VLB ARRAY MEMO No. 204

# Time and Frequency Averaging

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The extent to which the time-frequency domain data produced by the correlator can be averaged is determined by the accuracy to which "clock errors" can be determined and by the field of view which is to be left undistorted. If the source in question is strong and structurally simple, the clock errors can be determined directly from the source data. Failing this, a strong, simple calibrator source can be used to determine the "clock errors" which are then used to correct the source data. The corrected data can then be averaged without signifigant loss of coherence.

The second limitation on the degree of averaging is the desired field of view. The minimum number of frequency channels and maximum integration time are described in VLBA memo no. 47 and will not be reproduced here.

In the following we will assume that the array will be well enough calibrated that the residual fringe rate will be negligible. Due to the wide bandpass of the system, residual delay errors could be serious. Keeping the data in the frequency domain with relatively narrow frequency channels will reduce the sensitivity to delay errors as well as allow a wider field of view. In determining the number of frequency channels the number quoted below is the root-sum-square of the number needed for the uncertainty in the clock and the number needed for the desired field of view.

The accuracy to which the residual delay can be determined is illustrated in Figure 1.

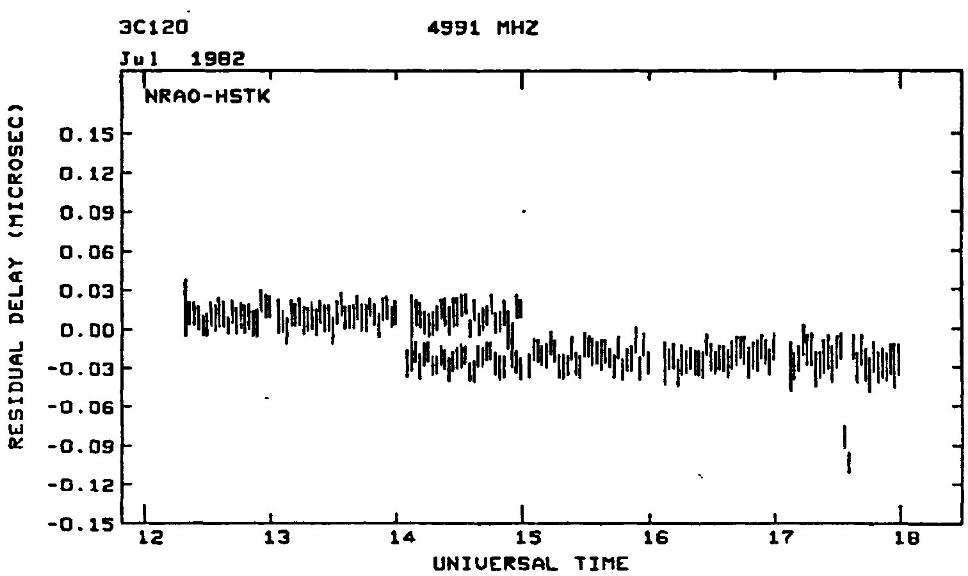


Figure 1. The delay residuals from the Haystack-Greenbank VLB baseline at 6 cm during two periods separated by six

days.

This plot shows delay residuals observed using 3C 120 at 6cm with a 2 MHz bandpass with an interferometer consisting of the Haystack and Greenbank antennas during two periods of time separated by six days. On the first day the mean delay residual was 9.7 nsec. and the standard deviation of the observations was 5.3 nsec.; on the second day the mean was -22.3 nsec and a standard deviation of 6.2 nsec.

Based on these two samples, we conclude that the "clock errors" can be determined to 6 nsec or less. The wider bandpass of the VLBA and an atmospheric model may help increase the accuracy in the determination of the clock delay. A clock error of no more than 6 nsec requires 3 frequency channels to cover a 50 MHz bandpass while limiting the amplitude degradation to 1.5%.

Table 1 gives the number of frequency channels needed for a delay error of 6 nsec and a bandwidth of 50 MHz for various fields of view.

Table 1
Minimum Number of Frequency Channels

| Field of View(") | No. Channels |
|---|---|
| 0.05 | 4 |
| 0.10 | 4 |
| 0.15 | 5 |
| 0.20 | 6 |
| 0.25 | 8 |
| 0.50 | 14 |
| 1.00 | 26 |

The maximum integration time for various combinations of frequency and field of view for the VLBA are shown in Table 2.

Table 2
Maximum Integration Time (sec)

| Field of View(") | Frequency(GHz) | | | | | |
|---|---|---|---|---|---|---|
| | 0.3 | 1.4 | 5.0 | 10. | 22. | 43. |
| 0.05 | 1300 | 304 | 85 | 42 | 19 | 10 |
| 0.10 | 650 | 152 | 42 | 21 | 10 | 5 |
| 0.15 | 433 | 101 | 28 | 14 | 6 | 3 |
| 0.20 | 325 | 76 | 21 | 10 | 5 | 2 |
| 0.25 | 260 | 61 | 17 | 8 | 4 | 2 |
| 0.50 | 130 | 30 | 8 | 4 | 2 | 1 |
| 1.00 | 65 | 15 | 4 | 2 | 1 | 0.5 |

It is important to note that Table 2 does not include atmospheric effects and in most practical cases averaging longer that a few minutes results in a coherence loss due to atmospheric phase fluctuations.

From Tables 1 and 2 it appears that in the moderate continuum case 6 frequency channels and 20 second integrations are feasable. This degree of averaging should be possible even using only calibrator data. Fringe fitting of the source will <u>not</u> allow a much greater degree of averaging in many cases.

## Comparison with the VLA

In order to make a comparison with the VLA, we will compare the results of 12 hours of observations of a 0".2 field at 5 GHz. Since a given source is not visible all of the time at all antennas we will assume that the equivalent of ten hours of full array data are obtained. In addition, we have assumed that source data was obtained 80% of the time and was averaged to 6 frequency channels and 20 seconds.

While six frequency channels do not increase the work by a factor of six, VLA data does not require fringe fitting so we have included the factor of six and ignored fringe fitting. It was also assumed that 10 interations of self-calibration was required resulting in 10 maps and CLEANs.

The VLA observations were assumed to use 80% of the time with 20 second averaging; 20 objects were assumed observed in the 12 hours, half of which were self-calibrated - resulting in 30 maps and CLEANs. A comparison is shown in Table 3.

Table 3
Comparison of the simple VLBA Case with the VLA
(10 Stations)

| | VLBA | VLA |
|---|---|---|
| no. visibilities | 390,000 | 600,000 |
| no. maps and CLEANs | 10 | 30 |

From this simple analogy, 10 station VLBA continuum processing needs, in the best case, about 1/3 to 1/2 of the computing required for the VLA. A 14 element array produces about twice the amount of data and the post correlation computing requirments for uv data would be roughly equivalent to the VLA in the simple continuum case; post-mapping processing requirments are relatively unaffected by the number of antennas. It is likely that much of the use of the VLBA will require larger fields of view than the 0.2 second example given here.

Contents of the VLBA Fringe Processor

There is a certain set of operations that must be performed on almost all VLBA visibility records and need only be done once. In the past, we have referred to some of these tasks as existing "in the processor". These tasks include : a priori amplitude calibration (apply on-line T sys, standard gain curves, standard atmos. model), edit the data using on-line flags (from the station log files), apply corrections to the processor model, and globally fringe fit using a point source model. The block diagram in Figure 2 illustrates the on-line fringe processing that could be done in the processor.

In the upper section of the block diagram, we apply phase slopes across delay channels and frequency channels. In the spectral line case, the station doppler shifts must be precisely tracked and removed. Current spectral line VLBI practice is to remove the doppler frequency shifts by rotating out phase slopes across the delay channels. We also remove the fractional bit delay tracking error by applying a phase slope across the frequency channels. Instrumental phase changes will be measured using something like the Mk III cal tone system. The instrumental phase shifts could be removed in either the delay channels or frequency channels, which ever is easier.

The tasks blocked out in the second section (the Fringe Processor) of Figure 2 are more complicated and are liable to change significantly during the life of the VLBA. The tasks should probably be mainly done in software for flexiblity. The fringe processor operations are basically threefold. First, we would apply corrections to the processor model, corrections that change more rapidly than the fringe processor averaging interval. Second, the global fringe fitting task measures station based residual delays, delay rates and phases. The fringe fit solutions of previous calibrator source observations help the fringe finding on weak program sources. Third, the delays, rates and phases from the fringe fit are removed from the visibility records. The main advantage of on-line fringe fitting is that it lengthens the array coherence in time and frequency. Thus we can average the visibility records to roughly 10 seconds and 4 to 6 frequency channels. The data rate is then reduced by a factor of several thousand. Finally, slowly varying corrections are applied to the averaged vis. records (T sys, standard gain curves, various geodetic models - polar motions, earth tides, general relativity, atmos. and ionospheric models). The fringe processor output would be archived and funneled on into the VLBA AIPS analysis computers. The output data would be written in AIPS uv format with extension files containing the fringe solutions and complete descriptions of the models used by the correlator and fringe processor.

An aside - Currently in Mk II VLBI, we are beginning to explore using phase reference sources. A reference source would typically be at least several arc minutes from the program source but possibly in the main beam of the telescopes. Simultaneous reference source observations now require two processing passes - the program source position and the reference source position. Dual processing passes would be uncomfortable for the VLBA. The processor design committee might consider how to process simultaneous dual source observations. Perhaps the VLBA correlator could operate in two separate sections, one for each source. Simultaneous program source - reference source observations may be fairly common on the VLBA.

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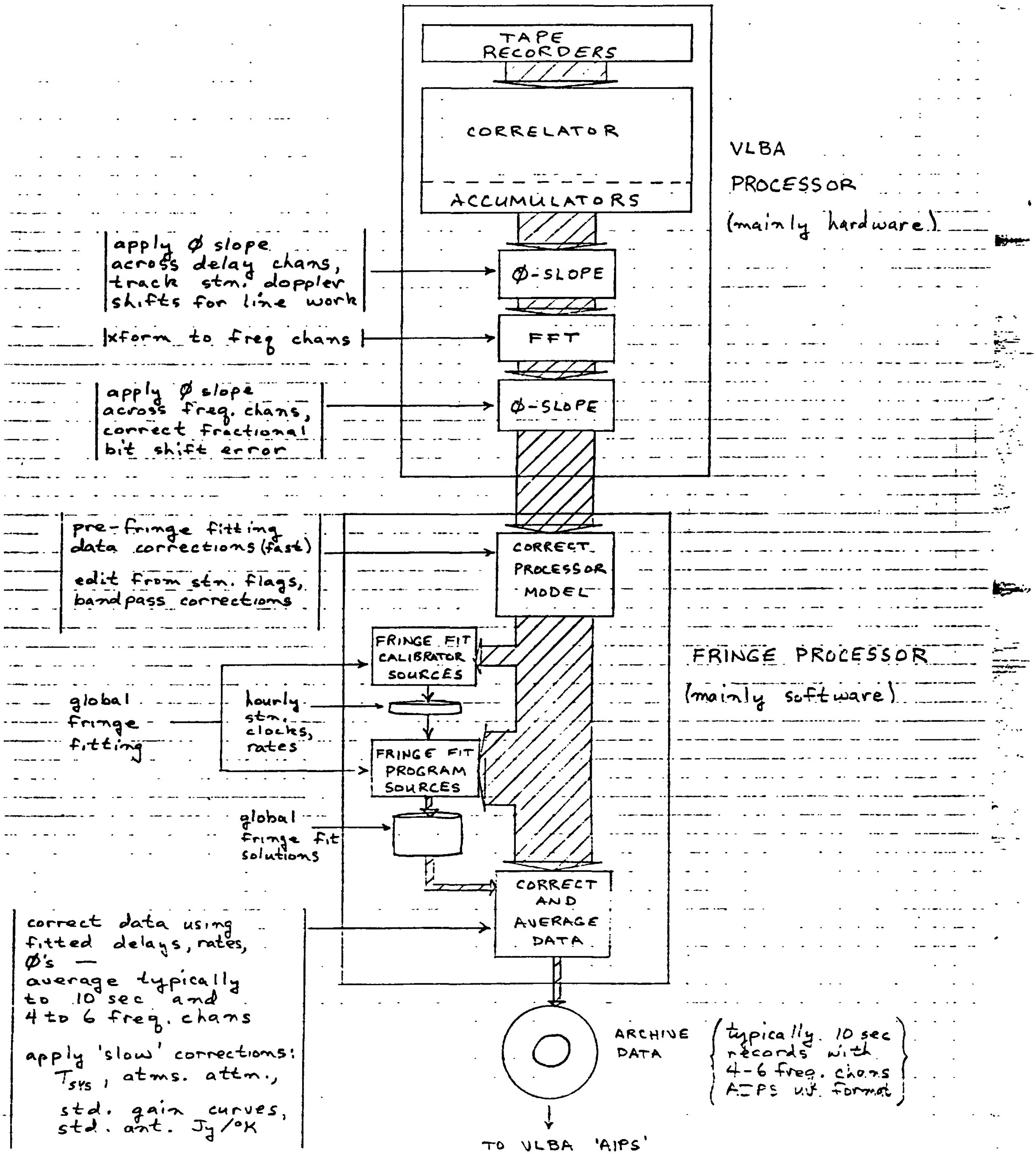
TAPE RECORDERS
CORRELATOR
ACCUMULATORS
VLBA PROCESSOR (mainly hardware)
apply Ø slope across delay chans, track stn. doppler shifts for line work
Ø-SLOPE
xform to freq chans
FFT
apply Ø slope across freq. chans, correct fractional bit shift error
Ø-SLOPE
pre-fringe fitting data corrections (fast)
edit from stn. flags, bandpass corrections
CORRECT PROCESSOR MODEL
FRINGE FIT CALIBRATOR SOURCES
FRINGE PROCESSOR (mainly software)
global fringe fitting
hourly stn. clocks, rates
FRINGE FIT PROGRAM SOURCES
global fringe fit solutions
CORRECT AND AVERAGE DATA
correct data using fitted delays, rates, Ø's — average typically to 10 sec and 4 to 6 freq. chans
apply 'slow' corrections: Tsys, atms. attn., std. gain curves, std. ant. Jy/°K
ARCHIVE DATA
typically 10 sec records with 4-6 freq. chans AIPS u.v. format
TO VLBA 'AIPS'

FIGURE 2