VLB ARRAY MEMO No. 333

VARIABLE PHASE SAMPLING

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Introduction

An annoying problem in traditional VLBI is the delay setting error which occurs because the digitized signal can only be delayed by an integral number of sample times. This has been called the "fractional bit shift error." There are techniques for correcting the error such that the effect is reduced to a small loss in SNR, but these depend on having the correlator's accumulation time be either much less than the time needed for the delay to change by one sample, or much greater than this time.

The problem is eliminated if the required delay is calculated at observe time, and if the phase of the sampling clock is adjusted accordingly. I propose that we adopt such a variable-phase sampler for the VLBA. Some details of its implementation and some consequences of this approach are considered in this memo. Generally, I see no adverse consequences for any kind of observation; the extra hardware required is negligible, so the main burden is that the station computers must calculate the delays in real time.

Description of Operation

Whether or not the sampler phase is varied, the time of each sample must be known at correlate time. This is easily done by breaking the sample stream into blocks known as "frames" and by attaching to each frame a header that specifies the time of the first sample. Within a frame, the time is determined by counting samples. With variable phase sampling, the only difference is that the time must be recorded to higher resolution. If the sampler phase is allowed to change during a frame, then the sample numbers of such changes must also be recorded; if we assume that the sampling time resolution is 1/16 of the sample period, then with respect to an earth-center reference the sampling phase changes no more than every 40 000 samples. For a frame length less than 40 000 samples, there can be at most one change per frame; for 20 000 samples per frame, little error is incured by insisting on zero changes within a frame.

Our present concept of the playback (DPS) to correlator interface allows the correlator to specify for each channel the exact time of any sample. Based on its current geometrical model, the correlator calculates the required timing of each channel,

including the correct delay. It must now do this to sufficient resolution to account for the variable phase sampling. If the correlator's model is identical to that used by the station computer at observe time, then it will specify a time identical to that of some sample, and the DPS can supply that sample. If the models differ (for example, because the correlator now wishes to observe at different place in the antenna beam than that specified at observe time), then the DPS should supply the nearest sample.

Implementation of the time accounting and delay setting described in the preceding paragraphs involves no more complexity than in the case of fixed-phase sampling; it merely involves longer words for the times.

Consequences

For most observations, the fractional-bit error is eliminated, provided that the sampler phase has sufficient resolution (1/16 of the sample period should be enough). If the correlate-time model differs from the observe-time model, some error is re-introduced, but it is almost always smaller than it would have been with fixed-phase sampling.

Consider, for example, that the station clock error is better known at correlate-time. If the error is constant, there will simply be a fractional-lag offset in the location of the peak cross correlation. Even if there is a clock rate error, it is very unlikely to cause a significant delay change during one accumulation period, so it can be corrected after correlation.

If we wish to track a different point in the beam than the one which was tracked at observe-time, then a delay error will tend to accumulate with time according to the difference in delay rates. When the error gets up to 1/2 sample time, the system described above will automatically insert a 1-sample delay change; we thus have the same fractional bit shift error of a fixed phase sampler. However, the rate of change of delay error depends on the difference in the tracking positions, and except for extreme cases there will be very little change during an accumulation period; thus post-correlation correction is adequate. (For an accumulation period of 10 sec and an 8 000 km baseline length, the worst case change is 5.6E-9 sec per arcmin of hour angle difference.)

Implementation Notes

Sixteen-phase samplers for 16 Msamples/sec should be easy to build, since 100 Ms/s ones were built for the VLA. Since we do not plan to allow different sampling rates on different channels, only one variable-phase sampling clock is needed for all 16 baseband converters. If the variable-phase clock can be used for all digital

operations from the samplers to the recorders, then no re-synchronization of the samples is needed; if not, then only two flip-flops per sampler must be added.

The DPS must maintain two internal time counters: one which holds the actual time of the current sample, derived from the frame headers and by counting samples; and one which holds the desired time of the current sample, derived from commands sent by the correlator. Both must have the full resolution of the sampler. Comparison of these determines whether delay must be added or subtracted to satisfy the correlator's request. The DPS can only change the delay by one sample steps, so it gets as close as possible.