VLBA Acquisition Memo # 007

NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY

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TO: VLBA Correlator and Recorder Groups

FROM: Alan E.E. Rogers and John C. Webber

SUBJECT: Fringe rotation and variable phase sampling.

A conventional VLBI system performs fringe rotation and fractional-bit-shift correction at the processor. The following alternate schemes have been proposed for the VLBA:

A) Variable phase sampling at the sites

This serves only to eliminate the "fractional bit shift" loss which is zero at bandcenter, 10% at the bandedge and 3.5% for continuum. The penalties which have to be paid are as follows:

1) Additional electronics is needed at each site to perform the variable phase sampling in a manner needed to achieve an accuracy (and accountability) at the 1 nanosecond level (1 ns = 1.4 degrees of phase at 4 MHz) out of a typical rate of 1500 ns/sec.

2) A model for the steering of the variable phase sampling needs to be transmitted and executed at each site.

3) Bit shift changes at the processor can only be made at the same "tape time" as the phase jumps made during acquisition. Thus changing the model at correlation time becomes somewhat more difficult.

B) Phase tracking (or fringe rotation) at the sites

This serves to reduce the number of accumulators needed in the processor by a factor of 2 and to eliminate high frequency fringe rotation in the processor. The penalties are as follows:

1) Highly accurate and accountable phase rotation (to the 1 degree level) has to be provided at the sites in each baseband converter.

2) A model for the phase tracking needs to be transmitted and executed at each site.

3) Certain systematic errors in phase reference techniques may now be introduced by virtue of the fact that the acquisition electronics will now "know" which object is being observed. For example, if the synthesizer thermal

dissipation is a function of fringe rate then thermally driven instrumental phase shifts may become a function of sky coordinates. While these errors will probably be very small, tests for such subtle effects will be needed.

4) A correlator dump rate of 60 Hz will be needed to allow adequate post correlation fringe rotation to cover the field of view of the primary beam. The post correlation fringe rotations will have to be accurate enough to avoid phase errors which may be a function of the position in the field of view relative to primary position used during data acquistion.

5) Because the fringe rate at the processor is close to zero, phase switching (like in the VLA) will now be needed at the stations and at the correlator.

6) Receiver images, which are normally completely rejected by the processing in the conventional VLBI system will show up at minus the residual fringe rate - see pending memo.

C) Clock tracking at the site

Both schemes A and B could be simultaneously accomplished at the sites by continuously phase shifting the output of the hydrogen maser (by an amount of up to $\pm$ 300 Hz at 100 MHz) so that the entire electronics system including first local oscillators follow the "earth center" time. A high resolution (femtosecond) comparison could be made between true station time and "earth center" time to independently verify the clock tracking. This scheme has all the problems of A and B (except that it eliminates the need for rapid bit shifting at the correlator) and in addition requires a higher phase accuracy (10^{-3} degrees of phase at 100 MHz = 0.5 degrees of phase at 43 GHz).

D) Digital SSB rotation at the processor

This serves to reduce the number of accumulators needed in the processor by a factor of 2. The penalties are as follows:

1) The Hilbert transform filtering is somewhat limited and the effective bandpass will contain ripples which have to be corrected in the post correlation processing.

2) The imperfect image rejection results in a small SNR loss - see memo by Larry D'Addario.

3) The output of the digital SSB mixer has to be quantized before cross-correlation and this results in an additional SNR loss which is time consuming to calculate in all cases. The table below gives some simple cases:

# Taps in Filter	# Levels in correlator: 2	3	4	5
1[a]	0.90	0.97		
2	--	0.90		0.97
4			~0.90	

2nd Quantization Loss (for rotation on baseline basis. Factors need to be squared when rotation is done on a station basis)

Notes: a) A single tap filter which provides 90° phase shift at bandcenter

4) The second quantization appears to produce a bandpass filter function which is a function of the input spectrum, at least in some cases just analysed - see pending memo.

5) Since the image rejection of the digital SSB mixer is poor (being almost none near the top and bottom bandedges) a processor using this technique provides little added rejection of receiver images - see pending memo.

In summary the digital SSB fringe rotation at the processor results in a loss in performance and some uncertainty about subtle defects which may be uncovered in the future. Is the cost saving worth the performance loss and the added risk of a new approach?

CONCLUSIONS

In our opinion, if the fringe rotation and variable-phase sampling (fractional-bit-shift correction) are done entirely at the processor in the conventional manner, we achieve the simplest possible block diagram. Furthermore, such a system would be guaranteed to be successful in all respects, namely that the loss factors are well understood, there is freedom from spurious signals, and phase accountability is excellent. Much effort over the last two decades has gone into understanding and implementing conventional VLBI systems; we should build on that experience rather than undertaking a major revision of the way VLBI science is done.

A conventional VLBI system has the following advantages:

1) The acquisition electronics are as simple as possible. The number of things which must work correctly at remote sites is thereby reduced. It is easy to ascertain if the acquisition rack is working properly, since all local oscillators operate at fixed frequencies locked to the station master oscillator and all video converters are sampled synchronously.

2) There is no necessity to supply extremely accurate _a prioris_ for source position and Earth rotation at record time.

3) Since the processor should have the ability to undo any bit-shifting which was done at record time in order to compensate for inaccurate _a prioris_ or to view other positions within the primary beams of the antennas, little if any complexity is introduced by retaining the philosophy of a conventional correlator.

4) A conventional system makes compatibility with existing VLBI acquisition systems easy and inexpensive.

5) A conventional system has the highest degree of generality and flexibility possible. It cleanly separates data acquisition from data processing, resulting in modularity which allows future improvements in any area to be implemented at minimal cost.

The price paid for these advantages in twofold:

1) There is a small loss in SNR compared to some alternate schemes.

2) The correlator has twice as many accumulators as might otherwise be necessary. It should be noted, however, that this does not affect the _complexity_ of the correlator significantly, but only the cost of _replication._

In summary: a conventional VLBI recording and processing system is greatly to be preferred for the VLBA.