VLB ARRAY MEMO No. 120

To: VLBA Memo Series

From: B. G. Clark

Subj: Frequency multiplexed correlators: the recording format

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The basic types of correlator are the familiar correlation function spectrometer, and the less familiar frequency multiplexed correlator. For VLB applications, the latter can be divided into two types depending on whether the conversion from time series to time multiplexed frequency channels is done prior to or following the tape recording/reproduction process. It is the purpose of this memo to consider the respective advantages of these two options.

There are many options for the process to do the conversion from time series to frequency channels. It can be done by filter banks, Butler Matrices of delay lines, acousto-optical devices, digital FFTs, and many interesting combinations of the above. There is also not a clear separation of the two types. The Mark III system may be regarded as a hybrid system in which the first time series to frequency conversion is done with a filter bank, and the frequency channels are further processed with a correlation function spectrometer.

I suspect, but have not proved, that the Fast Hadamard Transform will also work fairly well for converting to frequency channels. In a quick look, the sidelobes it introduces appear to be of the same order as the Gibbs Phenomenon sidelobes which we have learned to live with (albeit rather grumpily) in the case of the crosscorrelation function spectrometer.

In most VLB work the limiting factor is the bandwith of the equipment. Therefore, each recorded bit must carry as much information as possible, and other processes in the system must not discard information so laborously gathered. This has immediate consequences for both versions of the multiplexed frequency channel system. In the transform-after-record system, it dictates that the correlator proper must be a multibit system, probably three bit. (The arguments are carried out on the assumption that the source/system ratio is small in all channels. To preserve the full signal-to-noise ratio in the strong source case requires about 1/2 $\log_2$(Nchannels) bits, but the modest improvement in SNR that this gives seems not worth the extra complexity.)

In the transform-before-recording case, the usual considerations dictate that the frequency channels should be one-bit samples at the Nyquist rate. (One bit samples of inphase and quadrature components at half the Nyquist rate seems to be perfectly equivalent, and there may be some systems in which it is technically easier to achieve.) This has the interesting consequence that the correlator proper remains a one-bit device also, though the results must be distributed around a large memory at a rather rapid rate.

One additional parameter of the multiplexed-frequency-channel system that must be set it the channel width. One possibility would be to set the channel width to the narrowest of astronomical interest, say 1kHz. There seems to me to be no advantage to this approach. It is a little more natural to set the channel width sufficiently narrow that no explicit delay line need be incorporated, say 10Hz. This doesn't save any hardware; the equivalent delay must be incorporated in the time-series to frequency-channel converter. However, it does eliminate an interface; delay is applied along with the fringe phase, as a phase vs frequency effect. The practical, wider, frequency channels would be implemented as a boxcar average in the correlator hardware, or as a more sophisticated average in its software.

On balance, it appears to me that doing the transform prior to recording requires slightly less hardware overall than doing it after transform, because the correlator proper is a very large device and a one-bit correlator must be much smaller than a three bit one. On the other hand, it does require more hardware at the antenna. I think it would be necessary, if the transform is done at the antenna, to have a detector/averager attached to it, so that a quick look at a maser source could verify that the device is working properly. (This also check a number of other systems--gross LO and antenna pointing for instance).

Finally, I would like to terminate this rumination by noting that a fast Hadamard transformer, capable of transforming a 25MHz band to 6Hz channels could be built around about 4 MBytes of fast memory and 44 fast four-bit adders.