75 to 7.5 MHz. [Note for comparison: Metrum's WTF with similarly shallow ~ 10 um gap rolls off at most 1 dB.]
- The most efficient SP head at 21 dB, corrected to 24 dB if it had 48-turns, is still 3-4 dB less efficient than the typical 27-28 dB for WTF. With the SP stack's 5 dB spread (compared to 2 dB typically for Metrum), **worst-case SP channel was at least 6 dB inferior to worst-case Metrum.**
- The large **output differences between channels in the the SP headstack were found to be independent of wavelength** (or frequency at any given speed) to within less than 1dB. This rules out variable spacing and gap-length as causes. The wavelength-independent differences suggest large and variable back-gap reluctance as cause of the relatively poor and variable head efficiency observed.
- One of the SP channels showed **evidence of having a cracked tip**, an irregular second effective gap, which results in a **'fuzzed out' undecodable eye-pattern**. In this, as in some other such cases seen in the past, the spectrum observed with analyzer looks normal. Thus the eye as well as the spectrum should be checked when a headstack is tested for functionality within specification.

30may00 minutes#49

- For a standard **SP head write-crosstalk degradation of PER at 160 ips was found to be as severe as for a standard Metrum head at 320 ips**. A standard SP triple cap from HartRAO, with 2000-ohm write-only interface driven at 19 volts, showed clear evidence of significant write-crosstalk degradation writing at 160ips: Mode C PER $< \sim 10^{-5}$ degraded to $\sim 10^{-4}$ in mode A with measured S/WX ~ 17 dB. Earlier tests at Westford with a Metrum head and 1000-ohm write-only interface showed no such degradation with comparable S/WX at 160 ips, but comparable degradation at 320 ips with lower ~12 dB S/WX. The discrepancy is now thought to be due to characteristically higher Non-Linear Transition Shift, NLTS, written by SP heads, which increases or compounds PER sensitivity to write-crosstalk. No independent measure of NLTS has yet been attempted.
- The Hartrao assembly was conditioned for robust contact with a Metrum-proprietary wear-accelerating device in the tape path. For future reference: Caution! With this device in place, a single round-trip of Fuji H621 at 30" vacuum and 50% RH wore the triple-cap about 1/3 um. These

conditions maximize the head-conditioning wear-rate and produce an 'equilibrium-contour' for thin tape operating at 5" vacuum, which is a little flatter [more conservative for robust contact] than the equilibrium contour for actual thin tape operation at 10" vacuum. There are many ways to slow the conditioning process down while targeting the same equilibrium contour but none are calibrated.

13jun00 minutes#50

- SP typical problems, also seen by NRAO, summarized:
 1. Large 5 dB wavelength-independent head-to-head read-output variations within a stack.
 2. Low high-frequency efficiency, so that SNR at 160 ips is sometimes worse than at 80 ips instead of 3 dB higher.
 3. Significant probability of bad, easily-smeared gaps and cracked head-tips -- which can pass SNR spec but not open-eye check.
 4. Typically high and highly-stack-to-stack-variable adjacent-channel mode A write-crosstalk at 160 ips write-speed, at best averaging $PER \sim 10^{-4}$ comparable to Metrum at 320 ips, some SP channels typically failing $PER < 6 \times 10^{-4}$ spec but decodable at $PER < 10^{-2}$, worst cases sometimes undecodable or unuseable with high 5 -10 % resync rates.
 5. Can't qualify typical standard SP headstack for Mk4 320 ips mode A write-operation.
- Hartrao's SP write-stack returned to its 'fragile-contact' preconditioned state – with poor, unstable contact in high-numbered channels in forward 160 ips operation with only slightly-low 8-9" vacuum - - after a weekend shuttle of thin tape at 160 ips, 10" vacuum standard operating conditions.
- Experimental Metrum WTF after 1800 shuttle hours began to show spacing-increase evidenced by read SNR degradation. No degradation was observed to 1200 hours with a single shuttle tape; then fresh shuttle tapes began to be used at 48-72 hour intervals.
- S/WX (of Wettzell's SP write-stack under test at 160 ips write-speed) was only ~ 11 dB at bandedge, identical for trial write-voltages of 16 and 13 volts.
- Bandedge output at 13 v was reduced (underdriven) ~ 1 dB w/r 16 v. But PER at 13v was 2-3x lower than at 16 v.
- Even mode C recording, free of write-crosstalk, had lower PER at underdriven-bandedge 13 v write-voltage.
- Underdriven-bandedge optimization of PER was unexpected, and has never been observed with a Metrum headstack.
- Abnormal SP write-behaviour is probably linked to sharp rolloff of SP head efficiency with frequency. It becomes possible to overdrive mid-band wavelengths -- resulting in NLTS and therefore high PER -- at write-voltages lower than required to saturate bandedge. A good-compromise write-voltage, which minimizes PER of worst-case channel, thus becomes difficult to determine -- and remains in any case a highly sensitive 'fragile' function of write-speed in particular.

- Best compromise 13 v at 160 ips write-speed resulted in 3 of 14 tested channels with fail-spec PER = 10^{-3} to 10^{-2} – as read at 80 ips with ‘pretty-good’ 35-turn ½-inductance, 12-um ½-depth-of-gap, experimental SP headstack.
- Even this 12-um shallow-gap SP headstack exhibited high 3 dB efficiency rolloff to only 4.5 MHz, the 160ips-bandedge; standard depth-of-gap SP headstacks have comparable or even greater efficiency rolloff with frequency, typically ≥ 8 dB to 8-9 MHz.

1aug00 minutes#51

- Overdrive Danger, another example: A mode C 80 ips ‘reference tape’ was recorded at Westford, using by default the ‘operational’ 10 v write-voltage determined in some fashion at least a year earlier and never re-determined since. It produced unexpectedly high PER $> 10^{-3}$. Suspicion of overdrive led to new trial mode C recordings at 8 v -- which reduced PER $< 10^{-4}$, more than order-of-magnitude. Bandedge output also increased 2 dB at the lower write-voltage. This showed clearly that Westford’s heavily-worn Metrum stepped headstack was severely overdriven at 10 volts and needed the reduction to 8 v operational write-voltage.

Lesson: Determine (re-determine as needed, if suspect, if heavily worn) the operational write-voltage so as to minimize worst case error rate in mode C at 80 ips write-speed; check that error rates are higher at candidate operational voltage + and - 20 %. Use mode C at 80 ips to provide highest head efficiency at low speed and freedom from write-crosstalk.

- More write-crosstalk with SP than with Metrum at 160 ips: S/WX ~ 15 dB at 7/9 th bandedge was measured using Westford's worn [shallow-gap] stepped Metrum write-stack, driven at 8 v, writing 'mixed mode A' for write-crosstalk determination, at 160 ips. This Metrum 'reference' S/WX is 2.5 dB better than the corresponding S/WX ~ 12.5 dB of the SP Wettzell head under test above.
- Using the same experimental reduced-turns shallow-gap SP 80-ips read-configuration as above for the Wettzell SP 160ips-write evaluation, the Metrum mode A 160ips-write PER $\sim 10^{-4}$ - 10^{-3} was an order of magnitude better than could be obtained with Wettzell's standard SP write-stack.
- The digital read-performance of the low-turns, shallow-gap SP headstack, at its best with reasonable minimum 18 dB S/EN at 80 ips, was nevertheless an order-of-magnitude inferior to the good PER $\sim 10^{-5}$ - 10^{-4} observed with the operational standard-turns, 35-um deep-gap Metrum reader at Westford, with essentially equal S/EN. However, the apparent inferiority of the exp. SP head as an 80ips-reader was not conclusive -- could have been an artifact of subtle differences in Westford vs. 'Quabbin' test tape drive configuration and electronic interference.
- WTF sample was returned to Metrum for reconditioning of spoiled contour and possible re-evaluation thereafter. This was done after >2000 hours shuttle was stopped 19 June. And after noting
 1. Further read-performance degradation -- spacing-increase, instability, and direction-sensitivity -- at 270 ips, but
 2. No wear was detected (25 nm upper limit on reduction of depth of microindentation, corresponding to < 1 um optically-apparent shortening), and
 3. After the following final observations and sensitivity tests:
 - The 1st 4 and last 4 of 36 heads in WTF were accessed by modifying Mk3 interfaces as needed -- and found to behave like the central 28.

- A sign of further degradation was unstable contact even on the 'good' unspoiled-contour end of WTF at 270 ips, but
- At 135 ips, contact remained stable and no forward vs. reverse spacing difference ever became evident.
- Overnight 135ips shuttle at ~ 40% RH with dry air kit turned off: improved bandedge output (reduced spacing-loss) ~ 2 dB both at 135 and 270 ips and made the recent symptom of contact-instability on the 'good' end disappear.
- Second overnight shuttle at 67.5 ips had no further effect.
- Final test at 20% high 12" vacuum: The 'bad' accidentally-spoiled-contour end of WTF became stable, as never during the long 270-ips shuttle at 10", and the large characteristic forward/reverse difference in spacing at 270 ips on the 'bad' end disappeared as well.
- At 12" vacuum, observed best channel bandedge S/EN = 25.5, 24.5, 22.5 dB at 270, 135, 67.5 ips respectively. Can interpret 3 dB 'deficit' as 48 nm spacing increase going from 67.5 to 270 ips or 32 nm increase from 135 to 270 ips, assuming no frequency-dependent loss for WTF. When first tested, before wear/performance-maintenance shuttle, S/EN of this channel at 270 ips was ~ 28 dB -- which indicates that the frequency-dependent efficiency rolloff of the shallow-gap Metrum head is indeed < 1 dB as expected, and that the contour of WTF remained significantly spoiled: there should be no significant spacing increase with speed and there should be no spacing or contact-stability sensitivity to at least +/- 20% vacuum change with respect to the operating point at 10".
- Metrum delivered a second, expensive, WTF-contour prototype ordered in Dec 99 -- this one with 35 turns (1/2-inductance for > 6 dB read-crosstalk reduction), with 12-um depth-of-gap (shallow like sample, to maximize esp. 280-ips bandedge efficiency), and with additional Metrum-best-effort cross-talk further-reducing features (shorter fluxors with a common grounding provision using conductive epoxy).

Note : The attempted subsequent evaluation of this WTF-prototype was cut short when the good robust-contact performance obtained in Metrum's pre-delivery tests could not be repeated at Haystack -- for reasons that remain unclear. Lack of understanding of the apparent ease with which the WTF-contour is spoiled -- and high price -- have led us to abandon efforts to qualify the WTF-contour for implementation. However, the contour-conditioning method used by Metrum was tried in Dec 00 at Haystack and did in fact restore SNR performance fully to the Metrum-measured pre-delivery levels. See memo #287 by P. Bolis for details. Maintainability of restored performance remains unknown.

22aug00 minutes#52 Tests of New SP Heads for O'Higgins

1. Used diagnostic 'Mixed mode A', MA, recording and recorded-spectrum analysis, as described in note of 16feb in this memo, for determination of write-xtalk and S/WX functions of wavelengths and write-speed.
2. The interleaved independent random tracks in MA, like in mode C, are free of write-xtalk -- if the adjacent Ones tracks of MA are coherently anti-phased, as is usually the case.

3. For the better-performing write-only-interfaced SP headstack at 160 ips, the addition of write-xtalk in mode A raised average PER from 10^{-5} in WX-free mode MA to 10^{-4} .
4. A careful 'best-compromise' write-voltage determination is critically-important for SP headstacks -- because of typically large 5 dB efficiency variation within the stack. This was and should in general be done at 80 ips in mode C so as to comparably minimize PER on both high and low write-voltage sensitive worst-case channels. The large efficiency differences typical only in SP heads make 'reasonable' compromise tricky and fragile for SP headstacks.
5. TPE, Typical Parity Errors count in 10^6 -byte sample, was defined, with a simple edit-algorithm using 3 samples, to free the digital performance measure from anomalous atypically high counts due to tape-flaws and sync-loss: TPE > 600 is Fail-spec, 100-599 is Marginal, 10-99 Ok, <10 Good.
6. SP write performance at 80 ips was found to be unexpectedly inferior to 160 ips write-performance in xtalk-free modes C and MA. PER was typically 5-10 times higher at 80 ips than at 160 ips write-speed.
7. SP typical, best, worst channels all showed lowest PER with bandedge underdriven 1 to 3 dB -- unlike Metrum heads which have always 'liked' fully maximized (but not overdriven) bandedge response.
8. SP write-with-xtalk [mode A at 160 ips] digital performance was on average Marginal, less so by a factor of ~ 2 for the 1.5K-write-only than for the 2K-read-or-write interfaced stack. For the former 1 and for the latter 4 channels Failed spec, but all remained decodable with worst PER $\sim 3 \times 10^{-3}$.
9. The unexpected ~ 2 dB systematic bandedge-underdrive requirement of SP heads makes S/WX, hence digital PER performance, more susceptible to a given level of write-current cross-coupling -- because the underdriven write-response is proportional to total current.
10. SP stacks have both large channel-channel efficiency differences and large efficiency rolloff with frequency. Even use of a carefully refined best-compromise common write-voltage, as was done here, typically causes some channels to write with high NonLinear intersymbol interference or Transition Shift, NLTS. This may explain the 80 ips w/r 160 ips write-performance degradation observed. This write-defect is added in SP recordings to the written-in write-xtalk effect, that is, it compounds PER sensitivity to a given S/WX level.
11. The inferiority of write-performance of the 2K-read-or-write interfaced stack noted in 8. above was probably due to the asymmetric voltage-variable capacitive load presented by the base of the 3906 preamp transistor. This can result in writing with significant distortion, that is, a form of NLTS observable as an eye-pattern with vertical asymmetry, which can increase PER directly or indirectly ('compounded' with the NLTS of 10. above and/or write-xtalk).