VLBA ACQUISITION MEMO #397
MARK IV MEMO #252

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886-1299

Telephone: 978-692-4764
Fax: 781-981-0590

Spacing-Loss vs. Speed in 'Stepped' and 'Triple-Cap' Heads

Hans F. Hinteregger
MIT Haystack Observatory
24 June 1997

Introduction

Head-to-tape contact must be reliably maintained as the operational speed of VLBI recording and processing is increased from 80 or 160 ips to 320 ips for Mark4. In this memo, a method is presented for estimating a spacing increase that may occur when speed is increased.

Analyzed in this study are measurements of SNR as a function of wavelength and speed obtained for four heads: Two VLBI-standard 'stepped' headstacks, both worn to a small ~5 um remaining depth-of-gap; and two 'triple-cap' headstacks of like design, both with 30 um current depth-of-gap, one made by Metrum and one by Spin-Physics.

Method

Spacing-loss, at 55 dB/wavelength (18 nm/dB at 1 um), is linearly proportional to wavenumber, and hence frequency, at a fixed speed.[1]

In true (asperity) contact, there is a more fundamentally constant, irreducible effective spacing, namely, the sum of: 'average ' head/medium separation due to finite mechanical /magnetic roughness of tape and head, and the effective finite (arctangent model) transition length of recording.Thus, in the absence of additional explicitly frequency-dependent SNR losses, any linear-in-wavenumber speed-change-related SNR-change must be attributed to a spacing change. However, at about 2 MHz and higher there is also a significant frequency-dependent SNR-loss due to 1) the nonlinear rolloff with increased frequency of the head-core permeability and 2) increasing thermal head noise with frequency due to the growing real part of core impedance.

The explicit frequency dependence of SNR loss can probably be measured independently. For the current study, however, a more expedient *in situ* method was used to infer frequency-loss parameters 'simultaneously' [self-consistently] with spacing-change parameters.

A data-set of SNR as a function of wavelength [4, 2, 1 um] and speed [80, 160, 320 ips] was obtained for each head. The frequency corresponding to each wavelength is, of course, proportional to speed, in this case .5, 1, 2 MHz @ 80 ips, 1, 2, 4 MHz @ 160 ips, and 2, 4, 8 MHz @ 320 ips. A maximum of 3 parameters can be estimated from the data for each speed-difference. For example, if the spacing change is known to be zero, 3 differential frequency-dependent loss corrections [Δflc's] can be estimated. If, on the other hand, it is known *a priori* that there is no significant frequency loss up through 2 MHz and the 80-to-160 ips 'SNR deficit' at 2 um is twice that at 4 um [linear in wavenumber], then both a 80-to-160 ips spacing-change parameter and a 4 MHz flc can be estimated 'self-consistently'.

---

[1] Note: Gap-loss and recording-thickness-loss are different functions of wavelength but are certainly independent of speed.

The method of estimating spacing loss is based on a 'SNR deficit' measurement between two test tape-speeds:

1. Measure SNR as a function of wavelength, at a speed low enough so that spacing loss can't be reduced by further speed reduction (e.g. 80 ips):

$$SNR_1 = S_1 - N$$

   where S_1 is the signal power with the tape moving and N is the power with the tape stopped.

2. In a similar way, measure SNR_2 at a higher test speed, in this case either 160 ips or 320 ips.

3. The 'SNR deficit' is expressed as

$$SNR_{deficit} = \Delta_{ideal} - [(SNR_2 + flc_2) - (SNR_1 + flc_1)]$$

$$= \Delta_{ideal} - (\Delta SNR + \Delta flc)$$

   where $\Delta SNR = SNR_2 - SNR_1$ is the measured SNR difference, $\Delta flc = flc_2 - flc_1$ is the frequency-loss change between the two frequencies corresponding to a fixed wavelength on tape, and Δ_{ideal} is the 'ideal' increase in head SNR-gain due to tape speed alone -- 3 db for speed doubling, 6 db for speed quadrupling, assuming an inductive read head is used and that there are no 'features' in the signal spectrum which are narrower than the resolution bandwidth at the wavelengths of interest. A positive value of $SNR_{deficit}$ is due to an increase in head-to-tape spacing if flc's have been properly [independently or self-consistently] determined. If so, SNR deficits will be strictly proportional to wavenumber, to within the measurement error, in this case about 0.5 dB.

4. Signal and noise power densities were measured with 30 KHz resolution bandwidth, which is narrower than any signal or noise 'feature' at the frequencies of interest, namely 0.5, 1, 2, 4, and 8 MHz. Moving-tape signal measurements were made using a Sony D1 VLBI tape SVLB0272 recorded at Ft. Davis; only VLBA track #18 was observed, only in forward tape-motion direction.

Frequency-Loss Measurements

Independent frequency-dependent SNR-loss measurements have not yet been made to double check the self-consistent *in-situ* frequency-loss determination method employed here. The latter can also be much improved by increasing the range and number of wavelengths and speeds used. Measurement error can probably be reduced to 0.1 dB by taking advantage of as yet untapped spectrum analyzer signal processing features. IEEE488-to-PC connection would allow screen-memory dumps and multi-parameter least-square fitting could then yield 'professionally analyzed' spacing vs. speed and efficiency vs. frequency curves simultaneously.

Measurements and Analysis

Stepped Heads

Measurements were made on two Metrum standard stepped-contour head, under the following conditions:

1. Heads were prepared for thin tape with Fuji H621 at 28" vacuum, 1 round trip @ 320ips. Head 1 was mounted on Mark III correlator drive #8 and Head 2 on drive #1.
2. Approximately 5 um depth-of-gap. Later measured optically for Head 2, estimated for Head 1.
3. Tests were conducted at 5" vacuum only.
4. Signal and Noise measurements were made at the 'unequalized' monitor output.

The measurements made at 80 ips of SNR as a function of wavelength are tabulated in Table 1.

80 ips - stepped heads				
		Head 1	Head 2	Average
Wavelength (um)	Freq (MHz)	SNR (dB)	SNR (dB)	SNR (dB)
1	2	26.7	26.9	26.8
2	1	33.0	33.7	33.3
4	0.5	33.6	32.8	33.2

Table 1: Stepped-head measurements at 80 ips

Notes: Head 1 SNR's equal Head 2 SNR's, to within estimated measurement error at 1, 2, 4 um. SNR peaks between 2 and 4 um, and rolls off 6.5 dB to 1 um, from 33.3 to 26.8 dB.

Table 2 shows the $SNR_{deficit}$ measurements from 80 ips to 160 ips.

80 ips to 160 ips - stepped heads									
				Head 1		Head 2		Average	
Wvlngth (um)	ΔFreq (MHz)	Δ_{ideal} (dB)	Δflc (dB)	ΔSNR (dB)	$SNR_{deficit}$ (dB)	ΔSNR (dB)	$SNR_{deficit}$ (dB)	ΔSNR (dB)	$SNR_{deficit}$ (dB)
1	2-4	3	.8	2.1	0.1	2.3	-0.1	2.2	0
2	1-2	3	0	3.5	-0.5	2.8	0.2	3.1	-0.1
4	0.5-1	3	0	3.2	-0.2	3.7	-0.7	3.4	-0.4

Table 2: Stepped head SNR change from 80 ips to 160 ips

The value of 0.8 dB for Δflc = flc(4) - flc(2) is inferred as follows: ΔSNR measurements at 2 um and 4 um are sufficiently close to Δ_{ideal}=3 dB [average |SNR deficit| < 0.5 dB] that one can conclude there is no significant spacing increase from 80 ips to 160 ips, with an estimated upper limit of 18 nm corresponding to 0.5 dB at 2 um. Therefore, the loss at 4 MHz must be a frequency-dependent loss. With an average value of ΔSNR=2.2 dB for the two heads at 1 um, we conclude that the frequency-dependent loss at 4 MHz flc(4) is ~0.8 dB. We can now use this number in the 80 ips to 320 ips test.

Similarly, the $SNR_{deficit}$ measurements from 80 ips to 320 ips are given in Table 3 below.

80 ips to 320 ips - stepped heads							
				Head 1		Head 2	
Wvlngth (um)	ΔFreq (MHz)	Δ_{ideal} (dB)	Δflc (dB)	ΔSNR (dB)	$SNR_{deficit}$ (dB)	ΔSNR (dB)	$SNR_{deficit}$ (dB)
1	2-8	6	2.3	3.7	0	-0.7	4.4
2	1-4	6	0.8	5.3	-0.1	2.7	2.5
4	0.5-2	6	0	5.9	0.1	4.5	1.5

Table 3: Stepped head SNR change from 80 ips to 320 ips

The following conclusions can be drawn from Table 3:

1. Using Δflc=0.8 dB at 4 MHz as determined in Table 2, Head 1 data at 2 and 4 um are closely consistent with no spacing change (i.e. $SNR_{deficit}$ of +0.1, -0.1, respectively). Consistent with this conclusion, we set the 1 um SNR deficit to zero to solve for the 8 MHz frequency-loss correction, Δflc(8-2) = flc(8) = 2.3 dB.
2. Though Head 1 data shows no hint of spacing increase up to 320 ips, Head 2 data [with the same .8 and 2.3 dB frequency-loss corrections at 4 and 8 MHz] is consistent with a significant 79-86 nm spacing increase. At 18 nm/dB this spacing increase corresponds to 4.4 to 4.8 dB extra spacing loss [SNR deficit] at 1 um . An essential consistency check is that the SNR deficits are in fact proportionately smaller at the longer 2 and 4 um wavelengths to well within the measurement error.
3. Head 2 should be tested at 10" vacuum, possibly a more robust operating point at 320 ips.

Triple-Cap Heads

Two triple-cap heads were tested:

1. A Metrum prototype headstack mounted on correlator drive #4 ('Mark 4' configuration), with the following comments:
   a) This headstack has been in mixed-thick/thin-tape service at fixed 10" vacuum for more than two years and has shown no evidence of performance degradation on tape-thickness interchange.
   b) The headstack has been problem-free and has worn a total of ~10 um, from 40 to 30 um depth of gap.
   c) For the most recent 1300 running hours, the drive has been fitted with a 'dry-air kit' which keeps the relative humidity below ~20% at the head; during this time, headwear has been ~4 um, leading to an estimate of ~10,000 hours of *remaining* headlife. Under the same conditions of relative humidity and tension, this 3 nm/hr wear rate is probably 60% that of a standard stepped headstack (estimated ~5 nm/hr if wear rate is inversely proportional to the total contact length ratio).
   d) The tests were run with the head contour 'as is'.
2. A Spin Physics prototype headstack mounted on correlator drive #3 ('Mark 4' configuration), with the following comments:
   a) This headstack is nominally identical to the Metrum unit.
   b) Operational performance with thin/thick tape is virtually identical to Metrum unit.

c) Prior to these tests, this headstack had only a few days of operational use. Its contour shape may therefore not have fully stabilized and could be subtly different from the worn-in contour of the Metrum head. Prior to any operational use the Spin Physics head, which was delivered for evaluation with a 'triple-flat' approximation to a 6 mm contour radius, was lapped with Fuji H621 thick tape at 28" vacuum. Several 320 ips round trips were required to round the flats fully, to optical appearances. The prepared contour height is roughly 2 um as measured by height of focus, which is consistent with all fully tape-worn heads I have seen. More accurate contour profilometry is possible and needed to distinguish subtle contour differences.

The measurements were made under the following conditions:

1. SNR measurements were made through the 80 ips equalizer at 0, 80, 160, 320 ips, since the VLBA/Mark4-configuration has no 'unequalized' monitor output. No SNR biases were evident.
2. The two triple-cap heads were tested at 10" normal vacuum [2.2 N tension].
3. The tests were repeated at 15" and showed no significant (< 0.5 dB) differences. However, at 6" to 5" low tension, more than 14 to 17 dB extra loss at 1 um wavelength and severe signal instability were observed at 320 ips; even at 160 ips, up to 2.5 dB extra loss at 1 um was noted, which is consistent with a spacing increase of up to 45 nm.
4. Both triple-cap heads have about 30 um remaining depth-of-gap, whereas the heavily worn stepped heads tested have only about 5 um remaining depth of gap. Assuming all heads have equal gap length, the gap reluctance of these triple-caps, or of any new head specified to have 30 um minimum initial depth-of-gap, is at best only 1/6 that of a 5 um depth-of-gap head.

Head efficiency is the ratio of gap to total [sum of gap and core] reluctance. Core reluctance is inversely proportional to permeability [and area of cross-section] and directly proportional to the length of the flux path. Permeability is in general a low-pass function of frequency with the consequence that head efficiency decreases monotonically [but not linearly] as frequency increases. The permeability of magnetic materials is also easily compromised by a variety of head [especially gapped-bar] manufacturing processes.

SNR measurements for both heads at 80 ips are given in Table 4.

80 ips - triple-cap heads				
		Metrum	Spin Physics	Difference
Wavelength (um)	Freq (MHz)	SNR (dB)	SNR (dB)	SNR (dB)
1	2	22.7	22.2	0.5
2	1	28.0	29.9	-1.9
4	0.5	27.2	28.1	-0.9

Table 4: Triple-cap heads at 80 ips

Note the following:

1. Metrum head: The long-wavelength 2, 4 um average SNR is 27.6 dB, 5.7 dB inferior to that of the worn stepped heads tested. SNR rolloff to the 1 um short-wavelength is only 4.9 db compared to 6.5 dB for the worn stepped heads.
2. Spin Physics head: The long-wavelength 2, 4 um average SNR is 29.0 dB, 4.3 dB inferior to that of the worn stepped heads, but 1.4 dB better than the Metrum triple-cap. SNR rolloff to the 1 um short-wavelength is 6.8 dB, nearly the same as for the worn stepped heads.
3. Note the more sharply peaked [anomalous?] Spin Physics response at 2 um, 1 MHz.

SNR-change measurements as a function of wavelength for the 80 to 160 ips speed-change are given in Table 5. Self-consistently fit differential frequency-loss corrections and net SNR deficits are also tabulated for both triple-caps.

80 ips to 160 ips - triple-cap heads								
			Metrum			Spin Physics		
Wvlngth (um)	ΔFreq (MHz)	Δ_{ideal} (dB)	ΔSNR (dB)	Δflc (dB)	$SNR_{deficit}$ (dB)	ΔSNR (dB)	Δflc (dB)	$SNR_{deficit}$ (dB)
1	2-4	3	1.9	1.1	0	0.8	2.2	0
2	1-2	3	3.2	0	-0.2	0.8	1.6	0.6
4	0.5-1	3	3.1	0	-0.1	2.6	0	0.4

Table 5: Triple-cap head SNR change from 80 ips to 320 ips

Note the following:

1. The data on the Metrum triple-cap is consistent with no 80 to 160 ips spacing change and allows no other interpretation. The inferred 1.1 dB 4 MHz frequency-loss correction, Δflc(4-2) = flc(4) - flc(2) = flc(4), is not significantly greater than the 0.8 dB value which fits the worn-stepped-head data.
2. The data on the Spin Physics triple-cap is also consistent with no 80 to 160 ips spacing change. However, as indicated below, the interpretation of the present data has a small-at-160ips, larger-at-320ips ambiguity which can be resolved with additional data.
3. Unlike the Metrum heads, which need no frequency-loss correction at 2 MHz, the Spin Physics triple-cap data can be self-consistently fit only with a finite, 1.4 to 1.6 dB, frequency-loss correction at 2 MHz. The latter 1.6 dB value forces to zero the SNR deficit [error] at the longest 4 um wavelength (below in Table 6, the 80 to 320 ips SNR-change data). The former 1.4 dB also consistent value is the long wavelength 2, 4 um average SNR difference. between the Spin Physics and Metrum triple-caps at 80 ips (in Table 4 above).
4. For the Spin Physics triple-cap at the 1 um short wavelength (in Table 5), Δflc(4-2) = 2.2 dB forces the SNR deficit to zero. Given that flc(2) = 1.6 dB, flc(4) - flc(2) = 2.2 dB implies that flc(4) = 3.8 dB for the Spin Physics triple-cap [compared to 1.1 dB for the Metrum]. The difference between 4 and 2 MHz corrections, 2.2 db, is twice that of the Metrum head. The Metrum triple-cap has about 1.5 dB efficiency advantage at 4 MHz. The Spin Physics triple-cap has a 1.5 dB advantage at 1 MHz and lower frequencies. At 2 MHz efficiency is nearly identical.

80 ips to 320 ips - triple-cap heads								
			Metrum			Spin Physics		
Wvlngth (um)	ΔFreq (MHz)	Δ_{ideal} (dB)	ΔSNR (dB)	Δflc (dB)	$SNR_{deficit}$ (dB)	ΔSNR (dB)	Δflc (dB)	$SNR_{deficit}$ (dB)
1	2-8	6	1.0	5.0	0	-1.9	7.9	0
2	1-4	6	4.8	1.1	0.1	1.9	3.8	0.3
4	0.5-2	6	5.6	0	0.4	4.4	1.6	0

Table 6: Triple-cap SNR change from 80 ips to 320 ips

Please note:

1. The Metrum triple-cap shows no 80-320 ips spacing increase. At 8 MHz flc(8) = 5.0 dB fits the Metrum triple-cap data [forces the SNR deficit to zero]. This flc(8) exceeds the 2.3 dB value for the worn stepped head by 2.7 dB.
2. The Spin Physics triple-cap may have no 80-320 ips spacing increase either. However, at 8 MHz a large flc(8) = 9.5 dB is required to zero the SNR deficit. The 7.9 dB difference between 8 and 2 MHz corrections is large, almost 3 dB greater than for the Metrum triple-cap. The no-spacing-increase conclusion is self-consistent but weak because it is in effect derived from a single independent measurement at 2 um wavelength.

Comparison of Head Efficiencies

The apparent frequency dependence of head efficiency of the two triple-caps with 30 um depth of gap and of the worn stepped Metrum heads with about 5um depth of gap is given in Table 7.

	Spin-Physics Triple-Cap (30 um DOG)	Metrum Triple-Cap (30 um DOG)	Metrum Stepped (5 um DOG)
Freq (MHz)	Efficiency (dB)	Efficiency (dB)	Efficiency (dB)
.5	1.6	0	5.7
1	1.6	0	5.7
2	0	0	5.7
4	-2.2	-1.1	4.9
8	-7.9	-5	3.4

Table 7: Comparison of head efficiencies

We note the following:

1. At 2 MHz [0 dB] the triple-caps appear to have equal efficiency, calculated to be about 40 %, assuming the core reluctance remains constant while gap reluctance is inversely proportional to depth of gap.
2. The overall performance of Spin Physics and Metrum triple-caps at 30 um depth of gap should be nearly the same at 160 ips. Spin Physics may be a little better at 80 ips.

Conclusions

1. At 320 ips, 5" vacuum, one stepped head had no evidence of a spacing increase, the other showed a quite significant unambiguous 79 to 86 nm spacing increase. Whether contact is more reliable [spacing increase disappears] at 10" vacuum at 320 ips needs to be determined. At 160 ips both heads had no evidence of a spacing increase compared to 80 ips.
2. At 5um depth of gap, the SNR of a Metrum head is improved 6 dB at/below 2 MHz, more than 8 dB at 8 MHz, with respect to a head at 30 um [minimum initial]depth-of-gap.
3. At 320 ips, the Metrum triple-cap shows no spacing increase compared to 80 ips.
4. At 320 ips, the Spin Physics triple-cap may have a spacing increase of up to 54 nm, or a head efficiency rolloff from 2 to 8 MHz that exceeds the 5 dB Metrum triple-cap rolloff by up to 3 dB. Or possibly a combination of smaller spacing increase and smaller rolloff resulting in the same total extra 3 dB loss. The ambiguity as to the source of this loss should be resolved. More accurate measurements at longer wavelengths and additional speeds, and head vector impedance measurements to at least 10 MHz are needed.
5. Spin Physics triple-cap is about 1.5 dB more efficient than Metrum triple-cap at/below 1 MHz [at same 30 um depth of gap]. Additional head impedance measurements and statistics should clarify whether difference is systematic.
6. The prototype triple-cap design, specified by Haystack and embodied in the Metrum #16819211-006 and Spin Physics [Datatape] #204893 parts, is qualified for 'uncompromised' mixed-tape-thickness operation [using fixed 10" vacuum] at 80 or 160 ips with thin 15.2 um VLBI tapes at 56 Kfci [135 or 270 ips with thick 27 um tapes at 33 Kfci].
7. There is no significant loss of contact [spacing increase] at 160 ips for any of the heads tested, stepped heads at 5”, triple-caps at 10” vacuum [1.1, 2.2 N tension] respectively.
8. SNR at 2 MHz is about 6 dB higher for the stepped heads than for either triple-cap head. The difference is due to the shallow depth-of-gap of the heavily worn stepped heads that happened to be tested for comparison with the triple-caps. As a check, the remaining depth-of-gap of Head 2 only was measured optically and found to be only 4-6 um, ~1/6 of the 30 um depth-of-gap of the triple-cap heads; this shallow 5 um depth-of-gap is small enough to approximately double head efficiency, from about 40 to 80% at frequencies below ~2 MHz. More importantly for 320 ips operation, the efficiency at 8 MHz improves from ~22% to ~60%.
9. A no-wear head design [hard-cornered flat-top or triple-cap] with the 2 to 3 um depth-of-gap typically used in disk heads could maintain greater than 80% efficiency even with doubled resolution [a 180 nm half-present-length gap] and at the highest frequencies of interest.
10. With the triple-cap design, there is no significant temporary spacing increase when thin-tape operation follows a long period of thick-tape operation. With stepped heads, a temporary spacing loss of up to at least 6 dB is observed on the Haystack processor when such a switch takes place, in spite of the partial compensation for tape thickness employed, in which thick tape runs at 3, rather than ideally about 6 times, the tension used for thin tape. The Haystack processor uses 15” vacuum for thick tape, 5” for thin, as a practical 'compromise' for mixed-thickness operation with stepped heads. Optimum performance of the stepped head can be restored with a single round trip at high speed of Fuji H621 with vacuum set to 28” = 6 N.
11. With the triple-cap design, at 30 um initial depth-of-gap, a 10,000 hour headlife is expected, provided relative humidity in the tape path is kept below 20%.
12. No head design is yet fully qualified, specified, or tested for robust 320 ips operation at 56 Kfci. Significant effort is still needed to prepare for this Mark4 requirement.

Comments on Ambiguity of Spin Physics triple-cap Model: Spacing vs. Frequency Loss

Whether the apparently more dramatic rolloff of Spin Physics head-efficiency above 2 MHz is real must be questioned. An alternate model, in which the 2 to 4 and 2 to 8 MHz efficiency rolloff of Spin Physics triple-cap is constrained to be the same as for Metrum triple-cap, also fits the data, as shown in Table 8:

Wvlngth (um)	ΔFreq (MHz)	Δ_{ideal} (dB)	ΔSNR (dB)	Δflc (dB)	$SNR_{deficit}$ (dB)	Inferred spacing loss (dB)	Residual (dB)	Inferred spacing (nm)
80 to 160 ips								
1	2-4	3	0.8	1.1	1.1	1.2	-0.1	22
2	1-2	3	0.8	1.4	0.8	0.6	+0.2	22
4	.5-1	3	2.6	0	0.4	0.3	+0.1	22
80 to 320 ips								
1	2-8	6	-1.9	5.0	2.9	3.0	-0.1	54
2	1-4	6	1.9	2.5	1.6	1.5	+0.1	54
4	.5-2	6	4.4	1.4	0.2	0.7	-0.5	54

Table 8: Alternate interpretation of triple-cap data

In this alternative model there is only one independently fit flc parameter for the Spin Physics triple-cap, 1.4 dB at 2 MHz. The SNR deficit entries above for each speed-change, to the extent that they are significant and linear in frequency [inversely proportional to wavelength], should be interpreted as upper limits on spacing changes with speed:

For the 80-to-160 ips speed-change for example, the 1.1, 0.8, 0.4 dB SNR deficits at 1, 2, 4 um are linear well within the estimated measurement error, as shown by the small non-systematic residuals with respect the linear 1.2, .6, .3 db spacing-change model fit. At 18 nm per dB at 1 um this is equivalent to estimating a small 22 nm upper limit on 80-to-160 ips spacing-increase.

Similarly for the 80 to 320 ips speed-change, the 2.9, 1.6, .2 dB SNR deficits imply a more significant upper limit of 54 nm.

Recommendations

1. All new headstack purchases should be of the triple-cap design. The tested triple-caps have no relative disadvantages and several proven advantages.
2. A formal performance specification and test standard for 160 and 320 ips, 56 Kfci thin tape VLBI operations is being developed.
3. Purchase of triple-caps, even if tested only to original thick tape 135 ips 33 Kfci standard [24 dB min SNR at 2.2 MHz, 30 KHz RBW], is nevertheless encouraged immediately, in part because thin tape high density performance can usually be safely extrapolated.
4. For a 56 Kfci VLBI recording on Sony D1K tape read at 80, 160, 320 ips, a minimum 30KHz RBW SNR of 18, 21, 24 dB at 2.2, 4.4, 8.8 MHz respectively is expected.
5. Don't wait for the 'last word' -- a no-wear hard-cornered shallow-gap flat-top or triple-cap which is 80% efficient, or a TF/MR head implementation. 'A bird in hand is worth ..... '